Universitat Autònoma de Barcelona

Looking for a better information support in Municipal Solid Waste Management The Case Study of Panama City

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The Case Study of Panama City

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Preface

- Personal background

I am an electrical-mechanical engineer from the Technological University of Panama with a master's degree in Environmental Sciences from the Autonomous University of Barcelona, specializing in Technologies for Solid Waste Management. I have been working for more than eight years on solid waste management in the context of Latin American developing countries, especially in Panama, where I have:

i) collaborated with national thinktanks aiming to plan for Municipal Solid Waste (MSW) management system's enhancement; ii) given technical advisory support to representatives of the public administration;
iii) carried out multiple solid waste generation and characterization studies;
iv) supported the planning of objectives from these studies' insights to promote adequate MSW management legislation, always scoping for the technical and economic sustainability of implemented plans.

- Motivations

Throughout my short but enriching journey in the solid waste management field, I have observed that all efforts made by developing countries to improve the MSW management systems situation have often proved futile, year after year, despite different public administrations with vastly different governing points of view.

That's how I understood that the challenge entailed by the multidimensional complexity of MSW management systems is even more evident in these countries, a reflection contrasting with the common, simplistic discourse pointing at corruption as the unique cause of malfunctioning.

So, I devoted myself to identifying which aspects were affecting the performance of MSW management by paying close attention to details of the MSW management system of Panama, as an exemplary case study in a field in which the research in developing countries is very limited.

These observations are the basis of this thesis entitled *"Looking for a better information support in Municipal Solid Waste Management: The Case Study of Panama City."* The thesis presents an approach for a diagnostical procedure that promotes multilevel governance and participatory co-production of knowledge in MSW management systems of developing countries.

- The target groups

This thesis is targeted to both authorities and policymakers and those interested in studying the problems of MSW management and supporting them in taking decision in a more conscious and transparent way. The material of this thesis wants to contribute to the development of a body of knowledge helping to:

(i) check whether the approach they are implementing is suitable for the current situation of their MSW management systems;
(ii) get a sound analysis capable of diagnosing the situation first to make it possible creating adequate policies and investing millions in tailored approaches.

The reader should have a minimum understanding of basic and traditional MSW management concepts (and over the general background on their country's situation) to be able to compare the extent to which this thesis could support in improving the quality of current approaches by increasing the information needed to evaluate the performance of their MSW management systems.

The information delivered by this thesis can contribute to the development of a pocket manual that could be used as a strategic guide to build more effective long-term strategies to foster palpable MSW management system's improvements.

Acknowledgements

I would like to thank:

i) My tutor, Mario, for agreeing to guide my clumsy steps during this long and enriching journey, and for how he has been able to patiently contribute his wisdom and knowledge to each paper of this thesis;

ii) My directors Rosaria and Maddalena, for the time they devoted to nice coffee meetings to exchange and transmit their contributions of innovative ideas to enhance the rough concepts I tried to express through this thesis work;

iii) Sandra, for her empathy evidenced by her unconditional support to improve the non-native English grammar I used to write the Papers and for thoroughly guiding me to comply with all the bureaucratic procedures in each phase of the Ph.D.;

iv) My wife, Yelena, for always being the neck of my idea-congested head and for supporting my confusing decision-making process daily.

"I think we risk becoming the best-informed society that has ever died of ignorance."

Ruben Blades

Summary

Developing countries in general, lack sustainable municipal solid waste management systems in place. They tend to adopt waste management solutions as protocols from developed countries without proper adaptation while leaving behind the context of their situation and assuming beforehand that the results obtained locally will be equivalent to those obtained in developed countries granting these protocols. Despite efforts to successfully accomplish this, these systems seem to achieve limited improvements to remain sustainable over time. These sustainability issues are rooted in both the generation and management stages of the municipal solid waste management system. Drawbacks mostly affecting the generation stage are related to societal materialism, while those mostly affecting the management stage are related to political lethargy and technical nescience. A comprehensive consideration of these drawbacks should be achieved to understand the option space of solutions and get real improvements that account for noticeable progress in municipal solid waste management systems of developing countries. This thesis claims that managers of municipal solid waste management systems of developing countries should consider procedures created through local knowledge and consciousness before adopting foreign protocols for long-term municipal solid waste management systems sustainability. They should conduct diagnostic strategies capable of adequately identifying the actual symptoms of their sustainability problems from all technical, political, and social aspects' points of view. To accomplish this, this thesis poses the research question: Is that possible to devise a diagnostic strategy based on better and more transparent information to support the decision-making process of developing countries on using procedures instead of protocols before adopting MSW management systems from abroad? Devising such a diagnostic strategy may allow tailoring the use of adopted municipal solid waste management systems and fosters the adequate use of procedures. This thesis proposes that, instead of a static picture based on the standard typology of foreign municipal solid waste management systems, an effective diagnostic strategy should be devised to obtain a more dynamic and comprehensive representation of the current situation. The methodological approach aims to i) select a Case Study of a developing country failing to accomplish operational sustainability of its municipal solid waste management system due to social, political, and technical drawbacks; ii) define intrinsic issues tackling drawbacks specific to the Case Study; iii) establish key checkpoints to characterize defined issues; iv) determine fundamental questions from the characterization of defined issues; and v) devise the diagnostic strategy by answering the determined fundamental questions through a compendium of four different studies (published papers), each one tackling a defined issue. The Case Study of Panama City was selected, epistemological, material, socioenvironmental, and governance intrinsic issues of its municipal solid waste management system were identified, key checkpoints were based on validating crucial aspects on MSW management system's actors, baseline data, and planning,

as well as MSW generation patterns and studies, performed to raise the following fundamental questions: i) Is it always reliable the information obtained from assessments conducted from foreign consultancy on local MSW generation of developing countries without involving local experts?; ii) How to produce more valued materials for recycling from MSW management systems of goods' importing non-industrialized developing economies and mitigating the flow of MSW derived from the consumption of imported goods?; iii) How to allocate responsibilities for the societal impacts produced by landfill environmental pressures derived from uncontrolled MSW disposal in developing countries?; iv) Can better analysis of MSW generation patterns improve the quality and transparency of MSW management systems' decision-making of developing countries? These questions were answered by each published paper, thus enabling me to affirmatively answer the research question and devise the diagnostic strategy.

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Resum

Els països en vies de desenvolupament, en general, no tenen sistemes de gestió de residus sòlids municipals sostenibles. Solen adoptar solucions de gestió de residus com a protocols de països desenvolupats sense una adequada adaptació, deixant enrere el context de la seva situació i assumint per endavant que els resultats obtinguts localment seran equivalents als obtinguts als països desenvolupats que els donen aquests protocols. Tot i els esforços per aconseguir això amb èxit, aquests sistemes semblen aconseguir millores limitades per continuar sent sostenibles en el temps. Aquests problemes de sostenibilitat tenen les arrels en les etapes de generació i gestió del sistema de gestió de residus sòlids municipals. Els inconvenients que afecten principalment l'etapa de generació estan relacionats amb el materialisme social, mentre que els que afecten principalment l'etapa de gestió estan relacionats amb la letargia política i la ignorància tècnica. Cal assolir una consideració integral d'aquests inconvenients per comprendre l'espai d'opcions de solucions i obtenir millores reals que donin compte d'un progrés notable als sistemes de gestió de residus sòlids municipals dels països en vies de desenvolupament. Aquesta tesi afirma que els administradors dels sistemes de gestió de residus sòlids municipals dels països en desenvolupament haurien de considerar els procediments creats mitjançant el coneixement i la consciència locals abans d'adoptar protocols estrangers per impulsar la sostenibilitat dels sistemes de gestió de residus sòlids municipals a llarg termini. Han de fer estratègies de diagnòstic capaces d'identificar adequadament els símptomes reals dels seus problemes de sostenibilitat des de tots els punts de vista tècnics, polítics i socials. Per aconseguir-ho, aquesta tesi planteja la pregunta de recerca: És possible dissenyar una estratègia de diagnòstic basada en informació millor i més transparent per donar suport al procés de presa de decisions dels països en desenvolupament sobre l'ús de procediments en lloc de protocols abans de adoptar sistemes de gestió de residus sòlids municipals des de lexterior? El disseny d‟una estratègia de diagnòstic d‟aquest tipus permetria adaptar l‟ús dels sistemes de gestió de residus sòlids municipals adoptats i fomentar l‟ús adequat dels procediments. Aquesta tesi proposa que, en lloc d'un quadre estàtic basat en la tipologia estàndard dels sistemes de gestió de residus sòlids municipals estrangers, cal dissenyar una estratègia de diagnòstic eficaç per obtenir una representació més dinàmica i completa de la situació actual. L'enfocament metodològic apunta a i) seleccionar un estudi de cas d'un país en desenvolupament que no aconsegueix la sostenibilitat operativa del sistema de gestió de residus sòlids municipals a causa d'inconvenients socials, polítics i tècnics; ii) definir qüestions intrínseques que tractin els inconvenients específics de l'estudi de cas; iii) establir punts de control clau per caracteritzar problemes definits; iv) determinar qüestions fonamentals a partir de la caracterització de temes definits; i v) dissenyar l'estratègia diagnòstica donant resposta a les preguntes fonamentals determinades mitjançant un compendi de quatre estudis diferents (articles publicats), cadascun dels quals aborda un tema definit. Es va

seleccionar l'Estudi de Cas de la Ciutat de Panamà, es van identificar aspectes epistemològics, materials, socioambientals i de governança intrínsecs del sistema de gestió de residus sòlids municipals, els punts de control clau es van basar en la validació d'aspectes crucials sobre els actors del sistema de gestió de residus sòlids municipals, dades de línia de base i planificació, així com patrons i estudis de generació de residus sòlids municipals, realitzats per plantejar les preguntes fonamentals següents: i) És sempre fiable la informació obtinguda d'avaluacions realitzades per consultores estrangeres sobre generació local de residus sòlids municipals de països en desenvolupament sense involucrar experts locals?; ii) Com produir materials més valuosos per reciclar a partir dels sistemes de gestió de residus sòlids municipals de les economies en desenvolupament no industrialitzades d'importació de béns i mitigar el flux de residus sòlids municipals derivat del consum de béns importats?; iii) Com assignar responsabilitats pels impactes socials produïts per les pressions ambientals dels rebliments sanitaris derivades de la disposició incontrolada de residus sòlids municipals als països en desenvolupament?; iv) Una millor anàlisi dels patrons de generació de residus sòlids municipals pot millorar la qualitat i transparència de la presa de decisions dels sistemes de gestió de residus sòlids municipals als països en desenvolupament? Aquestes preguntes van ser respostes per cada article publicat, cosa que em va permetre respondre afirmativament a la pregunta de recerca i dissenyar lestratègia de diagnòstic.

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Resumen

Los países en vías de desarrollo, en general, carecen de sistemas de gestión de residuos sólidos municipales sostenibles. Suelen adoptar soluciones de gestión de residuos como protocolos de países desarrollados sin una adecuada adaptación, dejando atrás el contexto de su situación y asumiendo de antemano que los resultados obtenidos localmente serán equivalentes a los obtenidos en los países desarrollados que les donan estos protocolos. A pesar de los esfuerzos para lograr esto con éxito, estos sistemas parecen lograr mejoras limitadas para seguir siendo sostenibles en el tiempo. Estos problemas de sostenibilidad tienen sus raíces en las etapas de generación y gestión del sistema de gestión de residuos sólidos municipales. Los inconvenientes que afectan principalmente a la etapa de generación están relacionados con el materialismo social, mientras que los que afectan principalmente a la etapa de gestión están relacionados con el letargo político y la ignorancia técnica. Se debe lograr una consideración integral de estos inconvenientes para comprender el espacio de opciones de soluciones y obtener mejoras reales que den cuenta de un progreso notable en los sistemas de gestión de residuos sólidos municipales de los países en vías de desarrollo. Esta tesis afirma que los administradores de los sistemas de gestión de residuos sólidos municipales de los países en desarrollo deberían considerar los procedimientos creados a través del conocimiento y la conciencia locales antes de adoptar protocolos extranjeros para impulsar la sostenibilidad de los sistemas de gestión de residuos sólidos municipales a largo plazo. Deben realizar estrategias de diagnóstico capaces de identificar adecuadamente los síntomas reales de sus problemas de sostenibilidad desde todos los puntos de vista técnicos, políticos y sociales. Para lograrlo, esta tesis plantea la pregunta de investigación: *¿Es posible diseñar una estrategia de diagnóstico basada en información mejor y más transparente para apoyar el proceso de toma de decisiones de los países en desarrollo sobre el uso de procedimientos en lugar de protocolos antes de adoptar sistemas de gestión de residuos sólidos municipales desde el exterior?* El diseño de una estrategia de diagnóstico de este tipo permitiría adaptar el uso de los sistemas de gestión de residuos sólidos municipales adoptados y fomentar el uso adecuado de los procedimientos. Esta tesis propone que, en lugar de un cuadro estático basado en la tipología estándar de los sistemas de gestión de residuos sólidos municipales extranjeros, se debe diseñar una estrategia de diagnóstico eficaz para obtener una representación más dinámica y completa de la situación actual. El enfoque metodológico apunta a i) seleccionar un estudio de caso de un país en desarrollo que no logra la sostenibilidad operativa de su sistema de gestión de residuos sólidos municipales debido a inconvenientes sociales, políticos y técnicos; ii) definir cuestiones intrínsecas que aborden los inconvenientes específicos del estudio de caso; iii) establecer puntos de control clave para caracterizar problemas definidos; iv) determinar cuestiones fundamentales a partir de la caracterización de temas definidos; y v) diseñar la estrategia diagnóstica dando respuesta a las preguntas fundamentales determinadas a través de un compendio de

cuatro estudios diferentes (artículos publicados), cada uno de los cuales aborda un tema definido. Se seleccionó el Estudio de Caso de la Ciudad de Panamá, se identificaron aspectos epistemológicos, materiales, socioambientales y de gobernanza intrínsecos de su sistema de gestión de residuos sólidos municipales, los puntos de control clave se basaron en la validación de aspectos cruciales sobre los actores del sistema de gestión de residuos sólidos municipales, datos de línea de base y planificación, así como patrones y estudios de generación de residuos sólidos municipales, realizados para plantear las siguientes preguntas fundamentales: i) ¿Es siempre confiable la información obtenida de evaluaciones realizadas por consultoras extranjeras sobre generación local de residuos sólidos municipales de países en desarrollo sin involucrar a expertos locales?; ii) ¿Cómo producir materiales más valiosos para reciclar a partir de los sistemas de gestión de residuos sólidos municipales de las economías en desarrollo no industrializadas de importación de bienes y mitigar el flujo de residuos sólidos municipales derivado del consumo de bienes importados?; iii) ¿Cómo asignar responsabilidades por los impactos sociales producidos por las presiones ambientales de los rellenos sanitarios derivadas de la disposición incontrolada de residuos sólidos municipales en los países en desarrollo?; iv) ¿Puede un mejor análisis de los patrones de generación de residuos sólidos municipales mejorar la calidad y transparencia de la toma de decisiones de los sistemas de gestión de residuos sólidos municipales en los países en desarrollo? Estas preguntas fueron respondidas por cada artículo publicado, lo que me permitió responder afirmativamente a la pregunta de investigación y diseñar la estrategia de diagnóstico.

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1 Introduction

Solid waste generation is generally considered an 'urban' issue since it is inextricably linked to urbanization and economic development; as countries urbanize, solid waste generation increases along with economic wealth, standards of living, and disposable income for the consumption of goods and services (Hoornweg and Bhada, 2012). Today, more than 50 percent of the world's population lives in cities. The rate of urbanization is increasing quickly, especially in developing countries with booming economies, associated with increased materials consumption and solid waste generation (Zohoori and Ghani, 2017). In this situation, a high concentration of people entails that a minimum lack of attention in the proper waste management organization can cause disasters that affect the biosphere, society, or both (Butterworth et al., 2012; Sampaio et al., 2009). By 2015, the global solid waste generation rate was 1.3 billion tonnes per year, and it is expected to increase by 40% by 2025, with the largest contribution coming from developing countries (Hoornweg and Bhada, 2012).

Developing countries in general, lack effective solid waste management systems in place. They tend to adopt waste management solutions from developed countries without proper adaptation while leaving behind the context of their situation (Denuncio and Bastida, 2014; Medina, 1997; Zohoori and Ghani, 2017). But despite efforts from developing countries to adopt solid waste management systems that seem to obtain good results in developed countries, these seem to achieve limited improvements to remain sustainable over time. Adopting waste management solutions from developed countries without proper adaptation looks even worse when referring to the solid waste generated in the metropolitan or urban context, the so-called Municipal Solid Waste (MSW) (Troschinetz and Mihelcic, 2009).

The use of "Municipal" to classify a type of solid waste generated at households or a similar generated at commerce was termed in the 19th century exclusively referring to the establishment of a municipal service for locally generated-waste management (Louis, 2004), not considering its composition, recyclability, toxicity, stack-ability, re-usability and many other characteristics that solid waste possess today as new materials are being consumed. When referring to waste, it is easy to assume the inclusion or not of certain material fractions -e.g., household, commercial, industrial, institutional, street cleaning residues, septic tank sludge, waste from sewage cleaning (European Commission, 2000). The (European Parliament and Council, 2008) refers to MSW as a material that is discarded without being resold to other persons or companies, generating collection, transportation, and disposal costs. In Japan, MSW is defined based on the material's quality for use, supply and demand, product market, transaction value, and the owner's intention to sell, so recyclables are not considered waste because, even though they haven't been sold yet, they keep such potential (Kawai and Tasaki, 2016). Recyclable packaging waste is not included in MSW in Germany (Reichel and Milios, 2013) but it is in the United Kingdom

(Watson and Reichel, 2013). The Pan American Health Organization (PAHO) defines MSW, for Latin American and Caribbean countries, as solid or semi-solid waste including household, commercial, service, and institutional, market, hospital, or non-hazardous waste, those generated in the offices of the industries, in the sweeping and cleaning of streets and public areas, in the pruning of plants of streets, squares, and gardens (BID, 2011). The U.S. Environmental Protection Agency (EPA) defines it as trash or garbage and comprises various items Americans commonly throw away after being used. Packaging, food waste, grass clippings, sofas, computers, tires, and refrigerators are examples of such items; however, industrial, hazardous, or construction waste are not included (US EPA, 2014).

Definitions given to the concept of MSW entail criteria based on specific MSW generation and management contexts of the MSW management systems deployed at each place. Adopting MSW definitions between places with different contexts, without revising the criteria used locally to create such definitions and proper adaptation, makes it difficult to establish direct connections between the scope of MSW management in developed and developing countries and may suppose a counterproductive act affecting the deployment of sustainable MSW management systems in the latter (Medina, 2011; Serrona et al., 2014; Wilson et al., 2006).

From the MSW generation side, defining the concept of MSW should consider that it is the most heterogeneous solid waste fraction generated by a diversity of people influenced by varied factors conditioning the way they generate it (US EPA, 1991). The MSW generation side of the MSW management systems in most developing countries entails sustainability drawbacks on its operation concerning societal materialism -i.e., fast economic development and uncontrolled urban growth, large differences in socioeconomic characteristics of urban residents, and remarkable disparities in income level and material resources consumption, unsteady MSW generation behavior causing unpredictable quantities and quality- (Karlsson et al., 2004).

When dealing with MSW management, defining the concept of MSW should consider multiple treatment technologies to manage diverse combinations of MSW fractions contrasting between countries and solid waste management system types (EEA, 2007). The MSW management side of the MSW management systems of developing countries entails sustainability drawbacks on its operation concerning political lethargy -i.e., lack of effective MSW management systems in place, unclear and overlapping functions of the several public agencies involved in MSW management, weak implementation and enforcement of laws and regulations of MSW management- (Breukelman et al., 2019); and technical nescience i.e., lack of MSW studies backing up updated data collection on MSW generation, disagreement on the definitions locally given to MSW, lack of consideration of the multiple factors influencing MSW generation- (Kumar, 2016).

(Flintoff, 1984), in his book "*Management of Solid Wastes in Developing countries,"* states:

"Engineering training worldwide is standard and based on Western methods. This is valid in many fields, such as electricity generation, car assembly, and water distribution. But most Third World engineers who work in solid waste management assume that their aim should be to equip their cities with compactor trucks, suction sweeping machines, highly mechanized composting plants, or moving grate incinerators. However, in solid waste management, there is a wide range of options for almost every process, whereby labor can be traded for machines and draught animals for motor trucks."

As Flintoff's reflection suggests, adopting foreign MSW management systems without proper adaptation is typical from developing countries where sustainability problems are considered as if solely depending on technical aspects (to be faced by solving technical nescience), or even solely depending on political aspects (to be faced by solving political lethargy) (Guibrunet et al., 2017). This framing neglects the integration of the factors relevant for understanding the aspects of local social practices involving social materialism issues behind the pattern of MSW generation (Wilson et al., 2012). Not considering the valued information provided by social practices when addressing sustainability problems of developing countries' MSW management systems, translates into a systemic failure to understand the possible option space of solutions with which adopted foreign MSW management systems could contribute after adequately transferring environmentally sound technologies (UNCED, 1992). Understanding this option space of solutions needs comprehensive, sound, and flexible procedures created through local knowledge and consciousness more than adopted foreign protocols because they may be more effective and sustainable in the long term. Locally created procedures instead of externally brought protocols may be key to getting real improvements that account for noticeable progress because supports empowering local actors to boost the co-production of knowledge used to improve multilevel governance of MSW management systems in developing countries (Eshet and Yadav, 2015).

Here it is essential to make the distinction between (1) procedures – defined as a set of open instructions which guide the "why," "what," "how," "when" to be decided in relation to the "what for" of actions to be taken; and (2) protocols – defined as a list of closed steps which take care of the "why," "what," "how," "when" but ignore the key question of the "what for" of actions to be taken (NHS, 2006). Excessive reliance on protocol when solving sustainability problems can reduce the effectiveness of action because asking the "what for" question is essential in the context of MSW management of developing countries. The "what for" question can support to address the purposes of the various social practices associated with MSW generation. The "what for" question can help to tailor the possible solutions provided by foreign technology on local specific features. The lack of sustainable MSW management systems in developing countries can be explained with the normalized use of protocols that do not ask "what for" questions for each step required for MSW management. This blind application of protocols assumes beforehand that the results obtained locally will be equivalent to those obtained from applying these protocols in the MSW management systems of developed countries granting them (Umar et al., 2017).

This thesis states that to encourage managers of MSW management systems of developing countries to consider asking the "what for" question through procedures before recurring to Plug-and-Play approaches through protocols. They should conduct diagnostic strategies capable of adequately identifying the actual symptoms of their sustainability problems from all technical, political, and social aspects' points of view. To accomplish this, this thesis poses the research question:

Is that possible to devise a diagnostic strategy based on better and more transparent information to support the decision-making process of developing countries on using procedures instead of protocols before adopting MSW management systems from abroad?

Devising such a diagnostic strategy may allow tailoring the use of adopted MSW management systems and fosters the adequate use of procedures answering the "what for" question. This thesis proposes that, instead of a static picture based on the standard typology of foreign MSW management systems, an effective diagnostic strategy should be devised to obtain a more dynamic and comprehensive representation of the current situation. This representation might include its background, involvement of the different entities and types of functions to be expressed, biophysical and economic flows, functional units (household, community, town, district) generating MSW, relationships within the local social bodies and across geographical spaces, and legitimate non-equivalent perceptions of the different involved stakeholders to discuss options and co-produce knowledge about MSW management.

2 Methodological approach

This thesis intends to accomplish this diagnostic strategy by:

i. Selecting a Case Study of a developing country failing to accomplish operational sustainability of its MSW management system due to social, political, and technical drawbacks.
ii. Defining intrinsic issues tackling drawbacks specific to the Case Study.
iii. Establishing key checkpoints to characterize defined issues.
iv. Determining fundamental questions from the characterization of defined issues.
v. Devising the diagnostic strategy by answering the determined fundamental questions through

a compendium of four different studies (published papers), each one tackling a defined issue.

2.1 Case Study

Panama City has been selected as the case study, which motivations are widely explained on each of the studies of the compendium of published papers making up this thesis. Panama City is a 0.5M inhabitants city located in the Panama capital district, province, and country (**Figure 1**).

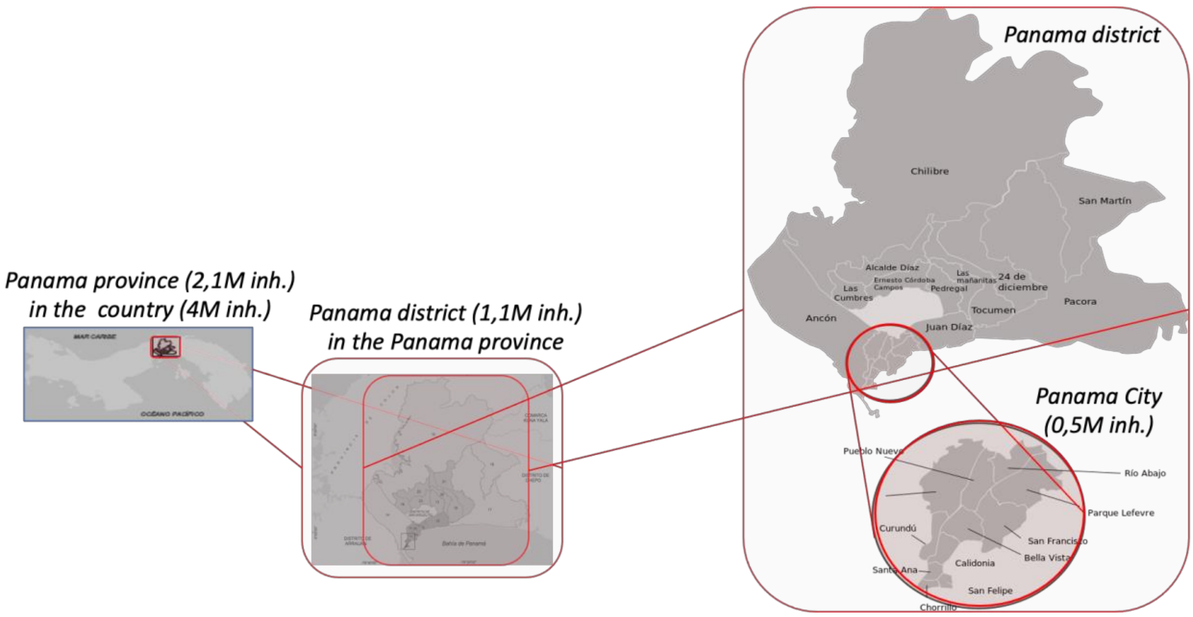

Figure 1. Panama City location

For more than 20 years, several foreign companies have conducted MSW generation studies in Panama to develop MSW management plans that have never been implemented and now are out of date. Meanwhile, the local authority of the MSW management system has been using standard unidimensional approaches to estimate the amount of MSW generated per person-day (Kawai and Tasaki, 2016). This choice led to the mismanagement of the system and an inefficient allocation of human, economic, logistical, and technical resources. Panama[1], is a clear case of developing country failing to accomplish operational sustainability of its MSW management system due to social, political, and technical drawbacks. The reasons are widely explained on each of the studies of the compendium of published papers making up this thesis.

2.2 Intrinsic issues

[1] *Panama is not considered officially as a developing country since 2020 by the World Bank. However, in relation to MSW management it is sharing the same problems of many developing countries.*

The intrinsic issues of the MSW management system of Panama are defined as epistemological, material, socioenvironmental and governance types:

i. The epistemological issues of identifying systemic mistakes determined by the application of standard scientific analysis of the issue of MSW management without a proper contextualization and tailoring on the specificity of the local society.;
ii. The material issues of including in explicit terms the effect of free-trade on the MSW management of importing developing countries when discussing the regulations of free-trade agreements.;
iii. The socioenvironmental issues of dealing transparently with an "environmental justice" topic determined by the fact that those generating more solid waste are not the ones getting the relative negative effects on both human health and the environment (their waste does not affect their habitat);
iv. The governance issues of properly identifying and characterizing essential factors to be studied to understand the patterns of MSW generation in space and time, and to plan and implement MSW management strategies properly.

2.3 Key checkpoints

The establishment of key checkpoint is based on validating crucial aspects on MSW management system's actors, baseline data and planning, as well as MSW generation patterns and studies performed:

i. Identity, origin, function, expertise, and motives of local or foreign, and public or private MSW management system's actors.
ii. Readiness, collection, capacity, reliability, access, and updating on MSW management systems' baseline data.
iii. Regulatory context regarding actions, frameworks, disparities, awareness, policymaking, and responsibilities on MSW management systems planning.
iv. Estimations, availability, considerations, definitions, and assumptions over the factors determining the past, current, and projected MSW generation patterns.
v. Existence, the robustness of approaches and methodologies, and ownership of MSW generation studies.

2.4 Fundamental questions

The determination of fundamental questions is based on the characterization of defined issues of the Panamanian MSW management system using the key checkpoints:

i. Is it always reliable the information obtained from assessments conducted from foreign consultancy on local MSW generation of developing countries without involving local experts?

ii. How to produce more valued materials for recycling from MSW management systems of goods' importing non-industrialized developing economies and mitigating the flow of MSW derived from the consumption of imported goods?

iii. How to allocate responsibilities for the societal impacts produced by landfill environmental pressures derived from uncontrolled MSW disposal in developing countries?

iv. Can better analysis of MSW generation patterns improve the quality and transparency of MSW management systems' decision-making of developing countries?

2.5 Diagnostic strategy

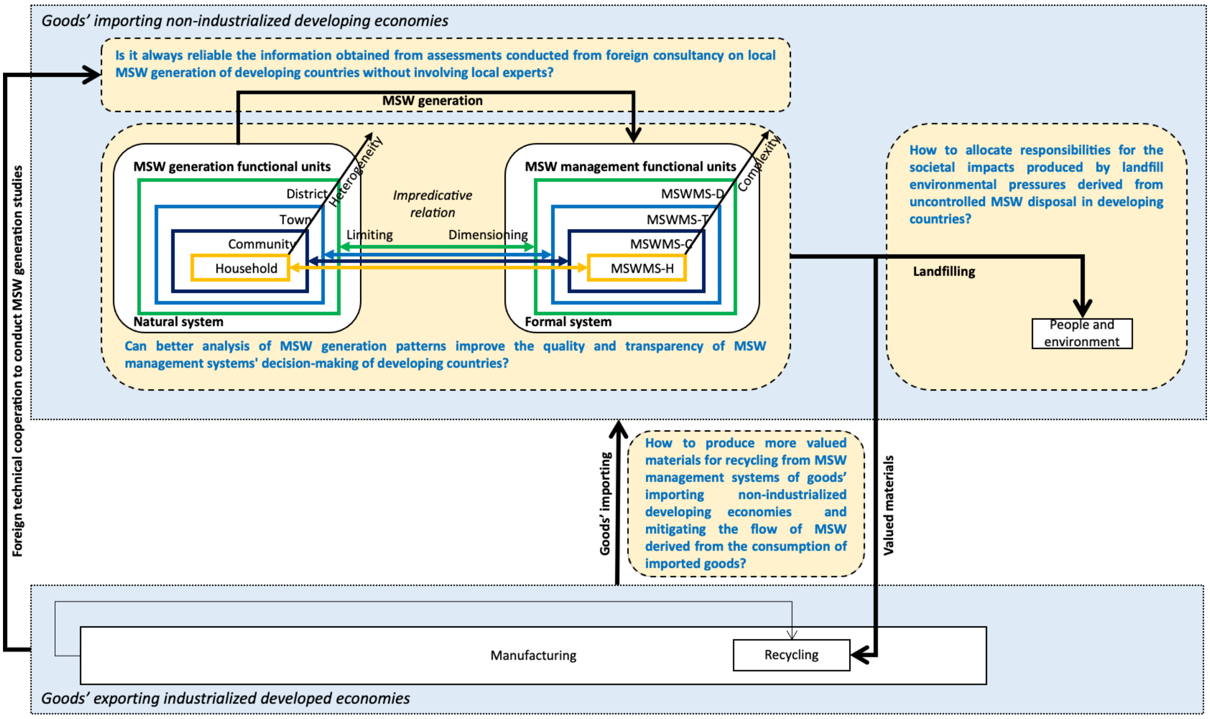

Figure 2. Integrated representation of all fundamental questions raised from intrinsic issues tackling drawbacks of the Panamanian MSW management system (MSWMS: MSW management system, H: Household, C: Community, T: Town, D: District).

Figure 2 shows a basic representation of the Panamanian MSW management system integrating fundamental questions which answers by published papers allows to build the diagnostic strategy and affirmatively answering the research question:

2.5.1 Epistemological issues

Paper #1: *"Identification of inference fallacies in solid waste generation estimations of developing countries. A case-study in Panama"* (Torrente-Velásquez et al., 2021)(Torrente-Velásquez et al., 2020c)

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Identification of inference fallacies in solid waste generation estimations of developing countries. A case-study in Panama

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Impact Factor: 7.14

Abstract: "The absence of sound sampling procedures and statistical analyses to estimate solid waste generation in many developing countries has resulted in incomplete historical records of waste quantity and composition. Data is often arbitrarily aggregated or disaggregated as a function of waste generators to obtain results at the desired spatial level of analysis. Inference fallacies arising from the generalization or individualization of results are almost never considered. In this paper, Panama, one of the fastest-growing developing countries, was used as a case-study to review the main methodological approaches to estimate solid waste generation per capita per day, and at different hierarchical levels (from households to the country). The solid waste generation intensity indicator is used by the Panamanian waste management authority to run the waste management system. It was also the main parameter employed by local and foreign companies to estimate solid waste generation in Panama between 2001 and 2008. The methodological approaches used by these companies were mathematically formalized and classified as per the expressions suggested by Subramanian et al. (2009). Seven inference fallacies (ecological, individualistic, stage, floating population, linear forecasting, average population, and mixed spatial levels) were identified and allocated to the studies. Foreign companies committed three of the seven inference fallacies, while one was committed by the local entity. Endogenous knowledge played an important role in these studies to avoid spatial levels mismatch and

multilevel measurements appear to produce more reliable information than studies obtained via other means."

2.5.1.1 ***Answering the fundamental question:*** *Is it always reliable the information obtained from assessments conducted from foreign consultancy on local MSW generation of developing countries without involving local experts?*

MSW generation studies performed by foreign companies commit MSW generation inference fallacies when applying their methodological approaches in the context of the MSW management systems of developing countries. These fallacies hinder the creation of proper MSW management plans' implementation mechanisms. Foreign cooperation is not always beneficial for developing countries neither the information obtained from assessments conducted on local MSW generation is always reliable; involving local experts boost reliability rates.

As a first step of the diagnostic strategy, developing countries could greatly increase the benefits rates of foreign technical cooperation by i) integrating endogenous knowledge in the planning and implementation of foreign actions to improve the effectiveness of MSW management during the whole process, from planning to implementation; ii) acknowledging inference fallacies committed in the past to identify potential drawbacks in future studies' proposals; iii) defining which foreign technical cooperation would be beneficial in order to reduce the risk of failure in implementing MSW management plans due to outdated information -i.e., requiring new budget allocation for other studies that will be at risk of becoming outdated again-.

In addition, lacking robust Plans to manage MSW in developing countries hampers controlling the import of massive amounts of consumer goods from developed industrialized countries, which is a common practice that non-industrialized developing countries have been performing since Trade Liberalization in the form of Free Trade Agreements.

2.5.2 Material issues

Paper #2: *"A waste lexicon for non-industrialized Latin American economies to negotiate Extended Producer Responsibility with industrialized economies in Free Trade Agreements"* (Torrente-Velásquez et al., 2020c).

ELSEVIER

Resources, Conservation and Recycling
Volume 156, May 2020, 104711

Full length article

A waste lexicon to negotiate extended producer responsibility in free trade agreements

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Abstract: "Latin American non-industrialized economies are overflown with imported Goods from the manufacturing industry of industrialized economies through Free-Trade Agreements. After consumption Goods end up in urban solid waste streams which destination is landfilling because of poor local solid waste management systems. This paper presents a methodological approach that adapts the recycling concepts of "Byproduct" and "Co-product" to the household sector urban solid waste stream derived. A lexicon was formalized to conceptualize an alternative Extended-Producer-Responsibility information system operating at global levels between such economies. The system proposed serves to i) determine the recyclability, reusability and treatability attributes of imported Goods as per their constitutive parts (primary package or product), material value as per their net value in the global waste market and final destination once consumed, ii) define specific conditions regarding Goods´ materials value and structural configuration of their constitutive parts that has to be fulfilled and declared by industrialized economies before importing Goods to Latin American non-industrialized economies through Free-Trade Agreements, and iii) check for the general fulfilment of the proposed conditions. The proposed methodology was applied to the Panamanian Case Study. It was found that 24%(%wt)-34.5%(%vol) of valued materials derived from imported Goods could be exported back to

industrialized economies keeping Free-Trade Agreements with Panama, 18%(%wt)-2.8%(%vol) reused, 58%(%wt)-62.5%(%vol) valorized as energy, organic amendment, fuel, etc., and only 16%(%wt)-16%(%vol) landfilled. Conditions on materials´ value overall imported Goods are unfulfilled in terms of weight and volume. Conditions on the structural configuration are fulfilled both in weight and volume terms.”

2.5.2.1 **Answering the fundamental question:** *How to produce more valued materials for recycling from MSW management systems of goods’ importing non-industrialized developing economies and mitigating the flow of MSW derived from the consumption of imported goods?*

Every time a new Free Trade Agreement is signed, a general joyful sentiment arises in the importing country because of new potential business opportunities to export goods. But for developing countries, these Free Trade Agreements can entail disadvantages for the citizens because of the existence of a side B of the story: imported consumer goods from the industrialized countries become waste after being consumed and adds-up to the incipient MSW management system of the non-industrialized countries that hardly accomplish collection, transport, and final disposal of MSW without any previous treatment.

Solving this issue is not easy. But with the touch of the right approach, it would be possible to reduce more than 80% of MSW generated from the consumption of imported goods through Free Trade Agreements. Extended Producer Responsibility is a local policy approach in which a producer's responsibility for a product is extended to the post-consumer stage of a product's life cycle.

Producing more valued materials for recycling from MSW management systems of goods’ importing non-industrialized developing economies and mitigating the flow of MSW derived from the consumption of imported goods is achievable by defining an information system allowing for a functional relationship between the quantity and quality of the imported goods from goods’ exporting industrialized developed economies.

As a second step of the diagnostic strategy, developing countries could formalize the use of this information system before signing Free Trade Agreements, considering already in this initial stage of trade the disposal of waste generated after the use of imported goods. In this sense, Free Trade Agreements should define opportunities and include clauses based on globally Extended Producer Responsibility mechanisms (up to the limits of the exporting country itself) to pose comprehensive environmental caretaking for importing countries and make bilateral trade agreements fair again.

However, if governments of developing countries do not care enough to demand the application of adequate Extended Producers Responsibility policies as part of Free Trade Agreements' negotiations, not much can be achieved. In this situation, the consumption of imported consumer goods summed to a lack of MSW source-separation will increase the direct final disposal of mixed MSW into landfills without any previous treatment or recycling.

2.5.3 Socioenvironmental issues

Paper #3: *"Landfill reactions to society actions: The case of local and global air pollutants of Cerro Patacón in Panama"* (Torrente-Velásquez et al., 2020b).

ELSEVIER

Science of The Total Environment

Volume 706, 1 March 2020, 135988

Landfill reactions to society actions: The case of local and global air pollutants of Cerro Patacón in Panama

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Abstract: "This paper studies the extent at which it is possible to raise awareness in the population of developing countries over the responsibility they bear for disproportionate impacts mutually exerted through irresponsible resource consumption and non-deliberate solid waste generation; it is uncontrollably disposed of in landfills, producing landfill gas emissions that generate local and global environmental pressures and societal impacts. Empirical data on Cerro Patacón, Panama´s city landfill, was acquired to describe the status of waste disposal. Ten known methane generation models were used to estimate the yearly emission rate of methane from landfill for a 100-year period starting in 1986, so to have a picture of the global environmental pressure exerted. From the models used, the GasSIM model was chosen to estimate emission rates of six long-term hazardous air pollutants. The AERMOD source dispersion model was used to simulate atmospheric downwind dispersion by their levels of concentration over nearby affected communities; results were mapped in Google Earth. Population awareness was depicted through allocations by towns of the waste generation, hazardous air pollutants emission rates and excess cancer cases from Cerro Patacón, forecasted to 2022. It was found that Cerro Patacón will average a methane emission rate of ~47 Gg by 2022. Waste generated by 1.5 million inhabitants directly impacts 73,600 inhabitants of the Panama district through the dispersion of hazardous atmospheric pollutants derived from landfill. The highest emission rates were from Hydrogen

Sulfide and Dichloromethane, allocated to the waste generated by the communities of Juan Diaz and Tocúmen. Calle 50, squatter settlement nearby Cerro Patacón, bears the highest environmental pressure with the highest concentration of Hydrogen Sulphide and Dichloromethane; it also receives environmental pressures from the highest concentration of Benzene. Excess cancer cases are for the communities of Ancón (2), Betania (5), Pueblo Nuevo (2) and San Francisco."

2.5.3.1 ***Answering the fundamental question:*** *How to allocate responsibilities for the societal impacts produced by landfill environmental pressures derived from uncontrolled MSW disposal in developing countries?*

People usually attribute poor landfill management to authorities, not recognizing they also share part of the responsibility (by producing the MSW in the first place or not source separating MSW to recover recyclable waste fractions). Allocating responsibilities for the societal impacts produced by landfills' environmental pressures derived from uncontrolled MSW disposal in developing countries is achievable to the extent in which it is acknowledged how part of the population affects another to raise awareness of the problem in the local society.

As a third step of the diagnostic strategy, developing countries could try for better monitoring and modelling of MSW generation and environmental pressures due to direct landfilling of MSW. This task should be carried out in collaboration with the rest of society through the creation of quantitative stories about societal impacts affecting people's health that occur from non-identified environmental pressures. People tend to alienate environmental pressures and become better involved with the social impacts that harm their health. However, environmental pressures evolve into social impacts and must be identified and mitigated before this occurs.

Appropriate community participation and information dissemination tools could support in arising awareness among general public about the effect of the indiscriminate generation of MSW on their health and the global environment and how their involvement and behaviour could help in fighting Climate Change. But this is not achievable in developing countries because, among other issues, public agencies involved in waste management have unclear responsibilities and a systemic overlap of their functions. There is no single agency designated to coordinate or assume responsibility for MSW management. This has led to weak implementation and enforcement of laws and regulations of MSW management.

2.5.4 Normative issues

Paper #4: *"Robust information for effective municipal solid waste policies: identifying behavior of waste generation across spatial levels of organization"* (Torrente-Velásquez et al., 2020a).

ELSEVIER

Waste Management
Volume 103, 15 February 2020, Pages 208-217

Robust information for effective municipal solid waste policies: Identifying behaviour of waste generation across spatial levels of organization

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Impact Factor: 7.14

Abstract: "This paper presents the results of a secondary analysis of data from a study on Betania, an urban sector of Panama City, with the aim to study the influencing factors (education, demographic, health, ethnic, economic activity and financial types) of domestic MSW generation rates across multiple levels of organization, to create a robust knowledge base for MSW management policies in fast growing urban areas in developing countries. The levels considered include individuals, households, and communities, hierarchically organized as functional units of MSW generation within Betania. Results show that household income is a strong determinant of resource consumption habits of each household inhabitant, and consequently causal of their MSW generation behavior; delinking income from MSW generation is not possible yet in developing countries. MSW generation behavior of Betania´s communities at the households´ level keeps 44% of the patterns that the inhabitants´ level presented; income at both levels may be the cause of this remaining alignment. It is concluded that MSW generation is not linear across levels, it has as many degrees of freedom as influencing factors shaping the levels of organization where functional units of waste generation exists. However, linear approximations of MSW generation behavior within each level can support policies for each functional unit of MSW generation and avoid overlapping policies causing legal gaps. Further improvements of

the approach presented are possible using separate (metal, plastic, paper, organic) instead of commingled MSW streams.”

2.5.4.1 ***Answering the fundamental question:*** *Can better analysis of MSW generation patterns improve the quality and transparency of MSW management systems' decision-making of developing countries?*

Multiple spatial levels of governance organization (reflecting the existence of MSW generation and management functional elements inside the MSW management system) may be identified across MSW management systems of developing countries. Therefore, each functional element's identity and function should be clearly defined and analyzed concerning its MSW generation/management behavior and its specific influencing factors at each identified level. In this way, better analysis of MSW generation patterns could improve the quality and transparency of MSW management systems' decision-making of developing countries.

As a final step of the diagnostic strategy, developing countries could analyze the MSW management system through functional units of MSW generation and MSW management at different spatial levels of organization (**Figure 2**) to shed light on their impredicative relation: MSW generation functional units assume the function of dimensioning MSW management functional units, while the latter simultaneously assume the function of limiting the earlier. MSW generation functional units behave like natural systems, whereas the higher the spatial level of organization, the higher the function's heterogeneity of the entities found. While MSW management functional units behave like formal systems, whereas the higher the spatial level of organization, the higher the function's complexity of the entities found.

3 Discussion

When dealing with fast-growing cities, the sustainable handling of MSW represents a relatively new challenge for human societies. This entails that the two factors required to face this challenge: (i) a proper understanding and know-how of the terms of reference of the problem (how to structure, represent and solve the practical concerns associated with MSW management); and (ii) an effective set of social practices – referring to both those generating MSW and those taking care of them - have not been clearly defined both in developed and in developing countries. The slower pace of urban growth in developed countries, the longer local experience, a more stringent regulation framework, and the larger quantity of resources that can be allocated to this task can explain the different levels of performance found when comparing the MSW management of developed and developing countries. However, it should be noted that a consistent problem with the MSW management - i.e., overload of dumping sites, occasional overflows of the MSW management, dependence on the solution of exporting wastes are commonly found also in many developed countries. This entails that, when talking of MSW management, also in the developed world, there are ample margins for improvement.

As noted earlier, the difference in the performance of MSW management operating in developed and developing countries can be explained mainly by a longer local experience (learning by doing) and by a higher level of resources invested by developed cities in MSW management. When considering the existing knowledge used to guide action in this field, we can say that a robust conceptual framework is still missing both in developed and developing countries. This is particularly important when considering that in MSW management, the applied know-how must be continuously updated, especially when the portfolio of consumed goods, the habits of the consumers, and the residential arrangements change rapidly. In this situation, simplistic assessments of the pattern of MSW generation based on conventional indicators to estimate the average MSW per capita per year provide a too coarse analysis. To put it in another way, the use of conventional indicators makes it difficult to handle the fine-tuning information reflecting local knowledge. Concomitant with paydays, the specific habits of residents when disposing of their wastes differ in different areas; the differences in the topology of different residential areas affect the access of different types of vehicles needed to collect solid wastes. The current use of simplistic indicators of MSW generation entails in many developing countries a lack of understanding of the factors that should be considered when deciding MSW management policies. However, the responsibility of this fact does not rely only on the lack of interest of local administrators. Rather, it is a consequence of the fact that the conceptual analysis of the metabolism of MSW management in urban settings, so far, has not been properly developed.

4 Future research

This thesis focused on Panama City as a case study, but many more case studies will be necessary to confirm the answers posed to the research question.

Deepening into multilevel MSW generation studies in developing countries, which present more robust information than studies conducted in other ways, is a task for future research. In this sense, it would be essential to explore solid waste generation case studies in other developing countries to develop consistent multilevel-like approaches. In addition, it will be necessary to design new research studies to study MSW generation capable of including endogenous knowledge from local companies and using a MSW generation multilevel approach. It is necessary a framework allowing the integrated study of; (i) the processes determining the pattern of MSW generation; (ii) an effective characterization of the option space associated with technical and organizational processes capable of handling different patterns of MSW generation. Building this kind of framework, can support in developing decision support capable of properly characterizing the nature of the problems to be faced and the pros and cons of possible solutions tailored to the specific context.

The waste lexicon proposed in the paper about Free Trade Agreement establishes relationships between the quality and quantity of imported consumer goods and the MSW derived. This idea could be developed and formalized into a software for application by developing non-industrialized governments assessing best Free Trade Agreements opportunities with developed industrialized countries. Also, specific clauses regarding consumer goods to be imported within future Free Trade Agreements should be designed and implemented in detail according to the types of materials contained on each good type to determine their specific management.

To generate a decision support tool based on the ideas presented in this thesis, additional research on user-friendly software to be used in a participatory co-production of knowledge will be necessary. This co-production could be especially important in relation to the methods used to quantify societal impacts produced by these environmental pressures and others – i.e., landfill surface fires and nearby infrastructure explosions. These events have a low-frequency occurrence, but they may have remarkable impacts. Also, further research will be necessary on societal impacts caused by leachate infiltration in groundwater since only communities close to surface water bodies will be affected. Concerning this task, different approaches will be necessary. Also, further research will be needed to understand societal impacts from landfills of developing countries, not only from an environmental pressure standpoint but multidimensionally, where other criteria to assess societal impacts can be considered - e.g., economic, socio-political, cultural.

To even better increase the robustness of information for decision-making in the MSW management system of developing countries, future research should be formalized into the multilevel governance framework and explore identities and functions of MSW generators and their influencing factors at several spatial levels of governance organization by each fraction contained on this stream–e.g., metal, plastic, paper, organic-, or even by waste type -e.g., commercial, municipal solid waste, tires, clinical waste, and construction & demolition waste-, more than just treat MSW as a mixed waste stream. This may support understanding of the extent to which influencing factors affect their generation at different levels regarding materials composing the MSW stream.

To avoid reductionism incurred by traditional quantification approaches informing MSW management policies, the methods applied to generate information used for informing policy might include the latest insights coming from complexity theory (pointing out that systems are unpredictable and emphasizes their changing interactions and feedback loops) (Wolfram, 1985), explicitly acknowledge the relevance of hierarchy theory (implying the need of using simultaneously different scales and dimensions of analysis) (Allen, 1983) and of post-normal science (stating how to guarantee the usefulness of the information for policy when dealing with issues affected by large doses of uncertainty and the co-existence of non-equivalent legitimate perceptions about what is the best thing to do) (Dankel et al., 2017; Funtowicz and Ravetz, 1993; Kønig et al., 2017; Ravetz, 1999)

I am aware that what is presented in this thesis does not provide a comprehensive contribution to developing a decision support tool capable of guaranteeing the quality of policies related to MSW management. However, I can say that it provides a series of reflections on key aspects to be considered in the search for a comprehensive and novel procedure to generate sound diagnosis about the problems to be faced in developing countries' MSW management systems. This novel procedure should be applied in a participatory way, helping the different social actors select a wise, context-specific strategy through an informed deliberation. Each of the four papers raises a specific research question. The answers to these questions provide insights on how to improve the overall quality of the decision-making process in MSW management. The titles and the abstracts of the papers addressing these four issues are provided below.

5 References

Allen, T.F.H., 1983. Hierarchy: Perspectives for ecological complexity. Behavioral Science 28, 305–306. https://doi.org/10.1002/bs.3830280407

BID, 2011. Informe de la evaluación regional del manejo de residuos sólidos urbanos en América latina y el caribe 2010.

Breukelman, H., Krikke, H., Löhr, A., 2019. Failing Services on Urban Waste Management in Developing Countries: A Review on Symptoms, Diagnoses, and Interventions. Sustainability 2019, Vol. 11, Page 6977 11, 6977. https://doi.org/10.3390/SU11246977

Butterworth, A., Clegg, I., Bass, C., 2012. Untangled. Marine debris: A global picture of the impact on Animal welfare and of animal-focused solutions, World Society for the Protection of Animals, London.

Dankel, D.J., Vaage, N.S., van der Sluijs, J.P., 2017. Post-normal science in practice. Futures. https://doi.org/10.1016/j.futures.2017.05.009

Denuncio, P., Bastida, R., 2014. Composition, distribution and waste management of Playa Grande, the most important touristic beach of Mar del Plata city, Argentina. Waste Management 34, 837–841. https://doi.org/10.1016/j.wasman.2014.01.013

EEA, 2007. The road from landfilling to recycling: common destination, different routes.

Eshet, B., Yadav, R., 2015. SOLID WASTE MANAGEMENT. Poll Res 34, 111–120.

European Commission, 2000. Commission Decision on the European List of Waste (COM 2000/532/EC). Official Journal of the European Communities 2000D0532, 1–31. https://doi.org/(2000/532/EC)

European Parliament and Council, 2008. Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain directives, Official Journal of the European Union. https://doi.org/2008/98/EC.; 32008L0098

Flintoff, F., 1984. Management of Solid Wastes in Developing Countries. World Health Organization, Regional Office of South-East Area, New Delhi.

Funtowicz, S.O., Ravetz, J.R., 1993. Science for the post-normal age. Futures 25, 739–755. https://doi.org/10.1016/0016-3287(93)90022-L

Guibrunet, L., Sanzana Calvet, M., Castán Broto, V., 2017. Flows, system boundaries and the politics of urban metabolism: Waste management in Mexico City and Santiago de Chile. Geoforum 85, 353–367. https://doi.org/10.1016/J.GEOFORUM.2016.10.011

Hoornweg, D., Bhada, P., 2012. What a Waste. A Global Review of Solid Waste Management. Urban development series knowledge papers 281, 44 p. https://doi.org/10.1111/febs.13058

Karlsson, N., Dellgran, P., Klingander, B., Gärling, T., 2004. Household consumption: Influences of aspiration level, social comparison, and money management. Journal of Economic Psychology 25, 753–769. https://doi.org/10.1016/j.joep.2003.07.003

Kawai, K., Tasaki, T., 2016. Revisiting estimates of municipal solid waste generation per capita and their reliability. Journal of Material Cycles and Waste Management 18, 1–13. https://doi.org/10.1007/s10163-015-0355-1

Kønig, N., Børsen, T., Emmeche, C., 2017. The ethos of post-normal science. Futures. https://doi.org/10.1016/j.futures.2016.12.004

Kumar, A., 2016. Analyzing the Factors Affecting the Sustainable Municipal Solid Waste Management (MSWM). Indian Journal of Science and Technology 9, 1–7. https://doi.org/10.17485/ijst/2016/v9i47/105286

Louis, G.E., 2004. A Historical Context of Municipal Solid Waste Management in the United States. Waste Management & Research 22, 306–322. https://doi.org/10.1177/0734242X04045425

Medina, M., 2011. Solid Wastes, Poverty, and the Environment in Developing Country Cities: Challenges and Opportunities, Urbanization and Development: Multidisciplinary Perspectives. WIDER. https://doi.org/10.1093/acprof:oso/9780199590148.003.0015

Medina, M., 1997. Informal Recycling and Collection of Solid Wastes in Developing Countries: Issues and Opportunities. UNU/IAS Working Paper No. 24.

NHS, 2006. Using protocols, standards, policies and guidelines to enhance confidence and career development Examples of national guidelines that provide robust evidence for clinical management.
Ravetz, J.R., 1999. What is post-normal science. Futures 31, 647–653. https://doi.org/10.1016/S0016-3287(99)00024-5
Reichel, A., Milios, L., 2013. Municipal waste management in Germany. Etc/Scp 1–11. https://doi.org/10.1504/AFP.2013.058573
Sampaio, A.M.M., Kligerman, D.C., Júnior, S.F., 2009. Dengue, related to rubble and building construction in Brazil. Waste Management. https://doi.org/10.1016/j.wasman.2009.06.017
Serrona, K.R.B., Yu, J., Aguinaldo, E., Florece, L.M., 2014. Developing a monitoring and evaluation framework to integrate and formalize the informal waste and recycling sector: The case of the Philippine National Framework Plan. Waste Management and Research 32, 882–895. https://doi.org/10.1177/0734242X14542146
Torrente-Velásquez, J.M., Chifari, R., Ripa, M., Giampietro, M., 2020a. Robust information for effective municipal solid waste policies: Identifying behaviour of waste generation across spatial levels of organization. Waste Management 103, 208–217. https://doi.org/10.1016/j.wasman.2019.12.032
Torrente-Velásquez, J.M., Giampietro, M., Ripa, M., Chifari, R., 2020b. Landfill reactions to society actions: The case of local and global air pollutants of Cerro Patacón in Panama. Science of the Total Environment 706. https://doi.org/10.1016/j.scitotenv.2019.135988
Torrente-Velásquez, J.M., Ripa, M., Chifari, R., Bukkens, S., Giampietro, M., 2020c. A waste lexicon to negotiate extended producer responsibility in free trade agreements. Resources, Conservation and Recycling 156, 104711. https://doi.org/10.1016/j.resconrec.2020.104711
Torrente-Velásquez, J.M., Ripa, M., Chifari, R., Giampietro, M., 2021. Identification of inference fallacies in solid waste generation estimations of developing countries. A case-study in Panama. Waste Management 126, 454–465. https://doi.org/10.1016/j.wasman.2021.03.037
Troschinetz, A.M., Mihelcic, J.R., 2009. Sustainable recycling of municipal solid waste in developing countries. Waste Management 29, 915–923. https://doi.org/10.1016/j.wasman.2008.04.016
Umar, U.A., Shafiq, N., Malakahmad, A., Nuruddin, M.F., Khamidi, M.F., 2017. A review on adoption of novel techniques in construction waste management and policy. J Mater Cycles Waste Manag 1361–1373.
UNCED, 1992. Earth Summit'92. The UN Conference on Environment and Development. Reproduction Rio de Jan, 351. https://doi.org/10.1007/s11671-008-9208-3
US EPA, 2014. Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2012. US Environmental Protection Agency 1–13. https://doi.org/EPA-530-F-14-001
US EPA, 1991. Characterizing Heterogeneous Wastes: Methods and Recommendations.
Watson, D., Reichel, A., 2013. Municipal Waste Management in the United Kingdom.
Wilson, D.C., Rodic, L., Scheinberg, A., Velis, C.A., Alabaster, G., 2012. Comparative analysis of solid waste management in 20 cities. Waste Management & Research 30, 237–254. https://doi.org/10.1177/0734242X12437569
Wilson, D.C., Velis, C., Cheeseman, C., 2006. Role of informal sector recycling in waste management in developing countries. Habitat International 30, 797–808. https://doi.org/10.1016/j.habitatint.2005.09.005
Wolfram, S., 1985. Complex Systems Theory. Emerging Syntheses in Science: Proceedings of the Founding Workshops of the Sante Fe Institute.
Zohoori, M., Ghani, A., 2017. Municipal Solid Waste Management Challenges and Problems for Cities in Low-Income and Developing Countries. International Journal of Science and Engineering Applications 6, 039–048. https://doi.org/10.7753/IJSEA0602.1002

6 Author's Accepted Manuscript of the Published Papers

6.1 Paper #1 - "Identification of inference fallacies in solid waste generation estimations of developing countries. A case-study in Panama"

Identification of inference fallacies in solid waste generation estimations of developing countries. A case-study in Panama.

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Abstract

The absence of sound sampling procedures and statistical analyses to estimate solid waste generation in many developing countries has resulted in incomplete historical records of waste quantity and composition. Data is often arbitrarily aggregated or disaggregated as a function of waste generators to obtain results at the desired spatial level of analysis. Inference fallacies arising from the generalization or individualization of results are almost never considered. In this paper, Panama, one of the fastest-growing developing countries, was used as a case-study to review the main methodological approaches to estimate solid waste generation per capita per day, and at different hierarchical levels (from households to the country). The solid waste generation intensity indicator is used by the Panamanian waste management authority to run the waste management system. It was also the main parameter employed by local and foreign companies to estimate solid waste generation in Panama between 2001 and 2008. The methodological approaches used by these companies were mathematically formalized and classified as per the expressions suggested by Subramanian et al. (2009). Seven inference fallacies (ecological, individualistic, stage, floating population, linear forecasting, average population and mixed spatial levels) were identified and allocated to the studies. Foreign companies committed three of the seven inference fallacies, while one was committed by the local entity. Endogenous knowledge played an important role in these studies to avoid spatial levels mismatch and multilevel measurements appear to produce more reliable information than studies obtained via other means.

Keywords

Solid waste generation intensity; estimation; multilevel analysis; inference fallacies; meta-analysis; developing countries; Panama.

1. **Introduction**

Waste generation rates are rising. There are currently about 2 billion metric tons of municipal solid waste produced annually worldwide. The World Bank (2018a) estimates overall solid waste generation (SWG) will increase to 3.4 billion metric tons by 2050. Most of this solid waste will be generated from developing countries due to their increasing population, economic growth and rapid urbanisation (Zohoori and Ghani, 2017).

Accurate data is required to have a deeper understanding of SWG behaviour in order to implement sustainable and feasible waste management policies (Bandara et al., 2007). Failure of sound SWG sampling and analysis may either over or under estimate the required capacity of waste treatment facilities and increase environmental impact due to the implementation of ineffective measures (Buenrostro et al., 2001).

Common methodological shortcomings of SWG studies performed in developing countries include: uncertainty on the exact number of inhabitants generating waste in certain locations, unrepresentative samples of inhabitants to represent large populations, misallocation of population belonging to certain spatial levels, SWG data collection from multiple unreliable sources, incomplete historical record of quantity and quality of SWG, and use of old SWG data as updated data (Afon and Okewole, 2007; Wilson and Velis, 2014). To mitigate these fallibilities, the SWG in developing countries is commonly obtained from the solid waste generation intensity (SWGI) indicator. The SWGI is the daily SWG of a determined spatial level or place, e.g. country, region, city, averaged over its population.

This indicator normalizes SWG per capita thus allowing its comparison among different places of equivalent spatial level (Linster, 2003). However, benchmarking this value among non-equivalent spatial levels generates inconsistencies in SWG studies and potentially makes solid waste management (SWM) plans technically unfeasible and economically unviable (DEFRA, 2013). Consequences are that SWM plans in developing countries are seldom implemented. Methodological approaches behind results are never publicly disclosed due to constraints of data disclosure, imposed by companies performing SWG studies. These studies become obsolete, new ones are then performed and the same pattern is repeated (Voss et al., 2013).

Inconsistencies derived from benchmarking SWGI values among non-equivalent spatial levels are mostly due to the misconception of the unit of observation and the unit of analysis. The unit of observation is at the level at which one observes, measures or collect the data. The unit of analysis is at the spatial level about one wish to say something, i.e., the focal level of the study. These levels can be the same, but they need not be. For instance, when data exists only at the municipal level and the objective is to understand the SWG behaviour of individuals, inferences may be drawn from the disaggregation of the data available. In this scenario, known as cross-level inference, a mismatch of observation and analysis levels occurs, thus potentially creating inference errors or fallacies (Alker jr., 1974; Blakely and Woodward, 2000).

Inference fallacies are properly documented in epidemiology since Robinson's study made a seminal contribution by demonstrating that correlations for the same two variables can be different depending on the level at which they are analysed (Robinson 1950). As indicated by Molina-Azorín et al. (2019a), most data come from phenomena where subjects form nested hierarchies. In this regard, there are two ways to study nested data: **aggregation** (obtaining data at a lower level and combining the values of those variables to the higher level) and **disaggregation** (data from higher-level units are disaggregated into data on a larger number of lower-level units). Either of these two strategies may produce errors when conclusions are drawn at the wrong level (Molina-Azorín et al., 2019).

The error due to aggregation is known as the *'ecological fallacy'*. This fallacy occurs where inferences about individuals are drawn from inferences on the group to which they belong, thus deriving conclusions about individuals solely on the basis of group data analysis (Winzar, 2015). For instance, calculating the SWG at a country level with the aggregation of SWGI per capita, obtained from a sample population of a specific town, generates an ecological fallacy. Here, the value fails to take into account the population distribution across other parts of the country (Afon and Okewole, 2007).

The error due to disaggregation is known as *'atomistic or individualistic fallacy'*. In this case, inferences about a group are based on data belonging to individual members of that group, thus deriving conclusions about the entire group solely on the basis of individual data analysis (Loney and Nagelkerke, 2014).

This paper identifies and compares typologies of SWGI estimations to detect ecological and individualistic fallacies committed. It also goes further and discusses new inference fallacies derived from flawed methodological approaches used for SWG surveying in three studies performed in Panama from 2001 to 2018. These studies were conducted by foreign (INECO and JICA) and local (GDR) companies which estimated the SWGI from SWG values at different hierarchical levels e.g. household, town, district (Guerrero et al., 2013).

Going forward, the study is structured as follows:

Section 2 provides an overview of the study area. It explains self-similarity of SWGI estimations and examines common sampling methods of SWG data. It also presents details on the SWG studies performed in Panama, displays typologies of SWGI estimations and identifies inference fallacies derived from their misuse.

Section 3 classifies the typology of SWGI estimated values from the SWG studies presented. It compares these values among them and against literature and discloses inference fallacies perpetrated by each analysed study. Finally, Section 4 concludes by discussing the uncertainties and the lessons learned from this study.

2. **Materials & Methods**

This section outlines the extent to which skewed multi-level population distribution produces self-similar SWGI estimations when approaching from broader spatial levels e.g. country- to more individual ones e.g. inhabitants. Panama serves as the case-study area. It also presents common SWG sampling approaches and introduces the measurement level as an intermediate spatial level to estimate SWGI values at the analysis level from values obtained at the observation level. It goes further to show how SWGI is locally estimated, how precise estimations are carried out within SWG studies and their mathematical formalization. Finally, it highlights typologies of SWGI estimations and fallacies derived from their misuse.

2.1. Study area and SWGI self-similarity as per population distribution

In the past decade, Panama has been one of the fastest-growing economies worldwide (INEC, 2016) and the highest Economic Annual Growth Rate country of Latin-America (IMF, 2018). In July 2018, Panama was re-classified from the upper-middle to the high-income level group of countries by the World Bank (2018b). This in itself is an indicator of economic affluence. The fast-increasing economic transition sharply contrasts with Panama's archaic waste management system struggling to react to the SWG derived from unsteady resource consumption habits (JICA, 2005; Ragossnig and Vujić, 2015).

Panama has around four million inhabitants. Like in most countries, the population is unevenly distributed throughout spatial levels, e.g. country, provinces, districts **(Figure 1a)** (Fujimoto et al., 2015). Roughly, 37% of the country's total population is concentrated in 15% of its area, which is the Panama province (PP). 71% of the population of PP is concentrated in 23% of its area which is Panama district (PD), while 5% of the population of PD is concentrated in 0.3% of its area which is Bethania Town (BT) and so on (INEC, 2006). This multilevel population distribution entails that the size of places is determined by additive population from subsets of places within them (Addison, 2000).

For instance, in **Figure 1b**, as places approach from left to right to the level of the smallest SWG unit (inhabitant or individual), population within same-level places (e.g. from province to province, from community to community, from household to household) appears to have the same size, and the SWG of those places, that now depends on fewer individuals´ values, derives on each time more self-similar SWGI estimations (Mandelbrot, 1967). For instance, the variation in family memberships between households is lower in comparison to the population variation between provinces. Therefore, resource consumption habits (and consequently SWG behaviour) will vary more from province to province than from household to household.

2.2. Introduction of the measurement level from SWG sampling methods to estimate SWGI

There are several methods to derive SWGI values at the analysis level from SWG values available only at the observation level. **Figure 2** illustrates four methods to infer SWGI at the analysis level of Bethania, a town located in Panama district with a population of 50,000.

Estimation (**a**) (upper-left side) would be inferred by obtaining SWG values of each household, then aggregating and averaging by the total population of the town. This method would be the most reliable SWGI estimation of Bethania because each household is being surveyed; however, the entire process is very cumbersome and expensive.

Estimation (**b**) (lower-left side) may obtain SWG values from a statistically representative sample of households located at a specific area of the town, instead of from all households. The downside with this method is that the results may be inaccurate because SWG behaviour may vary considerably between the sampled households and the rest of the population.

Estimation (**c**) (upper-right side) considers the SWG behaviour of households by clustering (Kohberger and Everitt, 2006) them according to a defined variable like income which reflects the resource consumption habits and the resulting SWG behaviour. In this case, statistically representative samples of households within each cluster are randomly selected for surveying and averaging their SWG. The SWGI of Bethania is obtained by averaging the SWGI of each sample by their population, and then averaging resulting SWGI by total clusters created. However, clustering households without considering spatial distribution as per households´ location produces floating clusters (Giampietro et al., 2009) that misses the causality of their SWG behaviour, necessary to assure reliability of the clustering process (Matuszewski, 2002).

Estimation (**d**) (lower-right side) introduces the measurement level to make it possible to consider spatial distribution as per households´ location. The measurement level is a spatial level in between the analysis and observation levels. In Panama, groups of households constitute communities while groups of communities constitute towns. As shown in **Figure 2d**, communities (green line surrounding households) are a geopolitically predefined group introducing context for households to be clustered taking into account SWG behaviour of the communities to which they belong. The use of the measurement level in this example allows inferring SWGI of the Bethania town by clustering households within communities and applying Estimation 3 within a known spatial level i.e., communities. This increases the reliability of the clustering process with the SWG behaviours defined by communities, as opposed to floating clusters of households, while keeping the process feasible.

2.2.1. Measurement level selection affecting SWGI estimations

The measurement level represents a geopolitically defined spatial level in between the analysis and observation levels. It gives robust context to places at the observation level to obtain reliable SWGI estimations at the analysis level. However, sometimes there are several measurement levels to choose from, where choosing one or another will affect the SWGI estimation.

Figure 3 shows the extent to which choosing from three different measurement levels (secondary y-axes) i.e., town (**Figure 3a**), community (**Figure 3b**), and household (**Figure 3c**) can change the average number of waste generating inhabitants at the analysis level (primary y-axes). This selection will determine SWGI estimations at different observation levels (x-axes) i.e., country, capital province, capital district, metropolitan towns, Bethania (as a stratified town) and communities of Bethania. Metropolitan towns are defined as a spatial sublevel between the levels of district and town, consisting of a set of urban towns of the capital district. Furthermore, Bethania has been named a stratified town since it contains a wide range of social classes, resource consumption habits, and SWG behaviours.

When observed from the country and capital province observation levels, SWGI estimated from average waste generating inhabitants at the town measurement level, presents an eight-fold difference (country and capital province bars of **Figure 3a**). When SWGI is estimated from average waste generating inhabitants at the community measurement level, results at the country and capital province observation levels are much closer (country and capital province bars of **Figure 3b**). The SWGI estimation from average waste generating inhabitants at the household measurement level presents almost the same results when observed from the country and province observation levels (country and capital province bars of **Figure 3c**).

The closer the measurement level is to the analysis level (from **Figure 3a** to **Figure 3c**), the more even and reliable the SWGI value across observations levels is. Consequently, it becomes more technically unfeasible and economically unviable, due to lower spatial levels' constraints, to collect SWG data e.g., the need for more entities to collect data from in order to comply with statistical representative samples.

Grey lines of **Figure 3** represent variations in the quantity of measurement levels at each observation level. For instance, for the observation level "country" of **Figure 3a**, the measurement level is towns, and the grey line indicates the number of towns at this observation level; a total of 678 that decreases to <100 at the "Capital province" observation level. The same is applied to the rest of observation levels of **Figure 3a**, and to **Figures 3b** and **3c**. It should be noted that: as the measurement level from **Figures 3a, 3b** and **3c** i.e. towns, communities, households, respectively approaches the analysis level (inhabitants), self-similarity is more and more present among their SWGI estimated values because the number of inhabitants generating waste present fewer variations across observation levels (Nottale, 2010).

SWGI estimations are affected if measurement levels are not correctly defined, leading to the fallacies which will be discussed in this study.

2.3. SWGI estimations by the local authority and SWG studies performed

2.3.1. SWGI estimation by the national waste management authority

The national waste management authority *(Autoridad de Aseo Urbano y Domiciliar or* AAUD), assumes that population at every observation level i.e. from households to country have a normal distribution with a default SWGI estimation of 1.3 kg $inh^{-1}d^{-1}$, that is aggregated by the population of the analysis level at which SWG is to be obtained (JICA, 2003). To update the number of inhabitants on the SWGI estimation, AAUD uses a compound annual population growth rate of 5% which is applied to population value of the 2010 census; **Equation 1** formalizes AAUD´s approach.

$$SWGI_{AAUD} = 1.05 \times 1.3 \times P_{2010}\,(CY - 2010) \quad \textbf{(1)}$$

Where, $SWGI_{AAUD}$ is the SWGI estimation used by AAUD, 1.05 is the 5% compound annual population growth rate, 1.3 is the generic SWGI value in kg $inh^{-1}d^{-1}$, P_{2010} is the population as per 2010 national census and CY is the current year when SWGI is to be estimated.

From 2001 to 2018, three studies have been executed to: (i) estimate SWGI; (ii) evaluate the situation of the Panamanian SWM system; and (iii) develop a SWM plan with defined normative and competence frameworks.

2.3.2. SWGI estimation by JICA

From 2001 to 2003, the Japanese company Kokusai Kogyo., ltd., representing the Japanese International Cooperation Agency (JICA), carried out the *"Study on the Solid Waste Management for the Municipality of Panama in the Republic of Panama 2003 - 2015"* (JICA, 2003) at a $2M cost. SWG values were obtained at the household observation level for 15 days to estimate SWGI at the district analysis level. Households were clustered by mixing two different measurement levels: communities and towns. JICA classified both levels as “town” without considering that communities are sublevels of towns and there are different factors influencing the SWG at each level. To keep things simple, the measurement level used by JICA will be referred to as “town” going forward.

Towns were clustered based on household “apparent” income level values. These clusters where determined by the physical location of the households, and not based on official income level values. No statistical sampling technic was used to select the number of households per cluster; twenty random households were chosen per cluster (JICA, 2005).
To estimate the SWGI, surveyed households´ SWG values were expressed per unit of an unspecified average value of waste generating inhabitants per household.

The SWGI was estimated from households´ clusters formed using apparent income level data rather than official income level values. Despite this fact, the average SWG contribution of each cluster was weighed based on official income level values i.e. 11% for high-income level population, 46% for middle-income level population and 43% for low-income level population. JICA performed a linear forecast of SWGI values from 2003 -2015 suing population growth as the main parameter, without considering a possible change in SWG behaviors which could potentially distort such a linear forecast.
Equation 2 mathematically formalizes the SWGI estimated by JICA and shows the aggregation of the weighted averages of SWGI results per cluster.

$$SWGI_{JICA} = 0.11(\frac{1}{n}\sum_{i=1}^{n}\frac{SWG_i}{P_i} + CI_{HI}) + 0.46(\frac{1}{m}\sum_{j=1}^{m}\frac{SWG_j}{P_j} + CI_{MI}) + 0.43(\frac{1}{p}\sum_{k=1}^{p}\frac{SWG_k}{P_k} + CI_{LI}) \quad \textbf{(2)}$$

Where, $SWGI_{JICA}$ is the SWGI estimation that resulted from JICA study, n is the total number of apparent high-income towns, SWG_i the SWG for the i apparent high-income towns, P_i the population in the i apparent high-income towns, CI_{HI} the confidence interval of the SWGI estimation for apparent high-income towns. The same nomenclature is used for middle and low-income towns with their respective weighed SWG contribution.

2.3.3. SWGI estimation by INECO

From 2015 to 2017, the Spanish public company INECO carried out studies in Panama to set up the *"National Integral Waste Management Plan 2017 - 2027"* (INECO, 2017) at a $4.5M cost. Their methodology involved defining countrywide towns as the observation levels of SWG and clustering them using geopolitically undefined places which INECO defined by socio-economic criteria i.e. economic level represented by the Human Poverty Index (HPI), average income per capita and level of agricultural activities. These places do not count as measurement levels according to the definition of measurement level given before; however, for the sake of simplification will be considered as such.

The SWM system of developing countries is commonly composed of roughly origin, transport, and final disposal management stages. Unlike other studies which used the origin stage to observe SWG, INECO got SWG from values of waste arriving to the final disposal stage Over 75 days, INECO collated SWG data from the Panama district landfill. However, this practice results in important misestimations because landfills serve several towns, and surveyed waste collection trucks had plied undefined routes and unclear origins at their arrival to landfills i.e. from several communities across various towns. This means that waste values collected at the final disposal stage actually account for Solid Waste Disposal (SWD) not SWG. For this reason, going forward, SWG values surveyed by INECO will be referred to as SWD. INECO attempted to correct this flaw by using a "correction coefficient" of 1.24 i.e., SWG = 1.24 SWD, but this simplistic approach dismisses waste losses along waste collection routes from origin to final disposal, commonly caused by waste collection and transport flaws e.g., containerization absence in the origin, incomplete waste collection routes and unspecialized collection human resource-.

SWGI values at the measurement level was estimated by dividing SWG values obtained at the observation level by the population of the clusters. Four clusters were obtained, and the per capita high-income level cluster was solely represented by Panama district and its

SWGI estimation mathematically formalized in **Equation 3**.

The SWGI value for the entire country (not shown in **Equation 3** for the sake of simplification) was obtained by aggregating SWGI estimated values from clusters and multiplying by the whole country population. Results were forecasted to 2027, not linearly but considering population growth and the changing SWG behavior.

$$SWGI_{INECO} = 1.24\left(\frac{\frac{\sum_{i=1}^{n} SWD_i}{\frac{1}{n}\sum_{i=1}^{n} P_i}}{n}\right) \quad \textbf{(3)}$$

Where, $SWGI_{INECO}$ is the SWGI that resulted from INECO study, 1.24 the correction coefficient, n is the total number of Panama district towns, SWD_i the SWD for the i Panama district towns, and P_i the population in the i Panama district town.

2.3.4. SWGI estimation by GDR

In 2018, the local company Gestión de Residuos (GDR) carried out *"Dynamic characterization study of the Urban Solid Waste of Bethania town by community clusters according to its sociodemographic characteristics"* (MUPA, 2018) at a $27K cost. The methodology involved using the community measurement level to cluster and survey SWG values of random observation level households by their income level to estimate SWGI at the Bethania town analysis level - refer to **Equation 4**. Four out of 26 communities were randomly selected to represent low, middle, upper-middle and high households´ income levels, depending on the sample statistical representativity and the feasibility of surveying tasks. SWGI was estimated by dividing SWG by communities´ population. GDR did not produce SWGI forecast.

$$SWGI_{GDR} = \frac{1}{n}\sum_{i=1}^{n} \frac{\sum_{i=1}^{n} SWG_{ii}}{nPi} \quad \textbf{(4)}$$

Where, $SWGI_{GDR}$ is the SWGI estimation that resulted from GDR study, n is the total number of representative communities in Bethania town, SWG_{ii} the SWG of each representative community made up of the aggregation of the SWG of the households *making up each community, averaged by the total amount of households in each community n and the inhabitants P_i of each household i*

2.4. Typologies of SWGI estimations and main fallacies derived from their misuse

By applying the approach suggested by Subramanian et al. (2009), ”Typology of health and disease studies”, **Figure 4a** shows five mathematical expressions configuring observation and measurement levels to estimate analysis level SWGI.

Expression **type (a)** (upper-left side) takes an individualistic focus. It is performed by aggregating, at the measurement level, average SWG values obtained at the observation level. Then dividing by the total amount of analysis level waste generating entities i.e., inhabitants, or places in cases where SWGI is not to be expressed in “per capita” terms. It aims to represent the SWGI of entities belonging to the same observation level from the standpoint of the individual contribution of entities’ samples at the analysis level (James, 1890). The generalization of SWGI estimations obtained from the **type (a)** expression to analysis levels of other observation levels, different from the ones to which waste generating entities belong, lead to the individualistic or atomistic fallacy. Here, it is assumed that a causal relationship exists between waste generating entities of different observation levels. Also, that the replication of SWGI estimations, obtained from the analysis level of a first observation level, to the analysis level of a second observation level is equally or more reliable than a SWGI estimation obtained from direct SWG data of the second observation level (Blakely and Woodward, 1999).

Expression **type (e)** (lower-right side) takes a generalizing focus and matches the observation and measurement levels so that collection and aggregation of SWG values can be performed at the same level. SWGI estimations are directly obtained by dividing by the total amount of waste generating entities of the analysis level. It intends to attribute to all waste generating entities the SWGI estimated value obtained from their large-scale contribution to the observation level (also the measurement level in this case), thus reflecting their SWGI estimation at the analysis level from their perspective as a whole group (Robinson, 1950). The individualization of SWGI estimations, obtained from the **type (e)** expression at certain observation level, to the individual basis of the analysis levels of another observation level, lend to the ecological fallacy. The term "ecological" refers to a large-scale context as per hierarchy of different spatial levels (Moon et al., 2005; Selvin, 1958). Idrovo (2011) propose three criteria for the identification of the ecological fallacy which must be integrally met for it to be determined. They have been applied to the context of SWG in this paper as follows: (a) SWGI estimation must be obtained from large-scale SWG data; (b) SWGI estimation must be inferred to different analysis levels than the one aggregated at the measurement level to obtain SWG; (c) and SWGI estimated from expression **type (e)** must be different from that estimated with expression **type (a)**.

Expressions **type (c)** and **(d)** (lower-left side) cannot be specified on their own, they will either take the form of expressions **types (a)** or **(e)**, respectively.

The expression **type (b)** (upper-right side) is a multilevel expression obtained by: (i) surveying SWG values at the observation level, aggregating them at several measurement levels and dividing by the total measurement levels used; (ii) for each measurement level used, an average SWG value is obtained by dividing the number of waste generating entities which constitute each measurement level used; and (3) dividing the aggregation of each average by the total amount of measurement levels used to estimate SWGI at the analysis level. The expression **type (b)** aims to represent observation level values in analysis level terms (Alker jr., 1974). This is possible by considering the input that every analysis level entity exerts in the SWGI estimation at the observation level from values surveyed directly at the measurement level. The expressions **type (b)** enhances the possibility for cross-level approaches that supports discerning about the relative contribution, of both analysis and measurement level, to results at the observation level when aggregating the SWGI estimation by total waste generating entities. The simultaneous assessment of many waste generating entities in the context of the measurement levels shaping their SWG behavior, allows for a better representation of the effect that selected measurement levels exerts in waste generating entities, given that their relation is mutually causal. This approach also supports a more comprehensive framework to understand the ways in which the measurement level could contextually affect the SWG of waste generating entities of the analysis level or, alternatively, waste generating entities of the analysis level could causally affect measurement levels (Subramanian et al., 2009).

2.4.1. Practical example to illustrate SWGI estimation typologies

A numerical example is shown in **Figure 4b** to demonstrate different SWGI per capita estimations using expressions of **Figure 4a**. It presents a community (analysis level) consisting of 4 households (measurement level) with 5, 2, 3 and 4 inhabitants (observation level) each. SWG_{ij} and SWG_i represent random SWG values for inhabitants and households respectively; their aggregation is the actual total SWG value at the community level. SWGI estimations are shown in the lower square in the same order as presented in **Figure 4a**. This simple example makes the best-case scenario feasible i.e., surveying actual number of inhabitants at each household and their SWG. It demonstrates the extent at which there are differences in the SWGI estimations. Results obtained from expressions **types (c)** and **(d)** match those obtained from expressions **types (a)** and **(e)**, respectively. The extent to which expressions **types (c)** and **(d)** could be replaced by expressions **types (a)** and **(e)**, respectively, depends on the more households to survey SWG from, which limit is imposed by technical feasibility and economic viability issues of the surveying process.

The result obtained from expression **type (b)** represents the highest SWGI estimation, which is preferable over other results to offset uncertainty arising in the SWG surveying process (Wittwer et al., 2008).

3. **Results and discussion**

The first part of the results classifies the typologies of SWGI values, estimated from the SWG studies presented according to **Figure 4a,** and compares these values among them and also against literature. The second part discloses inference fallacies committed by each analysed study.

3.1. Identification and comparison of typologies of SWGI estimations

Table 1 compares the main characteristics of the studies performed by GDR, JICA and INECO, all of which used different observation and measurement levels according to the way SWGI values were estimated in relation to their analysis levels. It shows the typology of SWGI estimation each study used according to **Figure 4a**. Also compares SWGI results at the analysis and measurement levels as per income levels. For instance, the analysis level of GDR and the main clustering unit of the measurement level of JICA were both Bethania town, and the analysis level of JICA and the main clustering unit of the measurement level of INECO were both Panama district.

The approach used by JICA to estimate SWGI corresponds to a **type (a)** configuration, by INECO to a **type (d)** configuration which ended up being type **(e)**, and by GDR, although it was meant to be configured **type (b)**, it ended up being **type (d)**. The SWGI estimation of INECO and AAUD at the analysis level shows little variance, 1.26 and 1.30 $kg\ inh^{-1}\ d^{-1}$, respectively. JICA presented the lowest SWGI estimation at the Panama district analysis level (0.59 $kg\ inh^{-1}\ d^{-1}$), in contrast with INECO´s value which was almost triple JICA´s (1.55 $kg\ inh^{-1}\ d^{-1}$). JICA also presented the lowest SWGI estimation at the Bethania town measurement level (0.66 $kg\ inh^{-1}\ d^{-1}$), very close to GDR´s at its analysis level (0.76 $kg\ inh^{-1}\ d^{-1}$). GDR´s SWGI estimation at the measurement level (0.96 $kg\ inh^{-1}\ d^{-1}$) was between its value at the analysis level (0.76 $kg\ inh^{-1}\ d^{-1}$) and INECO's SWGI estimation at the country analysis level (1.26 $kg\ inh^{-1}\ d^{-1}$).

Comparisons of the SWGI estimation at the country analysis level of INECO (1.26) with literature values at the countrywide observation level by income levels **(table 2)**, show that INECO´s SWGI estimation is over the average of upper-middle income level countries (1.06 *kg* inh^{-1} d^{-1}) and under the average of high-income level countries (1.66 *Kg* inh^{-1} d^{-1}). This may be due to fallacies in the configuration of the observation and measurement levels. Unsteady economic growth rates and high social inequalities of Panama (Indexmundi, 2015) are also influencing factors, reflected in resource consumption and SWG patterns compared to other similar income level countries (IMF, 2018).

3.2. Inference fallacies committed in the reviewed studies

Methodological inference fallacies have been identified for SWGI estimations in the studies analysed (**Table 3**).

JICA committed the "*individualistic fallacy"* by generalizing the SWGI estimation to the whole Panama district directly from households. JICA did not considered that income level varies broadly among households of a district so it cannot be generalized at this analysis level directly from the households´ observation level (Zohoori and Ghani, 2017).

Following the three criteria for the identification of the *"ecological fallacy"* proposed by Idrovo (2011), INECO committed *condition (a)* for ecological fallacy when using large-scale solid waste data surveyed in the landfill. JICA, INECO and GDR committed *condition (b)* for ecological fallacy when inferring the SWGI, estimated at the analysis level, to observation level entities, others than the ones aggregated at the measurement level. To avoid *condition (b)* for ecological fallacy, SWGI estimations should be directly surveyed from observation level entities, but this is a complex task to perform. To mitigate *condition (b)*, the observation level should be as close to the measurement level as possible, and the measurement level should consider very diverse observation level entities. The SWGI estimation of GDR will be used as proper reference for the evaluation of *condition (c)* to ecological fallacy incurred by INECO and JICA, because GDR kept the closest relation between the measurement level i.e., households and the observation level i.e., inhabitants, it is therefore likely to be closer to the SWGI estimation **type (a)**. JICA and INECO committed *condition (c)* for ecological fallacy. JICA mixed communities and towns together, handling them all as towns to cluster households based on their apparent income levels as clustering variable, whereas GDR used the actual income. INECO complies with all conditions for ecological fallacy, therefore as Idrovo (2011) proposed, this implies ecological fallacy perpetration.

Apart from the ecological and individualistic fallacies, other inference fallacies have been identified.

The "*Stage fallacy"* is the assumption that, after applying a correction coefficient, the results obtained at any stage of the SWM system e.g., final disposal, can also be considered valid for other stages e.g., waste generation. Correction coefficients are supposed to summarize in a single value the complexity of SWM system process subtleties at each of its stages. From the generation to the final disposal stage e.g. waste weight losses/gains during containerization due to excessive rain, underground waste market transactions by the waste transport civil servants or waste pickers of the streets, and informal recycling performed by waste pickers of the landfills (Scheinberg et al., 2011). However, in developing countries waste lost data along the SWM process is almost unaccountable since SWM information systems are seldom established. INECO incurred the Stage fallacy by equating their SWD study with a SWG study using a correction coefficient. Incurrence on this fallacy or poor estimation of the correction coefficient may be causal of a 3-fold SWGI estimation between INECO and JICA.

The "*Floating Population fallacy"* is a direct effect of studies using SWD values as SWG values. This fallacy represents unreliability of solid waste disposal intensity (SWDI) estimations derived from weighing collection trucks that dispose waste in landfills with unclear origins and undefined collection routes. The report on waste collection routes, commonly used by the local waste management authority (AAUD, 2014) for their waste collection activities, presents waste collection routes that either partially or totally mix communities. This makes it almost impossible to estimate the population from which waste is collected and disposed of. INECO committed the Floating Population fallacy by estimating SWDI using data from this report to select waste collection trucks to be sampled at the landfill, but also using fixed population values at the town level, not precisely belonging to mixed communities included in each route.

The *"Linear Forecasting fallacy"* presumes that future change will be a simple and steady extension of past trends, i.e. estimating SWGI over years without considering SWG and population of the analysis level, both unpredictable extensive variables with many factors shaping their context (Pereira et al., 2006). JICA committed this fallacy when linearly forecasting a SWGI estimation for Panama district and its constituting towns in 2015 based on results obtained in 2002. When subjected to similar changes, the SWM system may behave in similar patterns over time and past events can lead to predictions about its behaviour, however the timing or frequency of such behaviour cannot be predicted. Forecasting SWGI values considering no changes in the state of a SWM system over years will give results quite different from the reality, because over time the environment pushes the SWM system far away from its equilibrium state into chaos which can result in sudden, unpredictable changes (Seadon, 2010).

The *"Mixed Spatial Levels fallacy"* is the introduction of a measurement level composed of geopolitically undefined spatial levels to cluster observation level entities (inhabitants or places). This fallacy was committed by JICA when clusters were formed by mixing towns and communities, under the assumption that they were at the same spatial level. Also, a combination of the Individualistic and Mixed Spatial Levels fallacies may have caused JICA´s low SWGI estimation, where observation levels (households) and measurement levels (undefined between communities and towns) are very close to each other.

The "*Average Population fallacy"* occurs when using multilevel estimations of **type (b)** without accounting for the actual population of the surveyed observation level. GDR committed this fallacy by using average inhabitants per household instead of actual´s to estimate the SWGI, probably because of insufficient budget to execute this task.

The reason for the difference between GDR´s and JICA´s SWGI estimations of the analysis level and main clustering unit at the measurement level, respectively, may be an offset between the effects of the Average Population fallacy incurred by GDR and the Mixed Spatial levels fallacy incurred by JICA.

The effect of the Average Population fallacy incurred by GDR is a lower SWGI estimation, because instead of carrying on a multilevel estimation of **type (b)**, it uses an estimation of **type (d)** by considering the same population at each measurement level.

4. **Conclusions and recommendations**

SWM systems in developing countries are incipient and far from efficient when compared with developed countries. One of the main barriers to embedding robust SWM systems is the lack of data to understand the SWM situation. To create, develop and implement SWM system plans, diagnoses of the current waste management systems are carried out by companies contracted by the government in power. SWG surveys play a key role in those diagnoses; useful indicators such as SWGI can be obtained for planning sustainable SWM systems. However, methodologies to estimate SWGI often contain inference fallacies that undermine the reliability of results. SWM plans based on these results propose solutions that are difficult to implement because they are derived from incongruent SWGI estimations which do not represent the actual SWM system situation.

This paper reviewed the methodological approaches used for SWG surveying by the local SWM authority (AAUD) and three official studies performed in Panama. The generalized approach used by AAUD to estimate SWGI produces ineffective allocation of technical, logistic, economic and human resources to the SWM system (AAUD, 2018; ANAM, 2002; La Prensa, 2018, 2011; Linowes and Brown, 2006). Seven inference fallacies (ecological, individualistic, stage, floating population, linear forecasting, average population and mixed spatial levels) were identified and allocated to each reviewed study. It was determined that foreign companies committed three of the seven inference fallacies presented, while one was committed by the local entity. Endogenous knowledge and expertise played an important role in the latter. INECO committed the ecological, stage and floating population fallacies; JICA committed the individualistic, linear forecasting and mixed spatial levels fallacies while GDR committed the average population fallacy.

When there is a clear distinction between the spatial level at which the SWG is surveyed (observation level), the spatial level at which the SWG is aggregated (measurement level) and the spatial level at which the SWGI estimation is expressed (analysis level), then population distribution is taken into account (Loney and Nagelkerke, 2014). In this case, the use of explanatory variables to find a correlation with the SWG from household to country e.g. with family income or with GDP data (Kinnaman, 2009), respectively compensates the effect exerted by the uncertainty of population distribution over SWGI estimations. It also opens the possibility to cluster measurement levels. Differencing the analysis and observation levels and introducing the measurement level as an auxiliary resource of the estimation is an advantage to reach more accurate SWGI estimates.

Multilevel SWG studies appear to present more robust information than studies conducted in other ways. This offers a more comprehensive framework for understanding how places can affect people or, alternatively, how people can affect places. The data quality obtained when characterizing entities (inhabitants or places) at several spatial levels using explanatory variables e.g. education level, ethnic diversity, employment rate, healthcare access and financial development to estimate the SWGI, renders more reliable and accurate SWM plans.

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6. **References**

AAUD, 2018. Ejecución Presupuestaria de Ingresos y Gastos [WWW Document]. URL http://www.aaud.gob.pa/docs/Articulo10/Informes/Informe_FEB2018.pdf (accessed 4.29.18).

AAUD, 2014. Rutas de Recolección [WWW Document]. URL http://www.aaud.gob.pa/index.asp?sec=Rutas&id=ADiurno (accessed 7.10.18).

Achankeng, A.E., 2003. Globalization, Urbanization and Municipal Solid Waste Management in Africa, in: African Studies Association of Australasia and the Pacific. Adelaide, p. 22.

Adamović, V.M., Antanasijević, D.Z., Ristić, M., Perić-Grujić, A.A., Pocajt, V. V, 2017. Prediction of municipal solid waste generation using artificial neural network approach enhanced by structural break analysis. Environ. Sci. Pollut. Res. 24, 299–311. https://doi.org/10.1007/s11356-016-7767-x

Addison, S.R., 2000. A method to illustrate the extensive and intensive properties of thermodynamic variables [WWW Document]. URL https://faculty.uca.edu/saddison/GordonConference/GordonConferencePoster.pdf (accessed 6.4.18).

Afon, A.O., Okewole, A., 2007. Estimating the quantity of solid waste generation in Oyo, Nigeria. Waste Manag. Res. 25, 371–379.

https://doi.org/10.1177/0734242X07078286

Alker jr., H.R., 1974. A typology of ecological fallacies [WWW Document]. Soc. Ecol. URL https://eurekamaghttps//www.econbiz.de/Record/a-typology-of-ecological-fallacies-alker-hayward/10001842677com/research/026/127/026127182.php (accessed 6.9.18).

ANAM, 2002. La Basura: Un problema de todos [WWW Document]. URL https://www.jica.go.jp/project/spanish/panama/2515031E0/data/pdf/5-45.pdf (accessed 12.5.18).

Bandara, N.J.G.J.G.J., Hettiaratchi, J.P.A., Wirasinghe, S.C., Pilapiiya, S., 2007. Relation of waste generation and composition to socio-economic factors: A case study. Environ. Monit. Assess. 135, 31–39. https://doi.org/10.1007/s10661-007-9705-3

Blakely, T., Woodward, A.J., 1999. Ecological effects in multi-level studies. J. Epidemiol. Community Health 54, 367. https://doi.org/10.1136/jech.54.5.367

Blakely, T.A., Woodward, A.J., 2000. Ecological effects in multi-level studies. J. Epidemiol. Community Health 54, 367–374. https://doi.org/10.1136/jech.54.5.367

Buenrostro, O., Bocco, G., Vence, J., 2001. Forecasting generation of urban solid waste in developing countries - A case study in Mexico. J. Air Waste Manag. Assoc. 51, 86–93. https://doi.org/10.1080/10473289.2001.10464258

DEFRA, 2013. Environmental Reporting Guidelines [WWW Document]. URL www.gov.uk/defra (accessed 4.3.18).

Din, G.Y., Cohen, E., 2016. Modeling Municipal Solid Waste Management in Africa: Case Study of Matadi, the Democratic Republic of Congo, in: Solid Waste Management Policy and Planning for a Sustainable Society. Apple Academic Press, pp. 141–141. https://doi.org/10.1201/b19424-10

Forouhar, A., Hristovski, K.D., 2012. Characterization of the municipal solid waste stream in Kabul, Afghanistan. Habitat Int. 36, 406–413. https://doi.org/10.1016/j.habitatint.2011.12.024

Fujimoto, Shouji, Mizuno, Takayuki, Ohnishi, Takaaki, Shimizu, Chihiro, Watanabe, Tsutomu, Fujimoto, S, Mizuno, T, Ohnishi, T, Shimizu, C, Watanabe, T, 2015.

Geographic Dependency of Population Distribution. Springer Proceedings in Complexity. https://doi.org/10.1007/978-3-319-20591-5_14

Giampietro, M., Mayumi, K., Ramos-Martin, J., 2009. Multi-scale integrated analysis of societal and ecosystem metabolism (MuSIASEM): Theoretical concepts and basic rationale. Energy 34, 313–322. https://doi.org/10.1016/j.energy.2008.07.020

Guerrero, L.A., Maas, G., Hogland, W., 2013. Solid waste management challenges for cities in developing countries. Waste Manag. 33, 220–232. https://doi.org/10.1016/j.wasman.2012.09.008

Hoornweg, D., Bhada, P., 2012. What a Waste. A Global Review of Solid Waste Management. Urban Dev. Ser. Knowl. Pap. 281, 44 p. https://doi.org/10.1111/febs.13058

Idrovo, A.J., 2011. Three criteria for ecological fallacy. Environ. Health Perspect. https://doi.org/10.1289/ehp.1103768

IMF, 2018. World Economic Outlook: Cyclical Upswing, Structural Change [WWW Document]. Int. Monet. Fund. URL https://www.imf.org/external/pubs/ft/weo/2009/01/pdf/text.pdf

Indexmundi, 2015. Countries ranked by GINI index (World Bank estimate) [WWW Document]. URL https://www.indexmundi.com/facts/indicators/SI.POV.GINI/rankings (accessed 2.21.19).

INEC, 2016. Comentarios sobre la economía panameña [WWW Document]. URL https://www.contraloria.gob.pa/inec/archivos/P8371Comentarios.pdf (accessed 12.7.17).

INEC, 2006. Estimación de la población en la provincia de Panamá, por sexo, según distrito y corregimiento [WWW Document]. URL https://www.contraloria.gob.pa/inec/SINAMP/pdf/Panama.pdf (accessed 1.8.18).

INECO, 2017. Plan Nacional de gestión integral de residuos 2017 - 2027 [WWW Document]. URL http://aaud.gob.pa/plangestion//Docs/ANEXOS/20170731_E 1.3.3.3.5_Propuesta Nuevo Modelo de Gestion_v3.pdf (accessed 4.29.18).

Isugi, J., Niu, D., 2016. Research on Landfill and Composting Guidelines in Kigali City, Rwanda Based on China's Experience. https://doi.org/10.7763/IPCBEE

James, W., 1890. The Principles of Psychology, Volume 1.

JICA, 2005. Supporting Capacity Development in Solid Waste Management in Developing Countries; Towards Improving Solid Waste Management Capacity of Entire Society [WWW Document]. URL http://open_jicareport.jica.go.jp/pdf/11795846.pdf (accessed 11.26.17).

JICA, 2003. The Study on Solid Waste Management Plan for Municipality of Panama in the Republic of Panama [WWW Document]. URL http://open_jicareport.jica.go.jp/pdf/11712841_01.pdf (accessed 4.29.18).

Kaseva, M.E., Gupta, S.K., 1996. Recycling - An environmentally friendly and income generating activity towards sustainable solid waste management. Case study - Dar es Salaam City, Tanzania. Resour. Conserv. Recycl. 17, 299–309. https://doi.org/10.1016/S0921-3449(96)01153-6

Kinnaman, T.C., 2009. The economics of municipal solid waste management. Waste Manag. 29, 2615–2617. https://doi.org/10.1016/j.wasman.2009.06.031

Kofoworola, O.F., Gheewala, S.H., 2009. Estimation of construction waste generation and management in Thailand. Waste Manag. 29, 731–738. https://doi.org/10.1016/j.wasman.2008.07.004

Kohberger, R.C., Everitt, B.S., 2006. Cluster Analysis. Technometrics 36, 216. https://doi.org/10.2307/1270235

Kollikkathara, N., Feng, H., Stern, E., 2009. A purview of waste management evolution: Special emphasis on USA. Waste Manag. https://doi.org/10.1016/j.wasman.2008.06.032

Kumar, S., Bhattacharyya, J.K., Vaidya, A.N., Chakrabarti, T., Devotta, S., Akolkar, A.B., 2009. Assessment of the status of municipal solid waste management in metro cities, state capitals, class I cities, and class II towns in India: An insight. Waste Manag. 29, 883–895. https://doi.org/10.1016/J.WASMAN.2008.04.011

La Prensa, 2018. Basura, un grave problema [WWW Document]. URL https://www.prensa.com/politica/Basura-grave-problema_0_2722977869.html (accessed 1.8.18).

La Prensa, 2011. La basura, un negocio jugoso [WWW Document]. URL https://impresa.prensa.com/panorama/basura-negocio-jugoso_0_3163933628.html (accessed 1.8.18).

Linowes, R., Brown, M., 2006. The Tropical Waste Dilemma: waste management in Panama. Int. J. Emerg. Mark. 1, 101–112. https://doi.org/https://doi.org/10.1108/17468800610674453//

Linster, M. (Oecd), 2003. OECD Environmental Indicators: development, measurement and use. SNUC - Sist. Nac. Unidades Conserv. 25, 37. https://doi.org/10.1016/j.infsof.2008.09.005

Loney, T., Nagelkerke, N.J., 2014. The individualistic fallacy, ecological studies and instrumental variables: a causal interpretation. https://doi.org/10.1186/1742-7622-11-18

Mandelbrot, B., 1967. How long is the coast of Britain? Statistical self-similarity and fractional dimension. Science (80-.). 156, 636–638. https://doi.org/10.1126/science.156.3775.636

Matuszewski, A., 2002. Double clustering: A data mining methodology for discovery of causality, in: Intelligent Information Systems 2002. Physica-Verlag HD, Heidelberg, pp. 227–236. https://doi.org/10.1007/978-3-7908-1777-5_24

Mejía, C.A.Z., 2009. Metodología de diseño para la recogida de residuos sólidos urbanos mediante factores punta de generación: Sistemas de caja fija (SCF). Ing. e Investig. 29, 119–126.

Molina-Azorín, J.F., Pereira-Moliner, J., López-Gamero, M.D., Pertusa-Ortega, E.M., Tarí, J.J., 2019. Multilevel research: Foundations and opportunities in management. BRQ Bus. Res. Q. https://doi.org/10.1016/j.brq.2019.03.004

Moon, G., Subramanian, S. V, Jones, K., Duncan, C., Twigg, L., 2005. Area-based studies and the evaluation of multilevel influences on health outcomes, Handbook of health research methods: Investigation, measurement and analysis.

MUPA, 2018. Estudio de caracterización puntual y dinámica de la generación y composición de los residuos sólidos urbanos por conglomerados de lugares poblados del corregimiento de Betania según sus características sociodemográficas [WWW Document]. URL http://gestionderesiduos.com.pa/caracterizacion/EstudioBethania.pdf (accessed 7.10.18).

Nottale, L., 2010. Scale relativity and fractal space-time: Theory and applications. Found. Sci. 15, 101–152. https://doi.org/10.1007/s10699-010-9170-2

OECD, 2008. Key environmental indicators, OECD Environment Directorate. https://doi.org/10.2110/pec.72.02.0001

Pereira, Â.G., Vaz, S.G., Tognetti, S., 2006. Interfaces between Science and Society.

Ragossnig, A.M., Vujić, G., 2015. Challenges in technology transfer from developed to developing countries. Waste Manag. Res. 33, 93–95. https://doi.org/10.1177/0734242X15569403

Robinson, W.S., 1950. Ecological correlations and the behaviors of individuals. Am. Sociol. Rev. 15, 351–357. https://doi.org/10.1093/ije/dyn357

Scheinberg, A., Spies, S., Simpson, M.H., Mol, A.P.J., 2011. Assessing urban recycling in low- and middle-income countries: Building on modernised mixtures. Habitat Int. 35, 188–198. https://doi.org/10.1016/j.habitatint.2010.08.004

Seadon, J.K., 2010. Sustainable waste management systems. J. Clean. Prod. 18, 1639–1651. https://doi.org/10.1016/j.jclepro.2010.07.009

Selvin, H.C., 1958. Durkheim's Suicide and Problems of Empirical Research. Am. J. Sociol. 63, 607–619. https://doi.org/10.1086/222356

Shimura, S., Yokota, I., Nitta, Y., 2001. Research for MSW flow analysis in developing nations. J Mater Cycles Waste Manag 3, 48–59.

Subramanian, S. V, Jones, K., Kaddour, A., Krieger, N., 2009. Revisiting Robinson: The perils of individualistic and ecologic fallacy. Int. J. Epidemiol. 38, 342–360. https://doi.org/10.1093/ije/dyn359

Thanh, N.P., Matsui, Y., Fujiwara, T., 2010. Household solid waste generation and characteristic in a Mekong Delta city, Vietnam. J. Environ. Manage. 91, 2307–2321. https://doi.org/10.1016/j.jenvman.2010.06.016

The World Bank, 2018a. What is the World Bank Atlas method? – World Bank Data Help Desk [WWW Document]. URL https://datahelpdesk.worldbank.org/knowledgebase/articles/77933-what-is-the-world-bank-atlas-method (accessed 7.9.18).

The World Bank, 2018b. New country classifications by income level: 2018-2019 | The Data Blog [WWW Document]. URL https://blogs.worldbank.org/opendata/new-country-classifications-income-level-2018-2019 (accessed 7.9.18).

Troschinetz, A.M., Mihelcic, J.R., 2009. Sustainable recycling of municipal solid waste in developing countries. Waste Manag. 29, 915–923. https://doi.org/10.1016/j.wasman.2008.04.016

US EPA, 2014. Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2012. US Environ. Prot. Agency 1–13. https://doi.org/EPA-530-F-14-001

Voss, B. de L., Pfitscher, E.D., da Rosa, F.S., Ribeiro, M. de S., 2013. Solid waste environmental disclosures of public companies in Brazil of environmentally sensitive industries/Evidenciacao ambiental dos residuos solidos de companhias abertas no Brasil potencialmente poluidoras.(articulo en ingles). Rev. Contab. Financ. 24, 125. https://doi.org/10.1590/S1519-70772013000200004

Wang, H., Wang, C., 2013. Municipal solid waste management in Beijing: characteristics and challenges. Waste Manag. Res. 31, 67–72. https://doi.org/10.1177/0734242X12468199

Watson, D., Reichel, A., 2013. Municipal Waste Management in the United Kingdom.

Wilson, D.C., Rodic, L., Scheinberg, A., Velis, C.A., Alabaster, G., 2012. Comparative analysis of solid waste management in 20 cities. Waste Manag. Res. 30, 237–254. https://doi.org/10.1177/0734242X12437569

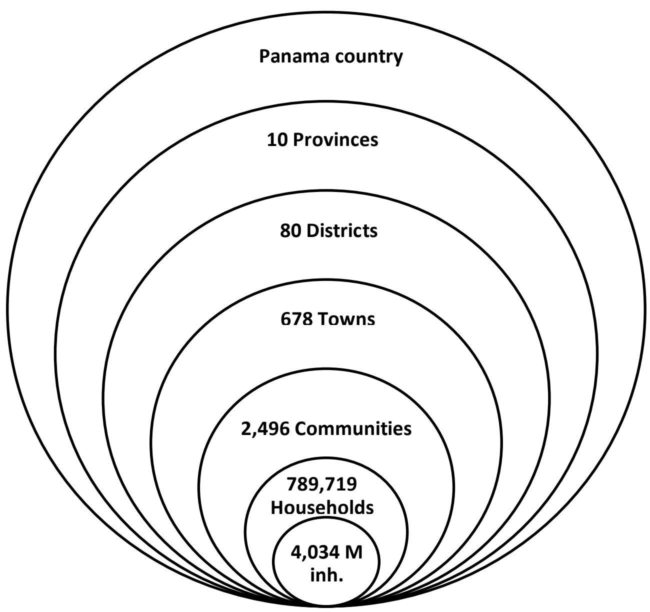
Wilson, D.C., Velis, C.A., 2014. Cities and waste: current and emerging issues. Waste Manag. Res. 32, 797–9. https://doi.org/10.1177/0734242X14547125

Winzar, H., 2015. The ecological fallacy: How to spot one and tips on how to use one to your advantage. Australas. Mark. J. 23, 86–92. https://doi.org/10.1016/j.ausmj.2014.12.002

Wittwer, J., Nückles, M., Renkl, A., 2008. Is underestimation less detrimental than overestimation? the impact of experts' beliefs about a layperson's knowledge on learning and question asking. Instr. Sci. 36, 27–52. https://doi.org/10.1007/s11251-007-9021-x

Zohoori, M., Ghani, A., 2017. Municipal Solid Waste Management Challenges and Problems for Cities in Low-Income and Developing Countries. Int. J. Sci. Eng. Appl. 6, 039–048. https://doi.org/10.7753/IJSEA0602.1002

a)



b)

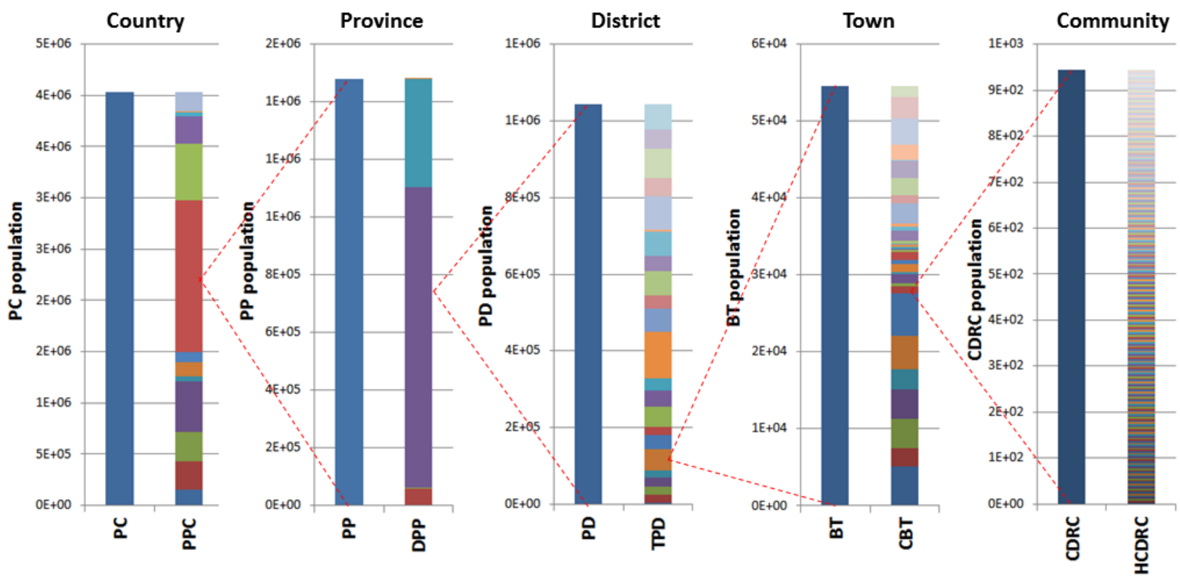


Figure 1. a) Absolute figures of Panama at several spatial levels. **b)** Multilevel population distribution from the country to household spatial level.

PC: Panama country; PPC: Provinces of the Panama country; PP: Panama province; DPP: Districts of the Panama province; PD: Panama district; TPD: Towns of the Panama District; BT: Bethania Town; CBT: Communities of the Bethania Town; CDRC: Condado del Rey Community; HCDRC: Households of the Condado del Rey Community.

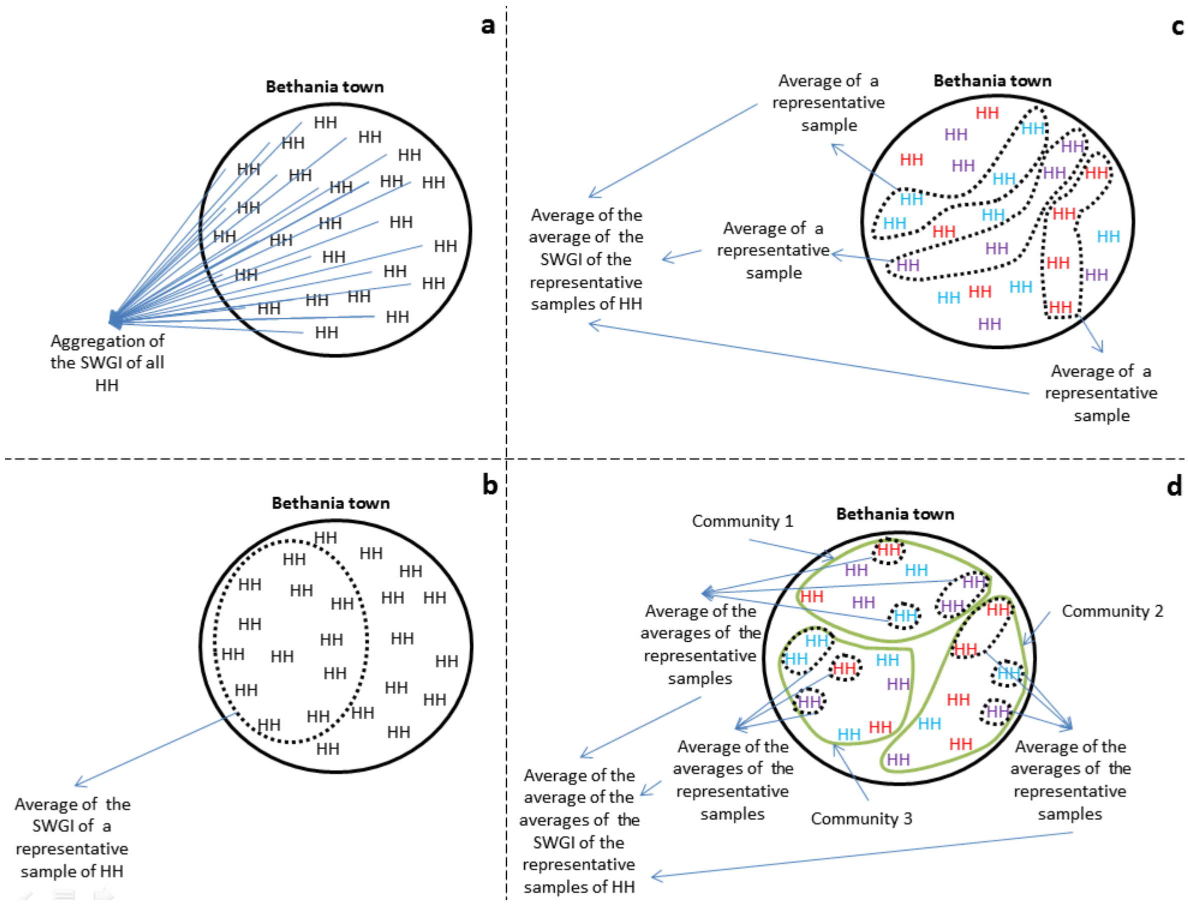
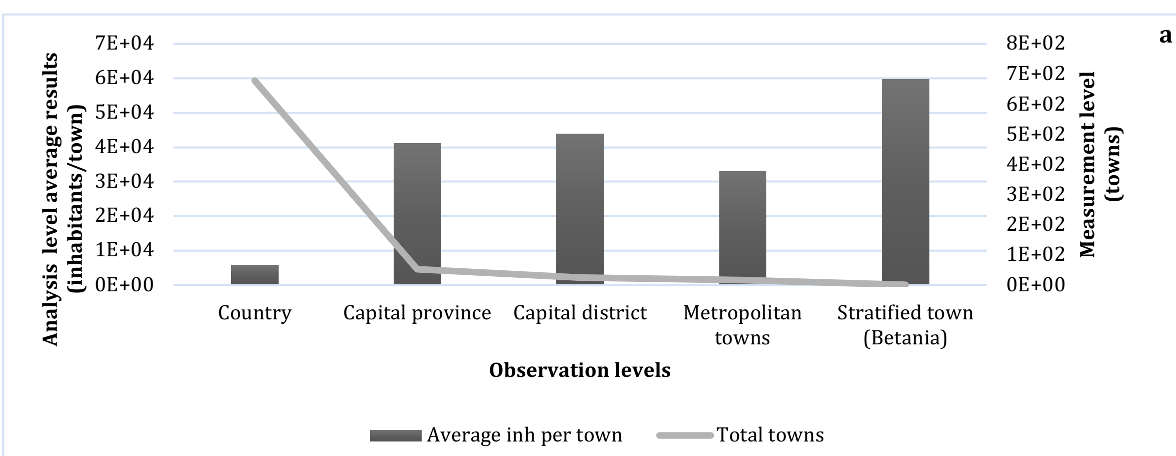


Figure 2. Households´ SWG sampling methods to estimate SWGI of Bethania town.

HH: Households. Blue arrows represent SWG. Dotted lines represent floating clusters of households. Green lines represent communities´ clusters of households.



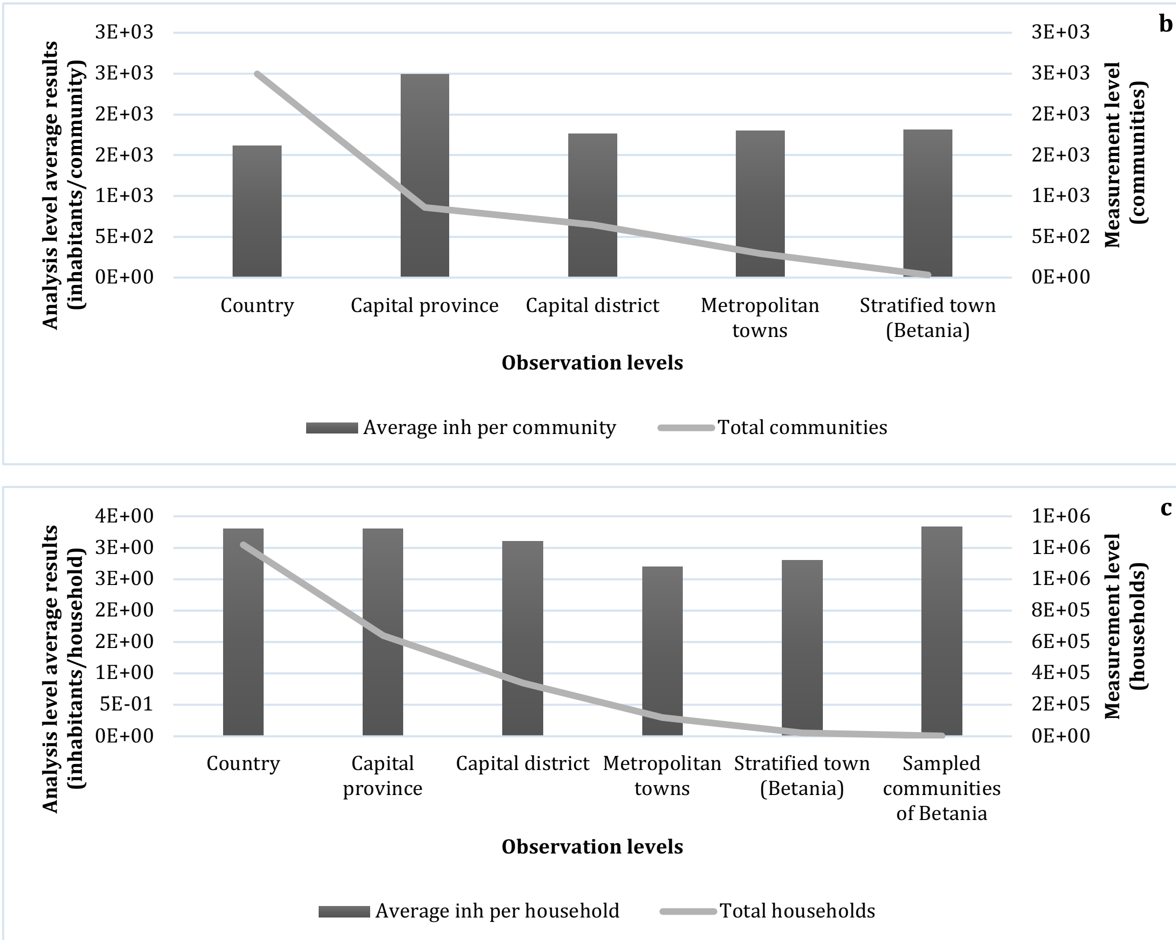


Figure 3. Waste generating inhabitant of the analysis level at several observations levels by the measurement level of a) towns, b) communities and c) households.

a)

a

$$\frac{1}{n}\sum_{i=1}^{n}\frac{SWG_i}{P_i}$$

b

$$\frac{\frac{\sum_{i=1}^{n} SWG_i}{n}\sum_{i=1}^{n}\frac{1}{Pi}}{n}$$

c

$$\frac{1}{n}\sum_{i=1}^{n}\frac{\sum_{j=1}^{m} SWG_{ij}}{P_i}$$

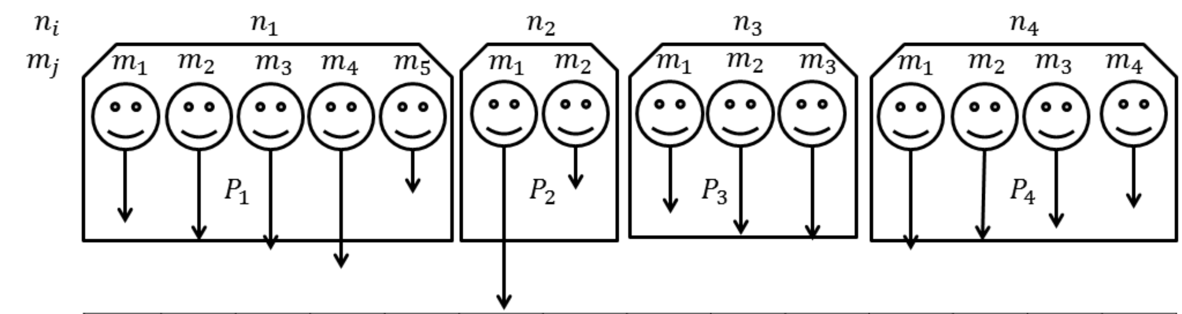
d

$$\frac{\frac{\sum_{i=1}^{n}\sum_{j=1}^{m} SWG_{ij}}{\frac{1}{n}\sum_{i=1}^{n} P_i}}{n}$$

e

$$\frac{\sum_{i=1}^{n} SWG_i}{\sum_{i=1}^{n} P_i}$$

b)



SWG_{ij}	0.50	0.60	0.73	0.82	0.30	1.20	0.30	0.50	0.60	0.68	0.75	0.66	0.51	0.45
SWG_i	2.95					1.50		1.70			2.37			
SWG	8.52													

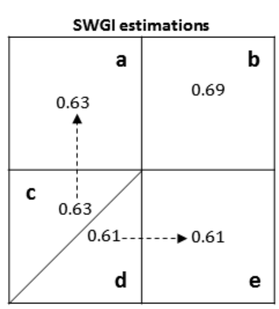


Figure 4. a) Mathematical expressions configuring the observation and measurement levels to estimate SWGI of waste generating inhabitants or places at the analysis level. *Where, n is the variable for the total waste generating inhabitants or places of a determined level, m; the total levels constituting each determined level n, i the sum index for waste generating inhabitants or places of the same determined level, j the sum index for waste generating inhabitants or places of the same level at each i determined level, and Pi the population of the waste generating inhabitants or places of a determined level i.* **b)** Numerical example showing different SWGI estimations per capita at different measurement and observation levels using expressions of **Figure 4a**. *Where, arrows leaving inhabitants are scaled up as per SWGI estimation of each inhabitant, n is the number of households of the community and m the number of inhabitants within each household.*

Table 1. Comparison among the reviewed studies performed by GDR, JICA and INECO

Company	**JICA**	**INECO**	**GDR**
SWGI estimation type from **Figure 4a**	a	d, e	b, d
Observation level	Household	Town	Household
Measurement level	Town	Defined by socio-economic criteria	Community
Main clustering unit at the measurement level/income level/SWGI (kg/inh*d)	Bethania town/middle/0.66	Panama district/high/1.55	Communities of Bethania/high/0.96
Analysis level/income level/SWGI (kg/inh*d)	Panama District/high/0.59	Country/upper-middle/1.26	Bethania town/middle/0.76

Table 2. Reference SWGI estimations (kg inh^{-1} d^{-1}) from literature by income level at a country analysis level, where upper-middle income (bold) match the income category for Panama.

	Income level[1]			
Source	*High*	***Upper-middle***	*Lower-middle*	*Low*
(Adamović et al., 2017)	1.67	1.03	0.71	---
(Shimura et al., 2001)	---	0.95	0.67	---
(OECD, 2008)	1.53	---	---	---
(Kofoworola and Gheewala, 2009)	---	---	0.72	---
(Afon and Okewole, 2007)	1.80	1.24	0.70	0.50
(Watson and Reichel, 2013)	1.51	---	---	---
(Wang and Wang, 2013)	---	0.88	---	---
(Wilson et al., 2012)	1.67	---	---	---
(Mejía, 2009)	1.22	---	---	---
(Hoornweg and Bhada, 2012)	---	1.20	0.79	0.60
(Kumar et al., 2009)	---	---	0.39	---
(Kaseva and Gupta, 1996)	---	---	---	0.17
(Thanh et al., 2010)	---	---	0.78	0.58
(Forouhar and Hristovski, 2012)	---	---	---	0.31
(Troschinetz and Mihelcic, 2009)	1.67	---	0.80	---
(Achankeng, 2003)	---	---	---	0.33
(Kollikkathara et al., 2009)	1.84	1.10	---	---
(Din and Cohen, 2016)	---	---	---	0.30
(US EPA, 2014)	1.99	---	---	---
(Isugi and Niu, 2016)	---	---	---	0.33
Average	**1.66**	**1.06**	**0.69**	**0.39**

[1]*The income categories are following the World Bank's gross national income (GNI) per capita. Low income: US$995 or less; lower-middle income: US$996 – US$3945; upper-middle income: US$3946 –US$12 195; and high income: US$12 196 or more (World Bank, 2010). Although Panama has recently been reclassified as an upper income level country (The World Bank, 2018b), this paper considers Panama´s income level as it was classified before 2018, as an upper-middle income level country, to match the years SWG studies were carried out.*

Table 3. Fallacies found in the last SWG measurement studies performed

Fallacy	JICA	INECO	GDR
1. Ecological (a+b+c)		X	
a. Results obtained with ecological (population) data		*x*	
b. Data inferred to individuals from ecological levels	*x*	*x*	*x*
c. Results obtained with individual data are contradictory	*x*	*x*	
2. Individualistic	X		
3. Stage		X	
4. Floating Population		X	
5. Linear Forecasting	X		
6. Average Population			X

7. Mixed Spatial Levels	X

6.2 Paper #2 - "A waste lexicon for non-industrialized Latin American economies to negotiate Extended Producer Responsibility with industrialized economies in Free Trade Agreements"

A waste lexicon to negotiate extended producer responsibility in free trade agreements

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Abstract

Developing economies largely rely on imported consumer goods from the manufacturing industries of industrialized economies through free-trade agreements.

After consumption, goods end-up in local waste streams and landfilled because of poorly developed waste management systems.

This paper proposes a methodology to extend responsibility to exporting country manufacturers for indirect waste disposal in developing countries through imported goods.

It establishes a functional relationship between the weight and volume of the imported goods and the local municipal solid waste stream derived from their consumption, by adapting the recycling concepts of by-product and co-product to the municipal solid waste stream derived from the household sector.

A lexicon is formalized to conceptualize an extended-producer-responsibility information system operating at the global level between exporting and importing countries. This EPR system i) determines the recyclability, reusability and treatability attributes of imported goods based on their constitutive parts (primary package or product), as well as the material value as per the net value in the global waste market and final destination once consumed, ii) defines specific conditions regarding the goods´ materials value and structural configuration of their constitutive parts for inclusion in Free-Trade Agreement clauses, and iii) checks for the fulfilment of these proposed conditions.

The proposed methodology was validated with a case study on Panama. It was found that 24%(w/w)-34.5%(v/v) of valued materials derived from goods imported in Panama through FTAs could be exported back to the country of origin, 18%(w/w)-2.8%(v/v) could be locally reused, and 58%(w/w)-62.5%(v/v) locally valorized. Only 16%(w/w)-16%(v/v) would have to be landfilled.

Keywords: Extended producer responsibility; free-trade agreement; imported consumer goods; developing economies; landfill waste diversion; decision-support system.

Highlights

- Trade liberalization through free-trade agreements involves indirect pollution
- An extended producer responsibility information system at global level is proposed
- A waste lexicon and decision support system are developed
- The approach is validated with a case study on Panama
- 24% (w/w) of valued materials derived from imported goods could be returned to origin

1. Introduction

In 1986, The Khian Sea ship attempted to deliver a cargo of 15,000 tons of incinerator toxic ash from Philadelphia to the shores of Panama. Just before arrival to destination, the deal was put off by the Panamanian government. For two years the ship roamed the seas in search of a host for its load (Uva and Bloom, 1992). In 1988, The Khian Sea returned home empty, the whereabouts of the cargo were never revealed. Had it not been for the massive closure of US landfills during the early ’80s, the ash might have been disposed of in the Philadelphia landfill. It was a global waste trade agreement that triggered the travel of The Khian Sea with the offer of 10 million USD to the Panamanian government for importing a total 250,000 tons of ashes ($40/ton) at the expense of the local environment (Uva and Bloom, 1992).

At present, the governments of most developing countries, including Panama, have acquired sufficient environmental consciousness to refuse this kind of deals (Llorach-Massana et al., 2015) with some exceptions (Kollikkathara et al., 2009; Papu-Zamxaka et al., 2010; Demaria, 2010; Hoornweg and Bhada, 2012). However, today’s global waste trade encompasses more than the direct export of waste; it also includes less evident processes that go under the name” trade liberalization”. Trade liberalization is a way of indirect pollution of developing countries through the import of consumer goods from industrialized economies that eventually will become waste after being consumed and non-deliberately disposed of in the local Municipal Solid Waste Stream (MSWS) of barely established waste management systems (Baldwin, 1993). Waste, either directly imported or generated in-situ from imported goods, is a threat to developing countries.

Today, the world’s 20 most industrialized economies manufacture and export 60% of the world goods (UNCTAD, 2018). The rest of the world exports on average 93% less goods per country than these industrialized economies (CIA, 2017). The Free Trade Agreement (FTA) (the most common type of bilateral trade agreement) is a fast-proliferating way for countries to satisfy their needs and achieve their economic goals. By 2007 every country in the world was a member of at least one FTA, most countries being member of several (Menon, 2007). FTAs, signed between industrialized and non-industrialized economies, generally do not include clauses about the Extended Producer Responsibility (EPR) for local waste streams associated with the exported goods (ECLAC, 2017).

After imported goods are consumed, they become 'consumed goods' and in most developing countries the materials making up their constitutive parts are indiscriminately mixed up in the local municipal solid waste stream because, more often than not, waste source-separation is poorly developed or implemented. In the household sector of these countries, the solid waste generated is collected and transported commingled as bulk waste and disposed of in landfills. Although landfills remain the most common method for waste disposal worldwide and are considered a reliable and low-cost alternative to final solid waste disposal (Powrie and White, 2004; Zacharof and Butler, 2004; Caprile and Ripa, 2014), there is little awareness that not all consumed goods have to end up as waste (JICA, 2005). Indeed, diverting waste from landfills through material and resource recovery is an important goal of many environmental policies worldwide (EEA, 2009; Ripa et al., 2017; UNEP, 2009).

Materials recovery, by reusing consumed goods as second-hand goods before being disposed of or by recycling in the manufacturing industry, as well as energy recovery, by valorizing waste materials in treatment plants as energetic resource before landfilling, requires integral and robust waste management strategies, like the 'zero-waste concept' (Islam and Jashimuddin, 2017). Many industrialized economies have locally implemented EPR systems¡ to make the manufacturer of the product responsible for the entire life-cycle of the product and especially for the take-back, recycling and final disposal (Lindhqvist, 2000a). Good examples are PRO Europe´s Green Dot®, NAFTA region´s Green Dot North America and UK´s VALPAK (Song et al., 2015). However, in developing economies, material and energy recovery of MSWSs by reusing or valorizing, are only slowly implemented. For recycling to be implemented through EPR systems, a minimum level of MSWS management and consumer´s contribution to waste source-separation would have to be accomplished first (Lindhqvist, 2000b). Local recycling of MSWS materials is still an unreliable option because the manufacturing industry is only incipient in these economies. Waste export thus remains the main alternative to divert waste from landfills and relief the local waste management system (Troschinetz and Mihelcic, 2009).

Waste exporting requires the assignment of value to waste materials as per the global waste market (**Figure 1**). In the global waste market, non-tradable materials are unvalued materials while tradable materials are valued materials (Kollikkathara et al., 2009). The global waste market defines the value of materials according to their technical and economic viability of recycling. Some waste materials are technically recyclable in the global waste market, but poor cost-effectiveness of available recycling methods results in a low net waste value, thus classifying them as unvalued materials and making local management through reuse, valorization or landfilling a more suitable option (Soo et al., 2017). For instance, expanded polystyrene, used for food-service, is a high-volume, low-weight material composed mainly of air with such high transport and recycling costs that it is considered 'economically non-recyclable' in the global market (NYCDOS, 2017). Also for wooden crates, locally used to deliver fruits and vegetables, local reuse or landfilling is preferred over global recycling (Ng et al., 2014). Unvalued materials, including the organic fraction, could be valorized in different ways but the global market net waste value does not apply to valued materials segregated from unvalued materials (**Figure 1**) (García et al., 2012; Ali and Courtenay, 2014; Lee et al., 2014).

The relative material composition of goods is measurable from the manufacturing stage to the point of consumption while the goods´ primary package (and product itself) is still in place. In the post-consumption stage, the material composition changes depending on country-specific variables, such as resource consumption habits, waste generation behaviors, waste deposition patterns (Kofoworola and Gheewala, 2009), local weather conditions and street animal behavior (Tchobanoglous, 2009). Within the MSWS, the constitutive parts of consumed goods are subject to weight and volume changes in variable degrees. For instance, volume changes of goods´ primary packages are less likely to happen than weight changes of both, organic product of the packaged goods and unpackaged products. The material composition of consumed goods in MSWSs can still be estimated in absolute quantities using waste classification traditional systems that classify waste by composition of material groups (DEQ, 2004; IPCC, 2000) but these systems are not useful to understand management options of consumed goods´ materials before consumption. Note that there is little awareness that volume measurements are complementary to weight measurements to accurately assess the recycling viability of the MSWS materials as valued material by their attributes before transformation into consumed goods (Bing et al., 2014).

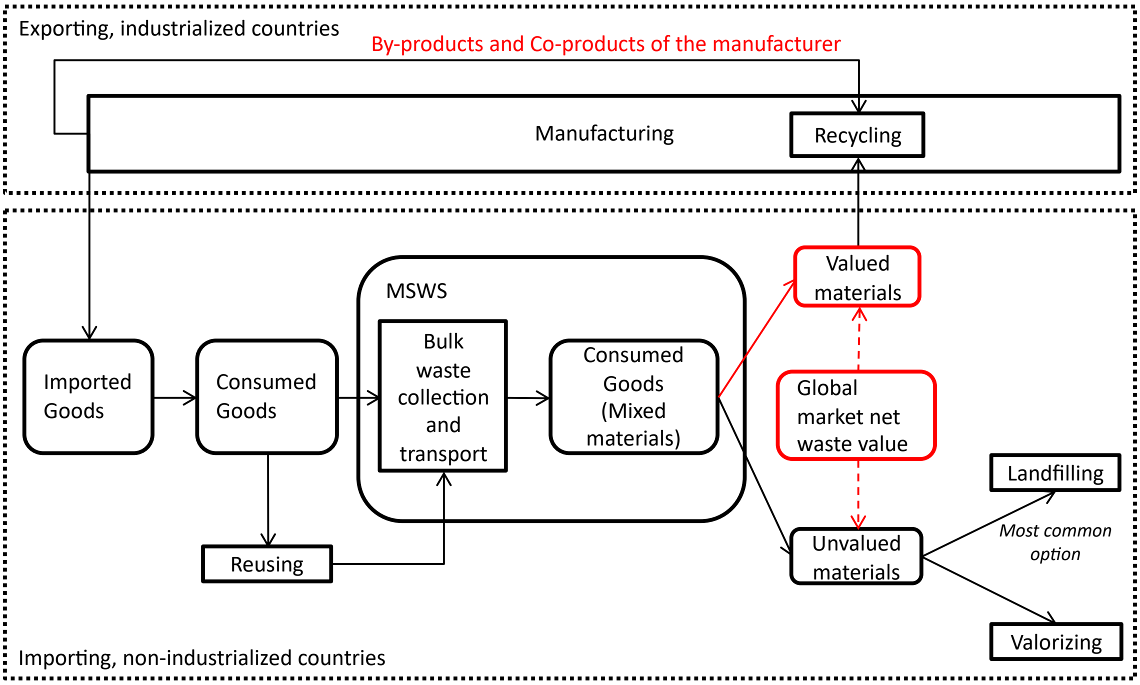


Figure 1. *Import of goods, municipal solid waste generation, and recycling.*

Recognition of the nexus between the quantity, (material) composition and proportions of the constitutive parts of imported goods (goods´ primary packages, primary packaged goods and unpackaged products) before and after ending up in the local (mixed) municipal solid waste stream (Savino et al., 2018) is a necessary step for developing economies to determine the recyclability potential of the waste materials derived from imported goods through FTAs and label them valued or unvalued materials according to the net waste value on the global market. Simply accounting for the quantity, composition and relative proportions of imported goods does not, and cannot accurately reflect the quantity, composition and relative proportions of the consumed goods´ mixed materials in the local MSWS so as to assign responsibility for the reception of valued materials derived from the economic activity. Indeed, there is a need for the formalization of a new lexicon for a functional waste classification system allowing to conceptualize the definitions of an EPR-like information system at the global level, thus recognizing the complex relation between industrialized exporting countries and developing importing countries. Such lexicon would facilitate the assignment of a globally extended responsibility to industrialized economies for the waste flows they produce in developing countries and to assess the potential of local MSWSs for local management as unvalued materials or recycling in the global market as valued materials.

This paper aims to open a debate about how to extend responsibility to industrialized economies for indirect waste disposal in developing countries through imported goods. It proposes a conceptual approach for an EPR information system at the global level that establishes a functional relationship between the weight and volume of the imported goods and the local municipal solid waste stream derived from their consumption. To this purpose, in the following section, a waste lexicon is defined. The recycling concepts of by-products and co-products of the manufacturer are adapted to imported goods and the corresponding waste generated to create a lexicon based on the constitutive parts, material value and final destination of the consumed goods. Conditions on the goods´ material value and structural configuration that should be declared in FTAs and fulfilled are proposed. In section 3, the proposed methodology is validated with a case study on Panama, using data on the quantity and composition of imported consumer goods through FTAs, and data on the quantity and composition of the consumed goods´ materials in the municipal solid waste stream. The case study examines the extent to which: i) consumed imported goods in the household sector could be reused before being inputted into the MSWS, ii) the materials of the MSWS are valued materials or unvalued materials as per their global market net waste value, iii) valued materials could be recycled back to industrialized economies, and iv) unvalued materials could be valorized or landfilled. Section 4 discusses the results and concludes.

2. Materials and methods

2.1 Lexicon for a consumed good material classification system

A "good" is defined here as a final product that may or may not be packaged for final consumption by consumers satisfying their current wants or needs rather than used in the production of another good. As for packaged goods, there are basically three major packaging layers that protect the goods during the stages of the trade process: (i) a transport packaging layer for manufacturing/transport, such as pallets, (ii) a secondary packaging layer for distribution/display, such as cases, and (iii) a primary packaging layer for acquisition/consumption (inner packs). The constitutive parts of goods are the goods´ primary package and the product itself which may be product of the packaged good or unpackaged product; the latter is a good acquired without primary packaging (Hansen et al., 2012; Robertson and Hamza, 2016).

Product manufacturing entails the generation of co-products of the manufacturer and by-products of the manufacturer. Both are secondary products linked to the manufacturing of goods; while co-products are planned for by the manufacturer, by-products are not. Co-products are normally tradable without any additional treatment, while by-products usually serve as additives or raw material replacement in the manufacturing of other products or even the same manufacturing process from which it was created (**Figures 1 and 2**) (Ali et al., 2009; Sandin et al., 2015).

By adapting the recycling concepts of by-products and co-products of the manufacturer to imported goods, a novel lexicon is proposed in **Figure 2** to define (i) consumed goods as a function of their final destination (i.e., recycling, reusing, valorizing, landfilling), and (ii) constitutive parts (i.e., goods´ primary package, product of the packaged good and unpackaged product) as a function of their net waste value in the global market (i.e., valued materials, unvalued materials).

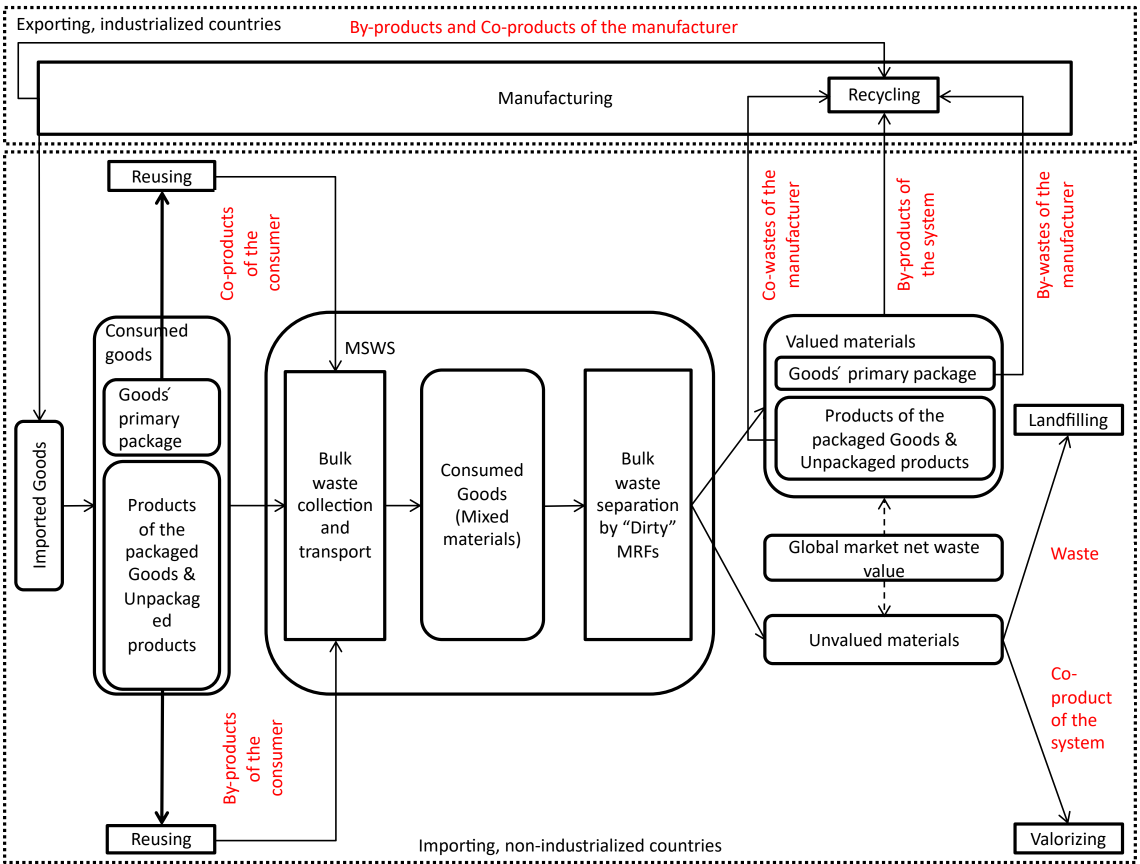


Figure 2. *An expanded waste lexicon for imported goods.*

2.1.2. Reusability: By-product and co-product of the consumer

As shown in Figure 2, before being inputted to the local MSWS, consumed goods´ parts can become either ‘by-product of the consumer’ or ‘co-product of the consumer’ through reuse. After goods are acquired, products (either product of the packaged good or unpackaged product) are used until they lose value for the consumer who acquired them. The concept of by-product of the consumer is analogous to that of by-product of the manufacturer: products that lost their value for the first consumer in an unplanned manner become useful for other consumers (second-hand products). This is the case for products like clothes, shoes, books, electronic products, toys, tires, etc. The exchange of the imported products among consumers is a closed deal and not associated with the terms of imported goods through FTAs. Reuse of a product of the packaged good or unpackaged product by the original (same) consumer is not considered here as reusing but using.

In a similar way, the concept of co-product of the consumer is the analogue of co-product of the manufacturer: the imported goods´ primary packages may find a new use for the consumer who acquired the packaged good in a planned and foreseeable manner thus deciding not to dispose of it. Examples are shoe boxes, mayonnaise jars, jewelry cases, etc.

Goods´ primary packages that are not (meant to be) reused by the first consumer who acquired the good (or other consumers) as well as products of packaged goods and unpackaged goods that can no longer be (re)used because they reached their end of lifetime are inputted into the MSWS.

The reuse of consumed goods will depend upon the consumer who acquired the goods, and will be influenced by local factors such as culture, education and environmental consciousness. In some cases, waste collection workers may act as secondary consumers of consumed goods disposed of by consumers.

2.1.3. Implementation of ‘dirty’ material recovery facilities

To open the possibility of returning valued materials to industrialized economies, a segregating/packaging/exporting process is considered where separation of mixed consumed goods´ materials in the MSWS by their constitutive parts and material value is performed by ‘dirty’ Material Recovery Facilities (MRFs) accepting commingled waste. ‘Dirty’ MRFs are expected to segregate unvalued materials, including most of the organic fraction, from dry recyclables materials (valued materials) that can be packaged and exported back to industrialized economies (Modak et al., 2015).

Traditional waste classification systems (DEQ, 2004; IPCC, 2000) can be used to identify material composition once the consumed goods´ parts are recovered from the MSWS. Material value in the global waste market can then be determined as per their global market net waste value, where valued materials are recyclable and unvalued materials are not (Martínez Urreaga et al., 2015).

2.1.4. Treatability: Co-product of the system and “waste” concepts

According to (Ali and Courtenay, 2014), an average of 92% of the MSWS inputted to ‘dirty’ MRFs could be recycled, 6% valorized and the remaining 2% landfilled. Unvalued materials of the MSWS with the potential to be valorized as energy, organic amendment, RFD, syngas, etc., are defined as ‘co-product of the system’ (**Figure 2**), because in a certain way they are being “reused” after proper treatment. Unvalued materials that cannot be recovered are defined as ‘waste’.

The handling of unvalued materials as co-product of the system or waste is a responsibility of the local waste management system. If this system is poorly developed then ‘co-product of the system’ will end up with ‘waste’ in landfills and produce environmental pressure, thus following the business-as-usual case (Schubert, 2014).

2.1.5. Recyclability: By-product of the system, co-waste of the manufacturer and by-waste of the manufacturer concepts

Valued materials derived from the output of consumed goods of the MSWS are considered ‘by-product of the system’ (**Figure 2**). They may need further processing through recycling in the manufacturing industry of the industrialized economy that produced the goods. After by-products of the system are exported back to the country of origin, they can either be used directly in the receiving manufacturing industry as co-products of the manufacturer or a second pre-treatment by a specific-purpose material recovery facility could be performed within their recycling process to increase the quality for use as by-products of the manufacturer.

The concepts ‘co-waste of the manufacturer’ and ‘by-waste of the manufacturer’ are introduced to define the valued-material waste returned to the manufacturer derived from, respectively, the product of the packaged good/unpackaged product and the primary package part of the consumed goods. The aggregate of co-waste of the manufacturer and by-waste of the manufacturer constitutes the ‘by-product of the system’.

The acknowledgement of the ‘by-product of the system’ would allow the importing country to inform the manufacturers in industrialized economies about the proportion of the imported goods being returned through recycling. The extent to which consumed goods become by-product of the system could determine the tradability level of goods before being included in FTAs. Valued materials recycled through this process would relief the local waste management system through landfill waste diversion.

2.2. Decision support system

The flow diagram in **Figure 3** provides a decision support system for the implementation of globally extended producer responsibility in trade agreements (FTA clauses) related to the import of consumer goods in developing countries. It establishes relationships among the defined lexicon (shown in blue) through proposed actions (shown in green) taken according to certain criteria/conditions (shown in yellow).

The information on imported goods required from the manufacturer in the exporting country includes, besides total quantity and type of product: i) constitutive parts (goods´ primary package and product of the packaged good or unpackaged product), ii) type, proportion and value of materials, including the current global market net waste value and its forecasted variation within a determined period. This information will allow the importing party to survey for valued materials in the MSWS, using the proposed lexicon, and return them to the manufacturer as per declared.

As shown in Figure 3, manufacturers do not have to guarantee that each valued material declared will be tradable as per its economic viability but recyclable as per its technical viability. This is relevant as the quality of valued material returned to industrialized economies will depend on the local separation process. It is the responsibility of the importing party to improve the efficiency of the dirty MRF so as to obtain the highest quality of valued materials.

Each good proposed for importing should be checked by both FTA parties for the fulfillment of the following conditions:

1. to encourage waste diversion from landfills, volume and weight of valued materials should be larger than volume and weight of unvalued materials as per the global market net waste value (i.e., in Fig. 3: $V_{VM} > V_{UM}$ and $W_{VM} > W_{UM}$, respectively), and
2. to discourage the consumption of over-packaged goods, the volume of imported goods that are valued materials should not be more than 3 times the volume of the products contained (product of the packaged good plus unpackaged product) ($V_{VM\ GPP+PPG+UP} / V_{VM\ PPG+UP} \leq 3$) (Wang et al., 2018). Unpackaged product is added to the condition to incentivize the import of goods without packaging. Also, the weight of the product parts of imported goods (products of the packaged goods plus unpackaged

products) that are valued materials should be larger or equal to the weight of the imported goods´ primary packages (in Fig 3: $W_{PPG+UP} \geq W_{GPP}$).

If any of these conditions are not met, proper justification should be given by industrialized economies before goods can be traded with non-industrialized economies through FTAs. Justification could be complimented with determined tariffs to industrialized economies to support diversion of unvalued materials from landfills and valorization instead.

In addition, the importing economies could locally check the fulfillment of these conditions by examining the following relationships among the MSWS outputs according to the defined lexicon: (i) volume and weight of 'by-product of the system' should be larger than volume and weight of 'waste and co-product of the system' ($V_{BPS} > [V_{Waste} + V_{CPS}]$ and $W_{BPS} > [W_{Waste} + W_{CPS}]$) and (ii) the volume of 'by-product of the system' should not be more than 3 times the volume of 'co-waste of the manufacturer' ($V_{BPS} / V_{CWM} \leq 3$) and weight of 'co-waste of the manufacturer' should be larger or equal to weight of 'by-waste of the manufacturer' ($W_{CWM} \geq W_{BWM}$). The use of the defined lexicon (co-waste of the manufacturer, by-product of the system, by-waste of the manufacturer, co-product of the consumer, by-product of the consumer, and co-product of the system) would be internal to the importing country, the industrialized exporting countries would only have to manage the concepts of valued and unvalued materials, goods´ primary package, product of the packaged good and unpackaged product for declaration purposes.

This overall assessment will also include goods of the MSWS that are not derived from FTAs, so relationships among the MSWS outputs should be checked according to the proposed lexicon before and after the FTA is implemented to assess the effects on the whole MSWS by comparing yields through time. Valued materials for return to the country of origin are allocated from the total output valued materials derived from the MSWS separation process according to the declared features of the imported goods –i.e. quantity, type and proportion of materials and functional parts as imported goods (goods´ primary package, product of the packaged good and unpackaged product).

As goods can also be reused as 'co-product of the consumer' or 'by-product of the consumer', qualitative mechanisms acknowledging reuse practices in society could be implemented to monitor the change in overall reusing rates in reference to the input of imported goods.

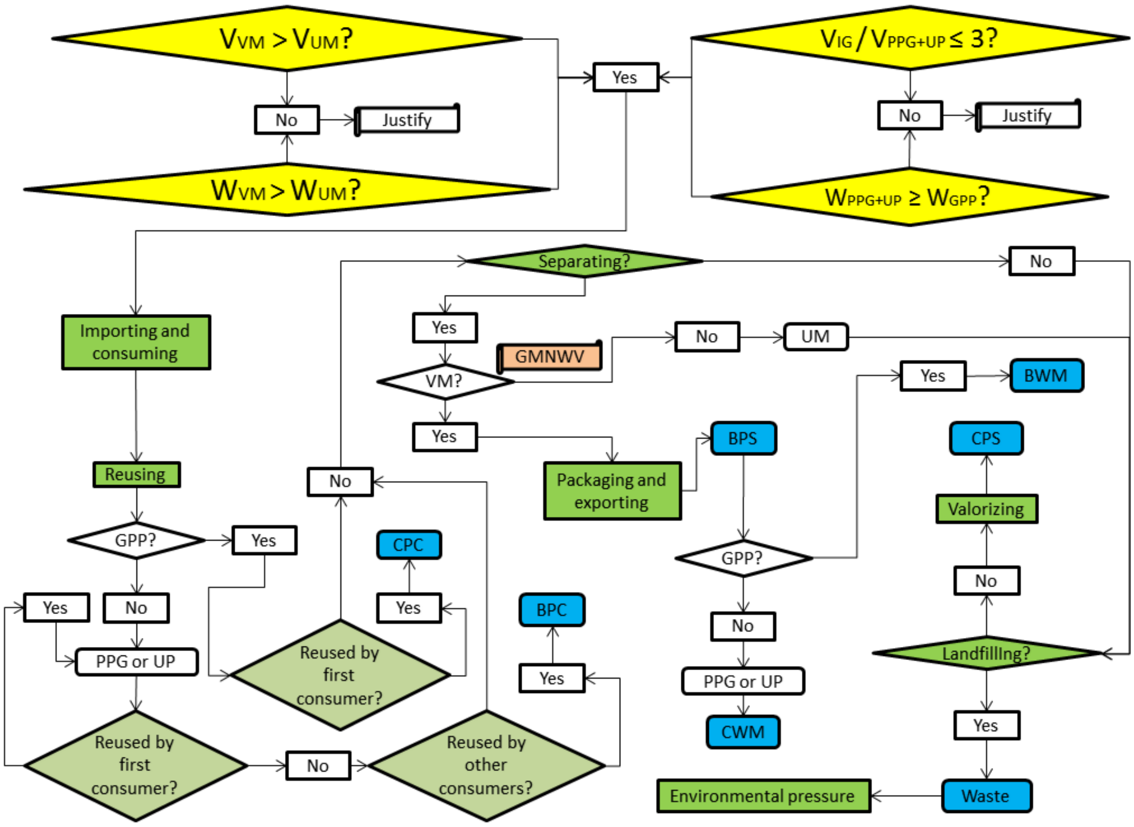


Figure 3. *Flow diagram to establish relationships among the defined lexicon (blue) through actions (green) taken according to criterions (yellow). Abbreviations: V: volume; W: weight; VM: values materials; UM: unvalued materials; IG: imported Goods; PPG: products of the packaged Goods; UP: unpackaged products; GPP: Goods´ primary package; BPC: by-products of the consumer; CPC: co-products of the consumer; BPS: by-products of the system; CPS: co-products of the system; BWM: by-wastes of the manufacturer; CWM: co-wastes of the manufacturer; GMNWV: global market net waste value.*

3. Case study

3.1. Case study selection

Panama accounts for 5% of the regional good imports in Latin America; it is ranked 6 out of the 26 Latin-American countries with 1.5% more imports than the average (SICE, 2018). With the highest GDP per capita of the region together with Chile (The World Bank, 2017) and liberal consumption habits acquired from the political and social influence of the USA, Panama is a consumer per excellence (Tagle, 1988). What makes the country particularly attractive for FTA negotiations with industrialized economies is its strategic position: the “hub of the Americas” (Muñoz and Rivera, 2010); Panama is projected as a relative interesting re-exporting market for industrialized economies (UNCTAD, 2017).. Since 2002, Panama has signed around 14 FTAs, 6 from which has been signed with industrialized economies (SICE, 2018) (**Figure 4**).

Currently, China and Panama are negotiating the second round of their FTA (La Prensa, 2018). The FTAs main aim is to increase the exchange of products and services, mostly from the most (China) to the least industrialized economy (Panama). Among the negotiated chapters reported thus far (MIRE, 2018), there is none including environmental provisions (Colyer, 2013) concerning any degree of responsibility for imported goods contribution to the local MSWS once consumed. Within the context of this FTA, the creation of the first Digital Free Trade Zone of the Americas in Panama was recently announced to function as a gateway for Chinese goods to reach Latin American economies in a more effective way through e-commerce and re-exporting (La Prensa, 2019). However, the experience with Panama's Free Trade Zone of Colón, the largest in the Americas and the second-largest in the world after Hong Kong, has shown that consumer goods will be nationalized as well (Blais et al., 2010).

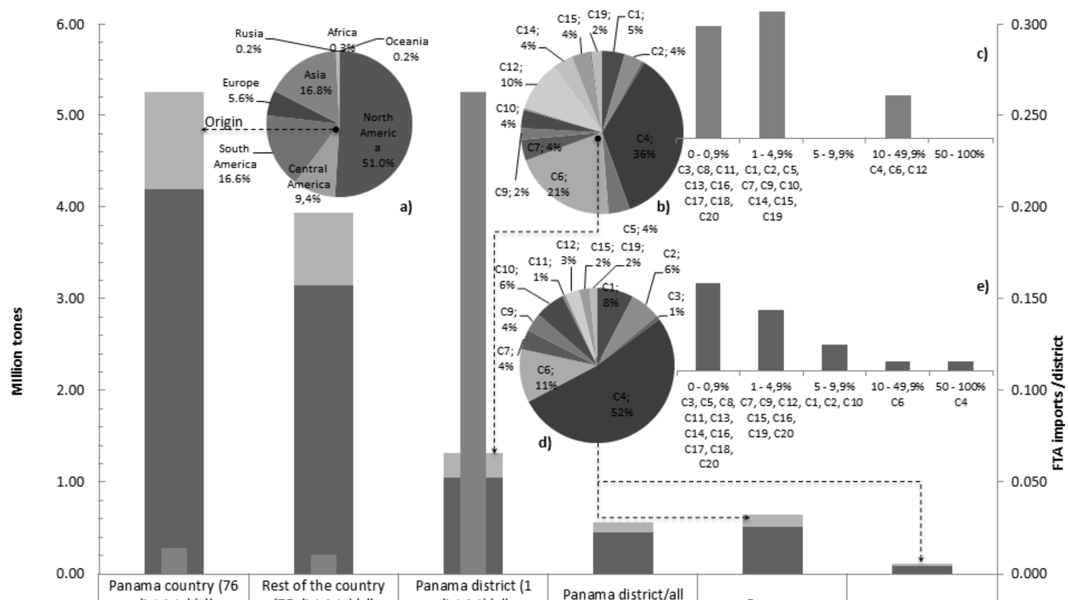
3.2. Import of consumer goods in Panama through FTAs and consumption of imported goods

Figure 4 shows Panama´s overall situation of imported consumer goods in 2016. Imported goods through FTAs with industrialized economies accounted for 20% of the total national imports (INEC, 2018), representing 1.05 million tons (Mt) consumed by the 76 districts that make up the country (**Figure 4,** 1st column). There are 20 differentiated types of imported goods (**Table A1, appendix section**) mainly brought in from North America (51%), South America (17%), and Asia (17%) (**Figure 4-a)**. The Panama district (capital) consumes 25% (0.26 Mt) of the total (national level) goods imported through FTAs; 95% more than the average consumption per district (**Figure 4-**2nd and 3rd columns).

With proportions over 10%, imported consumer goods of types C4, C6 and C12 together account for more than 65% of the weight of all imported types of consumer goods in the capital district (**Figure 4-b**). Once consumed, their contribution in quantity (w/w) to the MSWS is higher than the rest of the imported goods, which proportions (w/w) are lower, however the latter are richer in variety of materials because of their diversity (**Figure 4-c**). From the total imported goods being consumed in the Panama district, 43% (0.11 Mt) is not traded with primary packaging layer or unpackaged through traditional retailing to the end consumer, but with transport/secondary packaging layers through other trade ways (**Figure 4-4th column**) (INEC, 2018). The primary packages of these imported goods are easier to recover because they are not commingled with organic waste in the MSWS from households; they are finally consumed in specific activities of the commercial sector (Modak et al., 2015).

Around 57% of consumer goods imported through FTAs are consumed in the Panama district household´s sector and are retailed with primary packaging layer (product of the packaged goods + goods´ primary package = 0.13 Mt) or unpackaged (0.02 Mt) (**Figure 4,** 5th and 6th columns). When accounting only for this stream of imported goods, the relative contribution (w/w) of the types of goods changes (**Figure 4-d**), with C4 becoming most abundant (52%) and other types of goods becoming more prominent (**Figure 4-e**). This is also reflected in the package types ending up commingled in the MSWS, which is disposed of in the local landfill (**Figure 4-d**).

The density conversion factor as per the EWC code was used to estimate the volume of imported goods from their weight according to the waste type description that best suits each imported good (SEPA, 2015). The total volume of imported goods is around 470 km^3, of which 48% is goods' primary package and 52% is product of the packaged good and unpackaged product. Note that primary packaging accounts on average for 35% of the packaged goods weight but up to 3 times their volume (Wang et al., 2018).



Location/consumption sector/packaging layer of IGs when consumed	Panama country (76 districts)/all sectors/transport, secondary and primary packaging layers	Rest of the country (75 districts)/all sectors/transport, secondary and primary packaging layers	Panama district (1 district)/all sectors/transport, secondary and primary packaging layers	Panama district/all sectors except household/transport and secondary packaging layers	Panama district/household sector/primary packaging layer	Panama district/household sector/unpackaged
FTA imports	1.05	0.79	0.26	0.11	0.13	0.02
Other imports	4.20	3.15	1.05	0.45	0.51	0.08
FTA imports/district	0.014	0.011	0.26			

Figure 4. *Imported goods to Panama in 2016. Graph a: Origin of goods imported to Panama through FTAs (INEC, 2018). Graph b: Proportions of consumed goods´ types imported through FTAs and consumed in the Panama district with transport, secondary and primary packaging layers (w/w). Graph c: Quantities of consumed goods types by their proportion thresholds. Graph d: Redistributed proportions of consumed goods´ types imported through FTAs and consumed with primary packaging layer in the household sector of the Panama district (w/w) and average % per volume. Graph e: Quantities of consumed goods´ types consumed with primary packaging layer in the household sector by their proportion thresholds. Percentages smaller than 1% are not shown. IG refers to Imported Goods. Classification codes of types of goods are explained in Appendix Table A1.*

3.3. MSWSs to Panama district´s landfill

In 2016, the capital district landfill (Cerro Patacón) had accumulated more than 12 million m^3 of waste during 31 years of operation (AAUD, 2016). It was estimated that the landfill received of total of 2500 t of waste/d (0.913 Mt/y) from different sources; 89% is MSWS generated in households and commerce of the Panama district and its dormitory district, San Miguelito (**Figure A1, appendix section**).

A large part of commercial waste is generated clean and dry directly from commerce (120 t/d), thus allowing partial waste diversion from Cerro Patacón (37%) by the segregation/recovery activities of waste pickers in the landfill who trade the separated materials in-situ with the middleman. The middleman trades it with few wastes materials packaging/exporting companies that place it in the global waste market to the highest bidder as per the current global waste market net value at the moment of the trade. Waste recovered by waste pickers represents not more than 0.2% of all waste disposed of in Cerro Patacón, more than 99% is disposed of mixed without any halfway recyclable material segregation or recovery process (AAUD, 2016).

To account for the MSWS derived from the consumption of imported goods through FTAs in the household sector of the Panama district, only the proportional part of imported goods (20%) that ends up in the MSWS generated in the household sector of the capital district of Panama (336 t/d) is considered, that is, 14% of the total MSWS.

A total of 56 waste fractions in the MSWS from the household sector of the Panama district were characterized in 2016 by the local waste management authority (AAUD, 2016). Waste fractions were reduced to 29 as per their materials´ description (**Table A3, appendix section)** by aggregating them according to i) their structural and functional properties, ii) their tradability as by-product of the system and iii) the environmental pressure exerted when landfilled untreated.

Each fraction of the MSWS was categorized as per waste classification traditional systems assigning definitions to MSWS materials by their structural properties depending on their final destination (**Table A4, appendix section**). For instance, when the goal is to ensure the stability of waste bodies in landfills by the evaluation of waste mechanical properties, Dixon and Langer (2006) mention existing classifications systems based on: i) material groups by composition, size and dimension; ii) waste type by density, shear parameters, liquid/plastic limit, permeability; iii) organic/inorganic materials by degradability degree and shape, degradable/inert/deformable materials by strength, deformability and degradability, and on the distinction between soil- like and non-soil-like (i.e. fibrous) appearance. Zhou et al., (2014) classified municipal solid waste by their thermochemical properties based on proximate and ultimate analysis, heating value and statistical methods such as analysis of variance and cluster analysis. Classification as per their function as constitutive parts of goods (goods´ primary package, product of the packaged good, unpackaged product) and material value (valued and unvalued material) is also presented (**Table A3, appendix section)**.

Proportions in weight (w/w) and volume (v/v) of MSWS fractions of the household sector are shown in **Figure A2 of the appendix section***. Eighteen out of twenty-nine fractions (D12 – D29) are wet fractions, usually derived from product of the packaged goods and unpackaged products, that sum up to 60% (w/w) of the MSWS with an average per fraction of 3% (**Figure A2-a**). The density conversion factor as per the EWC code was used to estimate the volume of MSWS fractions from their weight values (SEPA, 2015) (**Figure A2-b**). Eleven out of twenty-nine fractions (D1 to D11) are light, voluminous and dry container fractions, usually corresponding to goods´ primary packages, that sum up to 50% (v/v) of the MSWS with an average per fraction of 4%. As is typical in developing countries, MSWS fractions of the household sector like D5, D10, D15, D16, D17, D18, D19 and D21 are predominant over other fractions in both weight and volume (Troschinetz and Mihelcic, 2009; Thanh et al., 2010; Dinesh et al., 2018).

The volume of the MSWS is around 457 km^3. Around 40% (w/w) and 49% (v/v) of the MSWS was found to be goods´ primary package, 28% (w/w) and 32% (v/v) to be product of the packaged good, and 33% (w/w) and 19% (v/v) to be unpackaged product. To allocate goods´ primary package from product of the packaged good in imported goods, the identified goods´

primary package fraction of the MSWS (40%) was used, which input as consumed goods and output in the MSWS is assumed to be equivalent. The same was assumed for unpackaged products since their weight proportion within imported goods is kept from imported goods to consumed Goods and to the MSWS.

Figure 5 shows the current allocation of the MSWS disposed of in Cerro Patacón as the final destination (123 kt) and imported goods consumed, collected and transported from the household sector of the Panama district (150 kt). Consumed goods not entering the MSWS (27 kt) could be reused, disposed of through underground dumping or other final destination method. Here it is assumed to be completely reused either by: i) other consumers, or by ii) waste collection workers who conveniently segregate valued materials from the MSWS for underground trading before ending collection routes; both proportions are undetermined (INECO, 2017).

The information shown in **Figure 5** on the imported goods input/MSWS output situation does not yet permit the definition and implementation of an EPR mechanism at the global level to account for the MSWSs locally generated from the imported goods. The implementation of dirty MRF facilities in the importing country is a prerequisite for the system to work.

Before entering the dirty MRF recovery process, around 45% (w/w) (35% goods´ primary package, 10% product of the packaged good plus unpackaged product) and 55% (v/v) (44% goods´ primary package, 11% product of the packaged good plus unpackaged product) of the materials in the MSWS is defined as valued materials (**Table A3, appendix section**). After the dirty MRF process, it is assumed that 29% (w/w) and 36% (v/v) could be recovered (CalRecovery, 2006); 65% of the total valued materials in the MSWS. Around 23% is goods´ primary package, 5.9% is product of the packaged good and 0.2% is unpackaged product (w/w), and 28.4% is goods´ primary package, 7% is product of the packaged good and 0.2% is UP (v/v). From the unvalued material, around 75% is assumed to be valorized and 25% landfilled (Ali and Courtenay, 2014).

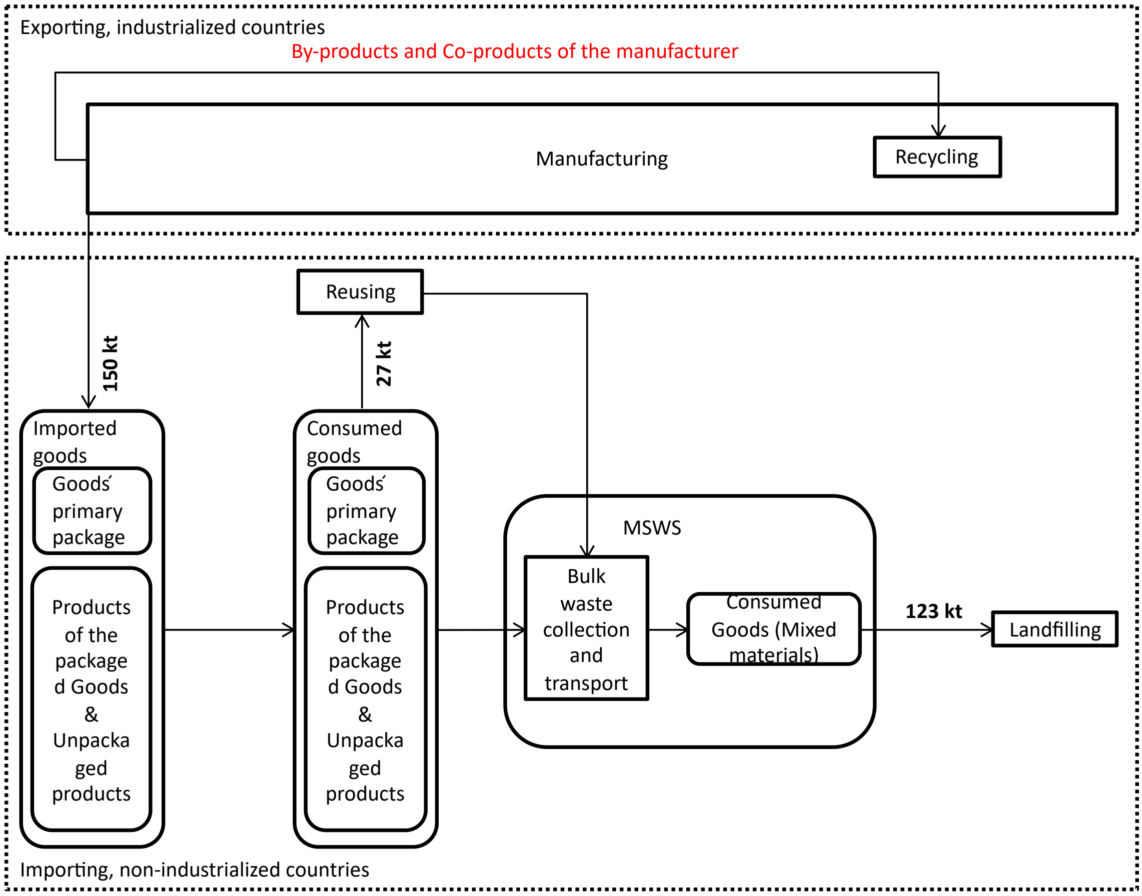


Figure 5. *Current input/output situation of the MSWS disposed of in Cerro Patacón and imported goods consumed, collected and transported from the household sector of the Panama district.*

4. Discussion and conclusions

Using the proposed methodological approach, material flows from imported goods to the MSWS as per the defined lexicon in terms of weight and volume were allocated for the Panama case (**Figure 6**). Overall results for the fulfilment of the proposed conditions for imported goods are also shown (**Table 1**).

Approximately 24% (w/w) / 34.5% (v/v) of imported goods could be exported back as by-product of the system to the industrialized economies through the FTAs with Panama; 5.3% (w/w) / 9.8% (v/v) as by-waste of the manufacturer, and 18.7% (w/w) / 24.7% (v/v) as co-waste of the manufacturer. Hence, the amount of MSWS disposed of as waste in landfills could be significantly reduced in Panama through the inclusion of extended producer responsibility in FTA clauses. Waste backhauling would represent an effective way for the goods´ exporting entity to save on logistics costs emerging from the implementation of the proposed methodology, as ships carrying goods to the importing country could load and carry back waste to the source of origin (Kellenberg, 2010).

Around 82% (w/w) / 97.2% (v/v) of imported goods in Panama is inputted to the MSWS; around 10.7% (w/w) / 2.1% (v/v) is supposedly reused as by-product of the consumer and 7.3% (w/w) / 0.7% (v/v) as co-product of the consumer. Appropriate local mechanisms to monitor the quantity and quality of reused consumed goods (as by-product of the consumer and co-product of the consumer) could improve the effectiveness of awareness campaigns and increase the reuse rate so as to reduce the input to the MSWS.

Around 58% (w/w) / 62.5% (v/v) could be valorized as co-product of the system, so only 16% (w/w) / 16% (v/v) would have to be disposed of as waste in the landfill (Cerro Patacón). It is evident that the implementation of local ´dirty´ MRFs is key to the diverting of >50% of the MSWSs from landfills through the proposed approach. This technology could be recommended as a clause of FTAs with the exporting industrialized economy assuming (partial) responsibility for design, implementation and funding of the facility(ies).

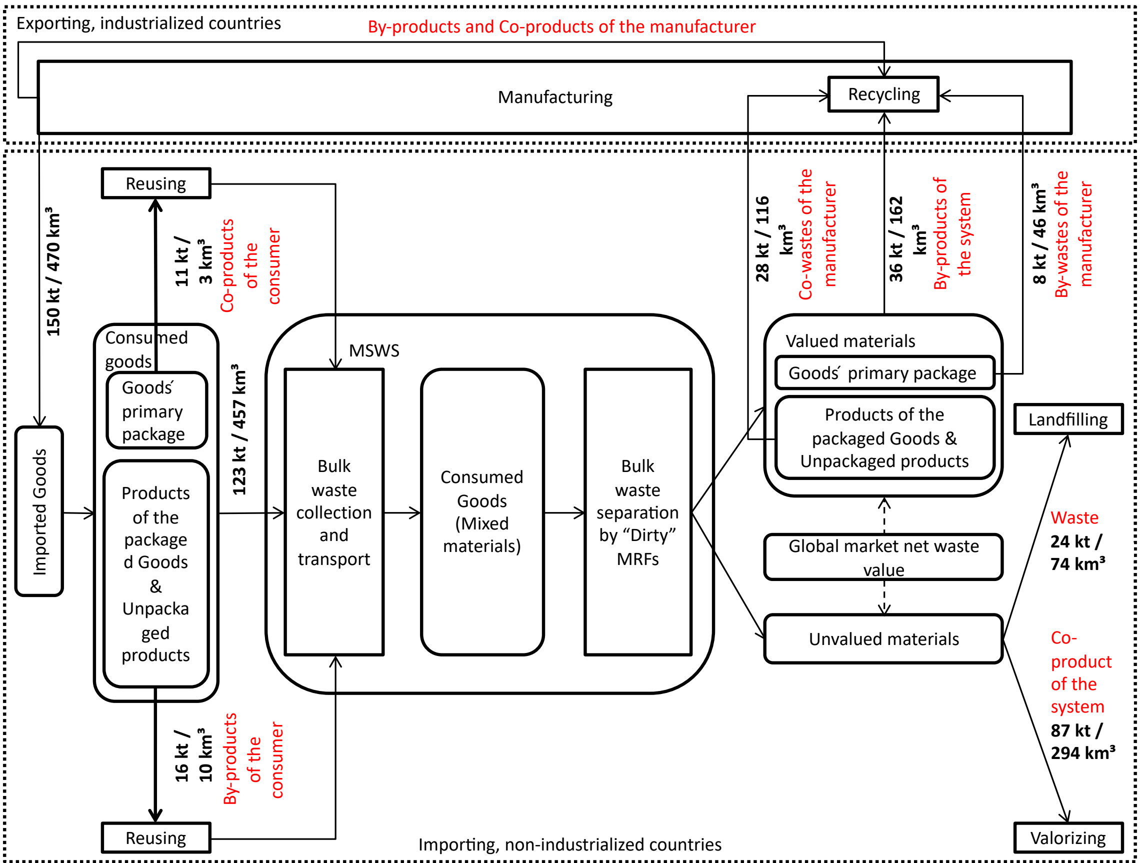


Figure 6. *Allocated material flows from imported goods to the MSWS as per the defined lexicon in terms of weight and volume.*

The aggregate of goods collectively imported by Panama through its FTAs with industrialized economies does not fulfil the materials´ value conditions, neither in terms of weight nor volume. On the other hand, the structural configuration conditions are met both in terms of weight and volume (**Figure 6**). This suggests that Panama would have to be more careful in the FTA negotiations and ban certain products from the agreement.

Imported goods´ conditions	**Type of condition**	**MSWS overall check**	**Fulfillment**
$V_{VM} > V_{UM}$	Materials' value	$V_{BPS} > V_{Wastes} + V_{CPS}$	no
$W_{VM} > W_{UM}$	Materials' value	$W_{BPS} > W_{Wastes} + W_{CPS}$	no
$V_{IG}/ V_{PPG+UP} \leq 3$	Structural configuration	$V_{BPS} / V_{CWM} \leq 3$	yes
$W_{PPG+UP} \geq W_{GPP}$	Structural configuration	$W_{CWM} \geq W_{BWM}$	yes

Table 1: *Overall fulfilment results for the proposed conditions to imported goods. Abbreviations: V: volume; W: weight; VM: values materials; UM: unvalued materials; IG: imported Goods; PPG: products of the packaged Goods; UP: unpackaged products; GPP: Goods´ primary package; BPC: by-products of the consumer; CPC: co-products of the consumer; BPS: by-products of the system; CPS: co-products of the system; BWM: by-wastes of the manufacturer; CWM: co-wastes of the manufacturer; GMNWV: global market net waste value.*

Local pollution in developing countries derived from the consumption of imported goods could be mitigated through adequate definitions of material flows getting in and out of the importing country and FTA clauses including EPR policies, negotiated between the exporting and importing country, where the responsibility for the MSWSs derived from imported goods is extended beyond local boundaries, to the country of origin.

The proposed methodology could be boosted through the eco-labelling of imported goods, such as the C2C (Cradle to Cradle) system (Llorach-Massana et al., 2015). This could help the importing country in assessing whether the imported goods fulfill the conditions drawn up and laid down in FTAs clauses and decide whether or not to ban goods with environmentally unfriendly packaging or unsustainable life-cycle outcome. Eco-labelled goods should be preferred over others if the objective is to increase the efficacy of the EPR clause of the FTAs.

Like is the case with Panama, many non-industrialized countries –notably in Latin-America– are facing a dramatic increase in resource consumption, where the vast majority of the goods consumed is imported from industrialized economies, a large part through FTAs (Saltelli et al., 2015). While industrialized economies have locally well-established MSW management systems, in non-industrialized countries MSW management systems are still incipient. FTAs encouraging waste generation in non-industrialized economies through indiscriminate and rapidly expanding imports of consumer goods represent an indirect polluting license and cannot be ignored by industrialized economies when committing to such agreements. Industrialized economies should assume responsibility when exporting consumer goods to non-industrialized economies with poorly developed waste management systems, while non-industrialized economies should demand the application of adequate EPR policies before signing an FTA.

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6. References

AAUD, 2016. PLAN NACIONAL DE GESTIÓN INTEGRAL DE RESIDUOS 2017-2027 Análisis y

Diagnóstico de la Situación Actual (TOMO I) [WWW Document]. URL http://aaud.gob.pa/plangestion//Docs/ANEXOS/20170731_E 1.3.3.3.5_Propuesta Nuevo Modelo de Gestion_v3.pdf (accessed 9.1.19).

Ali, M., Courtenay, P., 2014. Evaluating the progress of the UK's Material Recycling Facilities: A mini review. Waste Manag. Res. https://doi.org/10.1177/0734242X14554645

Ali, M.A., Lee, C.H., Kim, S.Y., Kim, P.J., 2009. Effect of industrial by-products containing electron acceptors on mitigating methane emission during rice cultivation. Waste Manag. https://doi.org/10.1016/j.wasman.2009.05.018

Baldwin, R., 1993. A Domino Theory of Regionalism. Natl. Bur. Econ. Res. Work. Pap. Ser. 4465, 1–39. https://doi.org/10.3386/w4465

Bing, X., de Keizer, M., Bloemhof-Ruwaard, J.M., van der Vorst, J.G.A.J., 2014. Vehicle routing for the eco-efficient collection of household plastic waste. Waste Manag. 34, 719–729. https://doi.org/10.1016/j.wasman.2014.01.018

Blais, A., Ritch, E., Berlin, R., Clima, R., Glendening, J., Gutierrez, V., Izard, J., Mallow, C., Nelson, R., Swigert, P., 2010. Managing Trash in Colón , Panama : A Case Study of Selected Strategies A Report of the Panama Initiative [WWW Document]. URL https://panama.evsc.virginia.edu/docs/team_panama_report_100621.pdf

CalRecovery, I., 2006. Preliminary Feasibility Study of Regional MRF Alternatives. California.

Caprile, M.D., Ripa, M., 2014. A Life Cycle Assessment of Landfilled Municipal Solid Waste in Argentina: The Influence of Waste Composition on Greenhouse Gases Emissions and Other Impacts. J. Environ. Account. Manag. 2, 145–162. https://doi.org/10.5890/JEAM.2014.06.005

CIA, 2017. The World Factbook [WWW Document]. URL https://www.cia.gov/library/publications/the-world-factbook/rankorder/2087rank.html (accessed 10.15.18).

Colyer, D., 2013. Environmental Provisions in Regional Trade Agreements.

Demaria, F., 2010. Shipbreaking at Alang-Sosiya (India): An ecological distribution conflict. Ecol. Econ. 70, 250–260. https://doi.org/10.1016/j.ecolecon.2010.09.006

DEQ, 2004. 2002 Oregon Solid Waste Characterization and Composition.

Dinesh, G.K., Chauhan, R., Chakma, S., 2018. Influence and strategies for enhanced biohydrogen production from food waste. Renew. Sustain. Energy Rev.

https://doi.org/10.1016/j.rser.2018.05.009

Dixon, N., Langer, U., 2006. Development of a MSW classification system for the evaluation of mechanical properties. Waste Manag. 26, 220–232. https://doi.org/10.1016/j.wasman.2005.02.018

ECLAC, 2017. International Trade Outlook for Latin America and the Caribbean.

EEA, 2009. Diverting waste from landfill: Effectiveness of waste management policies in the European Union 1–68. https://doi.org/10.2800/10886

García, A., Maulini, C., Torrente, J.M., Sánchez, A., Barrena, R., Font, X., 2012. Biological treatment of the organic fibre from the autoclaving of municipal solid wastes; preliminary results. Biosyst. Eng. 112, 335–343. https://doi.org/10.1016/j.biosystemseng.2012.05.005

Hansen, A.Å., Svanes, E., Hanssen, O.J., Void, M., Rotabakk, B.T., 2012. 8 - Advances in bulk packaging for the transport of fresh fish, in: Advances in Meat, Poultry and Seafood Packaging. Woodhead Publishing, pp. 248–260. https://doi.org/http://dx.doi.org/10.1533/9780857095718.2.248

Hoornweg, D., Bhada, P., 2012. What a Waste. A Global Review of Solid Waste Management. Urban Dev. Ser. Knowl. Pap. 281, 44 p. https://doi.org/10.1111/febs.13058

INEC, 2018. Anuario de Comercio Exterior, Volumen I - Importación: Año 2016 [WWW Document]. URL https://www.contraloria.gob.pa/inec/Publicaciones/Publicaciones.aspx?ID_SUBCATEGORIA=18&ID_PUBLICACION=866&ID_IDIOMA=1&ID_CATEGORIA=4 (accessed 10.15.18).

INECO, 2017. Plan Nacional de gestión integral de residuos 2017 - 2027 [WWW Document]. URL http://aaud.gob.pa/plangestion//Docs/ANEXOS/20170731_E 1.3.3.3.5_Propuesta Nuevo Modelo de Gestion_v3.pdf (accessed 4.29.18).

IPCC, 2000. IPCC Classification of MSW Composition.

Islam, K.M.N., Jashimuddin, M., 2017. Reliability and economic analysis of moving towards wastes to energy recovery based waste less sustainable society in Bangladesh: The case of commercial capital city Chittagong. Sustain. Cities Soc. https://doi.org/10.1016/j.scs.2016.11.011

JICA, 2005. Supporting Capacity Development in Solid Waste Management in Developing Countries; Towards Improving Solid Waste Management Capacity of Entire Society [WWW Document]. URL http://open_jicareport.jica.go.jp/pdf/11795846.pdf (accessed

11.26.17).

Kellenberg, D., 2010. Consumer waste, backhauling, and pollution havens. J. Appl. Econ. 13, 283–304. https://doi.org/10.1016/S1514-0326(10)60013-X

Kofoworola, O.F., Gheewala, S.H., 2009. Estimation of construction waste generation and management in Thailand. Waste Manag. 29, 731–738. https://doi.org/10.1016/j.wasman.2008.07.004

Kollikkathara, N., Feng, H., Stern, E., 2009. A purview of waste management evolution: Special emphasis on USA. Waste Manag. https://doi.org/10.1016/j.wasman.2008.06.032

La Prensa, 2019. Panamá invertirá $38 millones en la primera zona franca digital.

La Prensa, 2018. China negocia TLC con Panamá pensando en expandirse en América Latina [WWW Document]. URL https://www.prensa.com/economia/China-TLC-Panama-America-Latina_0_5072492759.html (accessed 10.24.18).

Lee, U., Chung, J.N., Ingley, H.A., 2014. High-Temperature Steam Gasification of Municipal Solid Waste, Rubber, Plastic and Wood. https://doi.org/10.1021/ef500713j

Lindhqvist, T., 2000a. Extended Producer Responsibility in Cleaner Production - Policy Principle to Promote Environmental Improvements of Product Systems.

Lindhqvist, T., 2000b. Extended Producer Responsibility in Cleaner Production. Policy principle to promote environmental Improvements of Product Systems. IIEE Diss. https://doi.org/http://www.lub.lu.se/luft/diss/tec355.pdf

Llorach-Massana, P., Farreny, R., Oliver-Solà, J., 2015. Are Cradle to Cradle certified products environmentally preferable? Analysis from an LCA approach. J. Clean. Prod. 93, 243–250. https://doi.org/10.1016/j.jclepro.2015.01.032

Martínez Urreaga, J., González-Sánchez, C., Martínez-Aguirre, A., Fonseca-Valero, C., Acosta, J., De La Orden, M.U., 2015. Sustainable eco-composites obtained from agricultural and urban waste plastic blends and residual cellulose fibers. J. Clean. Prod. 108, 1–8. https://doi.org/10.1016/j.jclepro.2015.06.001

Menon, J., 2007. Bilateral trade agreements. Asia. Pac. Econ. Lit. https://doi.org/10.1111/j.1467-8411.2007.00201.x

MIRE, 2018. RESUMEN DE ACUERDOS SUSCRITOS ENTRE LA REPÚBLICA DE PANAMÁ Y LA REPÚBLICA POPULAR CHINA.

Modak, P., Wilson, D.C., Velis, C., 2015. Waste Management: Global Status, in: Global Waste

Management Outlook. pp. 51–79. https://doi.org/10.1177/0734242X15616055

Muñoz, D., Rivera, M., 2010. Development of Panama as a Logistics Hub and the Impact on Latin America. Environ. Eng. Massachusetts Institute of Technology.

Ng, R., Shi, C.W.P., Tan, H.X., Song, B., 2014. Avoided impact quantification from recycling of wood waste in Singapore: An assessment of pallet made from technical wood versus virgin softwood. J. Clean. Prod. 65, 447–457. https://doi.org/10.1016/j.jclepro.2013.07.053

NYCDOS, 2017. Determination on the Recyclability of Food-Service Foam.

Papu-Zamxaka, V., Harpham, T., Mathee, A., 2010. Environmental legislation and contamination: The gap between theory and reality in South Africa. J. Environ. Manage. 91, 2275–2280. https://doi.org/10.1016/j.jenvman.2010.06.014

Powrie, W., White, J., 2004. Landfill process modelling, in: Waste Management. pp. 225–226. https://doi.org/10.1016/j.wasman.2004.02.001

Ripa, M., Fiorentino, G., Giani, H., Clausen, A., Ulgiati, S., 2017. Refuse recovered biomass fuel from municipal solid waste. A life cycle assessment. Appl. Energy 186, 211–225. https://doi.org/10.1016/j.apenergy.2016.05.058

Robertson, T.R., Hamza, M., 2016. Paper Products: Food Packages. Ref. Modul. Mater. Sci. Mater. Eng. https://doi.org/10.1016/B978-0-12-803581-8.09809-X

Saltelli, A., Giampietro, M., Avan, E., Ambientals, T., Autonoma, U., 2015. The fallacy of evidence based policy Science for policy . Predicaments and doubts. Futures 1–30.

Sandin, G., Røyne, F., Berlin, J., Peters, G.M., Svanström, M., 2015. Allocation in LCAs of biorefinery products: Implications for results and decision-making. J. Clean. Prod. 93, 213–221. https://doi.org/10.1016/j.jclepro.2015.01.013

Savino, A., Solórzano, G., Quispe, C., Correal, M.C., 2018. Waste Management Outlook for Latin America and the Caribbean.

Schubert, E.M., 2014. The Carbon Footprint of Waste Management Systems – Analysis and Comparison of Different Approaches.

SEPA, 2015. Guidance on using the European Catalogue (EWC) to code waste November 2015 Waste.

SICE, 2018. Acuerdos Comerciales en vigor [WWW Document].

Song, Q., Li, J., Zeng, X., 2015. Minimizing the increasing solid waste through zero waste strategy. J. Clean. Prod. 104, 199–210. https://doi.org/10.1016/j.jclepro.2014.08.027

Soo, V.K., Compston, P., Doolan, M., 2017. The influence of joint technologies on ELV recyclability. Waste Manag. 68, 421–433. https://doi.org/10.1016/j.wasman.2017.07.020

Tagle, M.A., 1988. Changes in the patterns of food consumption in Latin America. Arch. Latinoam. Nutr. 38, 750–765.

Tchobanoglous, G., 2009. Solid Waste Management, in: Environmental Engineering: Environmental Health and Safety for Municipal Infrastructure, Land Use and Planning, and Industry, Sixth Edition. pp. 177–308. https://doi.org/10.1002/9780470432822.ch3

Thanh, N.P., Matsui, Y., Fujiwara, T., 2010. Household solid waste generation and characteristic in a Mekong Delta city, Vietnam. J. Environ. Manage. 91, 2307–2321. https://doi.org/10.1016/j.jenvman.2010.06.016

The World Bank, 2017. GDP per capita (current US$) | Data [WWW Document]. URL https://data.worldbank.org/indicator/NY.GDP.PCAP.CD?locations=PA-CL&year_high_desc=true (accessed 10.22.18).

Troschinetz, A.M., Mihelcic, J.R., 2009. Sustainable recycling of municipal solid waste in developing countries. Waste Manag. 29, 915–923. https://doi.org/10.1016/j.wasman.2008.04.016

UNCTAD, 2018. World Investment Report.

UNCTAD, 2017. Trade policy framework: Panama [WWW Document]. URL https://unctad.org/en/PublicationsLibrary/ditctncd2016d3_en.pdf (accessed 12.16.19).

UNEP, 2009. Developing Integrated Solid Waste Management Plan Training Manual Volume 3: Targets and Issues of Concern for ISWM.

Uva, M.D., Bloom, J., 1992. Exporting Pollution: the international waste trade, Journal of Management Information Systems. Taylor & Francis Group . https://doi.org/10.1080/00139157.1989.9928938

Wang, Z., Stone, R.T., Mumani, A., Schnieders, T., 2018. How Packaging Characteristics Change the Perception of Product Net Weight. Proc. Hum. Factors Ergon. Soc. Annu. Meet.

Zacharof, A.I., Butler, A.P., 2004. Stochastic modelling of landfill processes incorporating waste heterogeneity and data uncertainty, in: Waste Management. pp. 241–250. https://doi.org/10.1016/j.wasman.2003.12.001

Zhou, H., Meng, A., Long, Y., Li, Q., Zhang, Y., 2014. Classification and comparison of municipal solid waste based on thermochemical characteristics. J. Air Waste Manag. Assoc. 64, 597–616. https://doi.org/10.1080/10962247.2013.873094

Landva, A., Clark, J., 1990. Geotechnics of Waste Fill, in: Geotechnics of Waste Fills—Theory and Practice. ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, pp. 86-86–18. https://doi.org/10.1520/STP25301S

DEQ, 2004. 2002 Oregon Solid Waste Characterization and Composition.

Dixon, N., Langer, U., 2006. Development of a MSW classification system for the evaluation of mechanical properties. Waste Manag. 26, 220–232. https://doi.org/10.1016/j.wasman.2005.02.018

IPCC, 2000. IPCC Classification of MSW Composition.

A. Appendix

Imported goods´ types index*	Imported goods´ types
C1	Animal
C2	Vegetable
C3	Oils/grease/wax
C4	Industrial food/alcohol/tobacco
C5	Minerals
C6	Chemical
C7	Plastic/Rubber
C8	Leather/skin/fur
C9	Wood
C10	Cellulose
C11	Textile
C12	Ceramic/glass
C13	Precious stones
C14	Metal
C15	Electric/electronic
C16	Vehicles
C17	Clinical
C18	Weapons
C19	Various
C20	Art

Table A1. Imported goods´ types to Panama through FTAs with industrialized economies. ** Index used through this study to refer to imported good types*

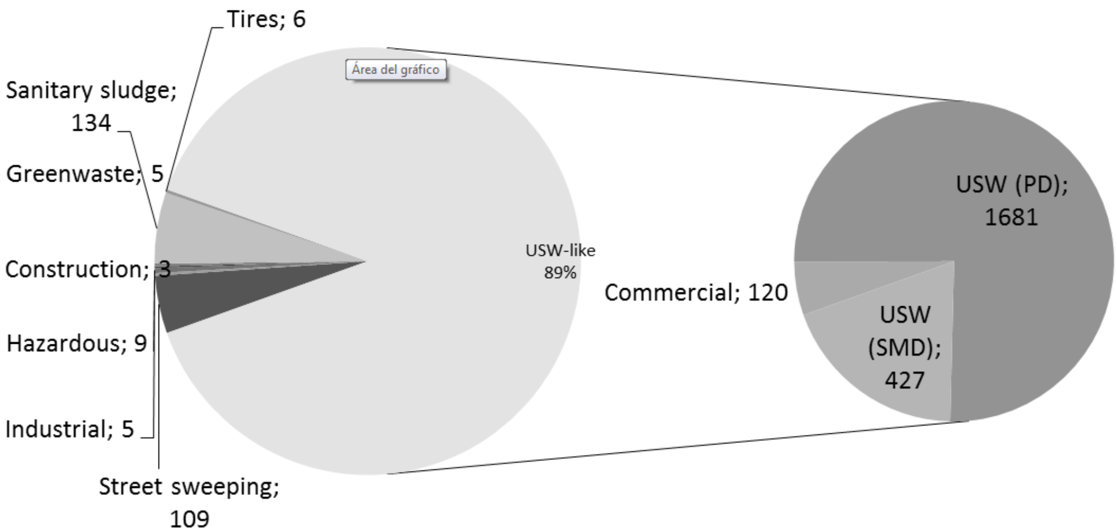

Figure A1. Fractions of all waste disposed in the Cerro Patacón landfill (t/d).

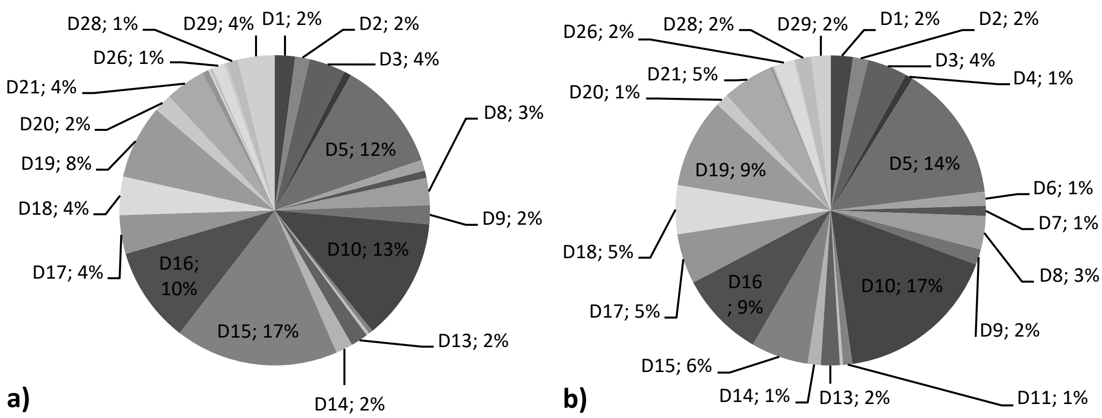

Figure A2. Proportions of the MSWS fractions from the household sector of the Panama district disposed of in Cerro Patacón as a: a) (w/w) and b) (v/v). *Percentages less than 1% have been omitted for space reasons.

Disposed MSW fractions Index**	Description	Materials	Constitutive part	Material value
D1	Bottle/jar package as container for beverage products	Polyethylene terephthalate (PET)	GPP	VM
D2	Bottle/jar package as container for household chemicals	High-Density Polyethylene (HDPE)	GPP	VM

D3	Dish/glass package as foam container for food and beverages products	Expanded polystyrene (EPS)	GPP	UM
D4	Family size packages as container for liquid products	Diverse plastics types	GPP	VM
D5	Plastic films for single-use bags	Low-Density Polyethylene (LDPE)	GPP	VM
D6	Cartoon with Tetra Pak® technology as container for beverage products	Tetra Brik®	GPP	VM
D7	Multi-layer bag as container for food and beverage products	Complex laminates	GPP	VM
D8	Metal can as containers for beverage products	Steel/Aluminum	GPP	VM
D9	Bottle as container for beverage products	Glass	GPP	VM
D10	Cartoon as container for beverage and packaging products	Cardboard	GPP	VM
D11	Crates as container for fruits and vegetables	Wood	GPP	UM
D12	Tubing and hydraulic application accesories	Polyvinyl Chloride (PVC)	UP	VM
D13	Non-container applications waste	Diverse plastics	PPG	VM
D14	Non-container application waste	Steel/Aluminum	PPG	VM
D15	Household kitchen food waste	Food rest	UP	UM
D16	Household gardens green waste	Ligneous/non-ligneous raw	UP	UM
D17	Disposable kitchen/toilet paper waste	Lignocellulosic biomass	PPG	UM
D18	Disposable absorbent wearable waste	Sanitary pad/diapers	PPG	UM
D19	Rags/clothes/leather/wood fragments waste	Textile/leather/wood	PPG	UM
D20	Minor construction/earthenware, pottery and porcelain waste	Concrete/brick/Ceramic/Clay	PPG	UM
D21	Writing and printing paper waste	Lignocellulosic biomass	PPG	VM

D22	Kitchen, automobile or commercial used lipophilics/hydrophics liquids	Oil	PPG	UM
D23	Electrochemical cells device waste	Batteries	PPG	VM
D24	Household application chemicals	Chemical substances	PPG	UM
D25	Medical application materials waste	Diverse materials	PPG	UM
D26	Electrical/electronic appliances/cables/CFL components waste	Waste of Electrical and Electronic Equipment (WEEE)	PPG	VM
D27	Vehicle wheels rim cover waste	Tires	UP	UM
D28	Non-container application voluminous waste	Diverse materials	UP	UM
D29	Fine refuse/earth/stones/glass bottle cullets waste (<20 mm)	Diverse materials	UP	UM

Table A3. Fractions of the MSWS of the household sector of the Panama district, materials, constitutive parts and material value as per the global market net waste value. *** Index used through this study referring to disposed MSW fractions.*

Disposed fraction	*Organic/inorganic materials (Landva and Clark, 1990)*	*Composition of material groups (DEQ, 2004)*	*Size and dimension of material groups (Dixon and Langer, 2006)*	*Degradability (Dixon and Langer, 2006)*	*IPCC classification (IPCC, 2000)*
D1	Non-Putrescible organic	Plastic	Flexible plastic	Very difficult/ non-degradable	Plastic
D2	Non-Putrescible organic	Plastic	Flexible plastic	Very difficult/ non-degradable	Plastic
D3	Non-Putrescible organic	Plastic	Flexible plastic	Very difficult/ non-degradable	Plastic
D4	Non-Putrescible organic	Plastic	Flexible plastic	Very difficult/ non-degradable	Plastic
D5	Non-Putrescible organic	Plastic	Flexible plastic	Very difficult/ non-degradable	Plastic
D6	Non-Putrescible organic	Mixed	Paper/ cardboard	Medium difficult	Paper/ cardboard
D7	Degradable inorganic	Plastic	Flexible plastic	Very difficult/ non-degradable	Other

D8	Degradable inorganic	Metal	Metal	Very difficult/ non-degradable	Metal
D9	Non-Degradable inorganic	Glass	Mineral	Very difficult/ non-degradable	Glass
D10	Non-Putrescible organic	Paper	Paper/ cardboard	Medium difficult	Paper/ cardboard
D11	Non-Putrescible organic	Organic	Wood/leather	Difficult	Wood
D12	Non-Putrescible organic	Plastic	Rigid plastic	Very difficult/ non-degradable	Plastic
D13	Non-Putrescible organic	Plastic	Rigid plastic	Very difficult/ non-degradable	Plastic
D14	Degradable inorganic	Metal	Metal	Very difficult/ non-degradable	Metal
D15	Putrescible organic	Organic	Organic	Easy	Food waste
D16	Putrescible organic	Organic	Organic	Easy	Wood
D17	Non-Putrescible organic	Paper	Paper/ cardboard	Medium difficult	Paper/ cardboard
D18	Non-Putrescible organic	Organic	Miscellaneous	Medium difficult	Other
D19	Non-Putrescible organic	Organic	Wood/leather	Very difficult/ non-degradable	Textiles - Rubber/ Leather
D20	Non-Degradable inorganic	Inorganic	Mineral	Very difficult/ non-degradable	Other
D21	Non-Putrescible organic	Paper	Paper/ cardboard	Medium difficult	Paper/ cardboard
D22	Non-Putrescible organic	Hazardous	Miscellaneous	Medium difficult	Other
D23	Degradable inorganic	Hazardous	Miscellaneous	Very difficult/ non-degradable	Other

D24	Non-Putrescible organic	Hazardous	Miscellaneous	Medium difficult	Other
D25	Non-Putrescible organic	Inorganic	Miscellaneous	Very difficult/ non-degradable	Other
D26	Degradable inorganic	Metal	Miscellaneous	Very difficult/ non-degradable	Other
D27	Non-Putrescible organic	Organic	Rigid plastic	Very difficult/ non-degradable	Rubber/ Leather
D28	Non-Putrescible organic	Organic	Miscellaneous	Difficult	Other
D29	Non-Degradable inorganic	Inorganic	Mineral	Very difficult/ non-degradable	Other

Table A4. Fractions of the MSWS of the household sector of the Panama district classified according to various classification systems regarding structural properties.

6.3 Paper #3 "Landfill reactions to society actions: The case of local and global air pollutants of Cerro Patacón in Panama"

Landfill reactions to society actions: The case of local and global air pollutants of Cerro Patacón in Panama

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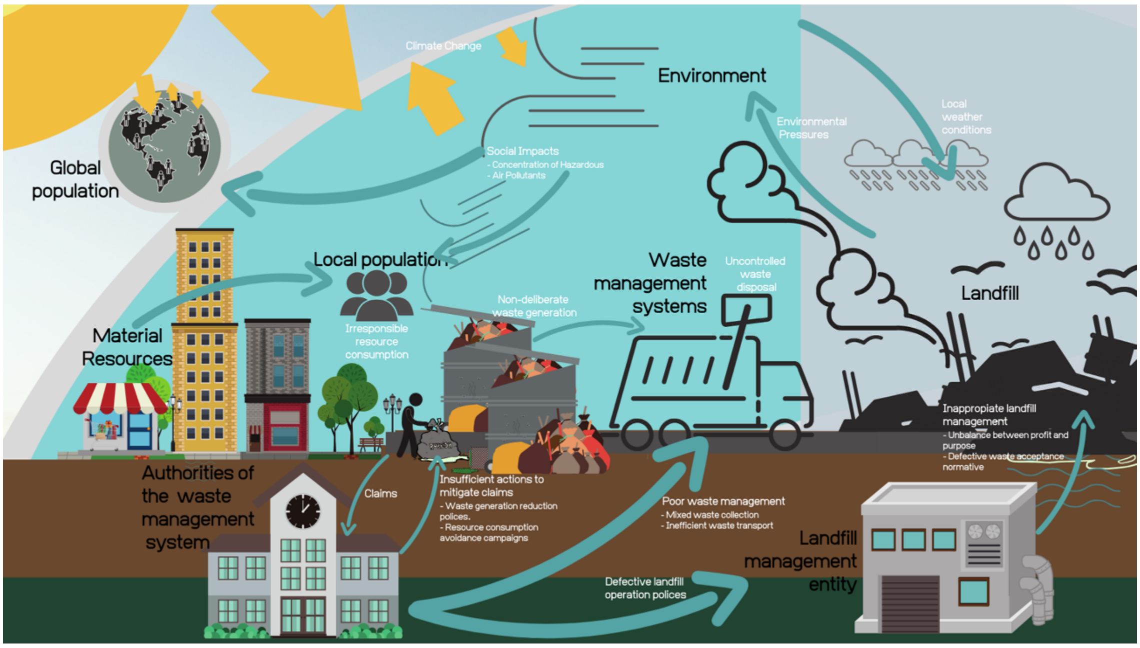
Abstract

This paper studies landfill emissions and the related environmental and health risks in Panama City, with the aim to sensitize the population about the harmful effects of irresponsible resource consumption and non-deliberate solid waste generation that it is disposed of in an uncontrolled manner in landfills. Empirical data on Cerro Patacón, Panama City's landfill was obtained to describe the status of municipal waste disposal. Ten known methane generation models were used to estimate the yearly emission rate of methane from the landfill for a 100-year period starting from its inception in 1986. From the models used, the GasSIM model was chosen to estimate emission rates of six long-term hazardous air pollutants. The AERMOD source dispersion model was used to simulate their atmospheric downwind dispersion by levels of concentration over nearby affected communities; results were mapped in Google Earth. The relative contributions by population of the 32 towns making up Panama City to the forecasted waste generation in 2022 and related hazardous air pollutants emission rates from the landfill were assessed. It was found that Cerro Patacón will generate 45% of the countrywide methane generation by 2022; an average of 47 Gg. The solid waste generated by the 1.5 million inhabitants of Panama City impacts the health of ~73,600 inhabitants in nearby communities through the dispersion of hazardous atmospheric pollutants derived from the landfill. The highest emission rates were from hydrogen sulfide and dichloromethane, which can be largely attributed to the waste generated by the communities of Juan Diaz and Tocúmen. The concentration of Hydrogen Sulfide and Benzene was over the reference concentration

(uncertainty factor spanning three orders of magnitude) for all communities and years simulated. The concentration of Vinyl Chloride was over the RfC for all communities and years simulated, except in 2018 for 12 communities.

Keywords: Uncontrolled municipal waste disposal; landfill emissions; air pollution; environmental pressure; Panama City

Graphical abstract



Caption: Interactions between actors of the waste management system and responsibilities for resulting environmental pressures and social impacts.

Highlights

- The anthroposphere non-deliberately generates waste without responsibility allocation
- Uncontrolled waste disposal exerts pressure over the biosphere and atmosphere
- Local and global environmental pressures from Panama City landfill were identified
- Local societal impacts were allocated to 5% of communities affected by the rest 95%
- Data becomes useful when people acknowledge mutual impacts through waste generation

Abbreviations

Phrase	**Abbreviation**
Municipal Solid Waste	*MSW*
Developing country	*DC*
Non-methane Organic Compound	*NMOC*
Hazardous Air Pollutant	*HAP*
Panama District	*PD*
San Miguelito District	*SMD*
Cerro Patacón	*CP*
Reference Concentration	*RfC*
Degradable organic carbon	*DOC*
Zero Order Decay	*ZOD*
First Order Decay	*FOD*

1. Introduction

Landfills require land availability and have negative side effects on the environment and for this reason their placement is often opposed by surrounding residents (Hoornweg and Bhada, 2012). Nonetheless, it remains the most common method for waste disposal worldwide and is considered a reliable and low-cost alternative to final MSW disposal (Caprile and Ripa, 2014; Powrie and White, 2004; Zacharof and Butler, 2004).

In most countries, the costs of using landfills for MSW disposal and household waste collection and transport are covered by public fees that are defined by the (local) authorities based on many different factors, such as household income level, household area, water usage or waste generation. However, the operation and maintenance of landfill sites are often left to private companies who establish a fee per ton of waste, its size depending on the landfill's engineering complexity, that is intended to not only cover the costs but also generate profit (Kinnaman, 2009).

In an effort to promote sustainable waste management, in developed countries more stringent limits on the proportion of organic waste in landfills have driven advanced engineering solutions for landfills sites (Pan et al., 2014). As a result, MSW landfills in developed countries are now mostly used to dispose of inert materials resulting from pre-treated MSW under strict conditions (DEFRA, 2010). This allows the establishment of fixed and transparent landfill operation and maintenance costs due to the relatively homogeneous physicochemical characteristics of the waste (Rigamonti et al., 2016).

DCs, on the other hand, face serious problems of uncontrolled waste disposal due to the absence of separated collection practices and waste treatment before it is disposed of in landfills. In addition to accepting untreated MSW, most landfills also accept sludge, hospital and industrial waste without any pre-treatment and thus retaining bacteriologic activity. This leads to unpredictable landfill operation and maintenance costs, limits the pre-treatment technologies that can be deployed on-site and encourages irresponsible resource consumption (Wilson et al., 2012).

These irregularities affect the local and global environment throughout the landfill's active life, and eventually derive in societal impacts (OECD, 2008). Indeed, landfills are the final stage of the waste management system where uncontrolled waste disposal, combined with local weather conditions—temperature and humidity—and inappropriate management, creates environmental pressures (Sarptaş, 2016). The shifting of landfill costs to the environment is the central concern of the opposition to landfill sites, since such environmental pressures are the chronicle of foretold societal impact.

When the society resents the impacts, claims arise to the waste management authorities for solutions. The authorities need a source of information that will allow them to describe and show society that these impacts are partly caused by the population's own irresponsible resource consumption and non-deliberate waste generation. In this regard, there is an urgent need for reliable estimates and non-steady-state assumptions about the environmental pressures caused by landfill emissions, and there is a general lack of such data in DCs (Bogner and Matthews, 2003).

More in general, there is a need for a holistic perspective of the MSW management system (Chifari et al., 2016; Ziout et al., 2014) in order to understand the extent to which the environmental pressures exerted by landfills is coupled to other aspects of the MSW management system and resource consumption. These insights are also necessary to assess the extent to which claims by the society are caused by uncontrolled waste disposal and inappropriate landfill management, or conversely, are derived from non-deliberate waste generation and irresponsible resource consumption (Chifari et al., 2016; Ziout et al., 2014).

With this information in hand, authorities will be better equipped to create meaningful waste acceptance criteria (DEFRA, 2010) and impose effective operation and maintenance policies on the landfill managers, giving the latter a threshold with which to balance economic profit and socio-ecological interests. Policies to reduce waste generation and campaigns for responsible resource consumption could be fostered in society, and based on the relevant technical, economic and socio-ecological aspects of the entire mechanism of landfill environmental pressure, thus giving the population a reference point for the level of responsibility they have for their own claims.

This paper studies landfill gas emissions in Panama City and the related local and global environmental pressures and human health effects with the aim to raise awareness among the population about the responsibility they bear for the disproportionate impacts mutually exerted through irresponsible resource consumption and non-deliberate solid waste generation that is disposed of in landfills in an uncontrolled manner.

Empirical data on CP, Panama´s main city landfill, was obtained to describe the status of waste disposal. Ten known methane generation models were used to estimate the yearly emission rate of methane from CP for a 100-year period starting in 1986 to generate a picture of the environmental pressure exerted. From the ten models used, the GasSIM model was chosen to estimate also NMOC emission rates, specifically of the six long-term HAPs that presented the higher dispersion rates from CP. The AERMOD source dispersion model, local meteorological conditions data were used to simulate HAP´s atmospheric downwind dispersion by their levels of concentration over nearby affected communities and results were mapped in Google Earth.

To gain insight in the environmental pressure exerted on local communities, the local concentration of HAPs was compared with the inhalation chronic reference concentration RfC [$\mu g\ m^{-3}$], which is an estimate of the level of human exposure through chronic inhalation throughout life that is unlikely to have an appreciable deleterious effect (US EPA, 2011).

Relative contribution to forecasted (2022) MSW generation and HAPs emission rates from the landfill by the 32 towns making up Panama City was assessed to sensitise the population about (potential) environmental and health effects of irresponsible resource consumption and uncontrolled MSW disposal.

2. Case Study

Panama is an upper-middle income DC (The World Bank, 2018) with the most rapid economic growth of all Latin-American cities (Coleman et al., 2014). It is also the world's highest-ranking city in terms of well-being, based on purpose, social, community, physical and financial elements, with 61% of Panamanians thriving in three or more elements (GALLUP, 2014).

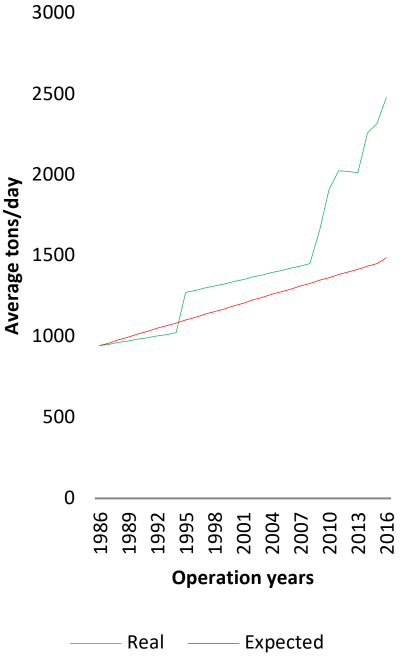
The metropolitan area of Panama City consists of two districts, PD and SMD. PD is made up of 23 towns and SMD of 9 towns; a total of 276 communities make up the 32 towns of PD and SMD (INEC, 2000). According to the last census, the population of the metropolitan area was ~1.4 million people, representing 35% of the national population (total land area 75,517 km^2). The national population density is 53 people/km^2, while that of the metropolitan area is 673 people/ km^2; the most crowded in the country (Weitz et al., 2008). Recent studies estimated the MSW generation per capita for PD in 1.55 and for SMD in 1.28 kg $inh^{-1}day^{-1}$ (INECO, 2017).

2.1. Panama City landfill: Cerro Patacón

CP is the landfill for the metropolitan area of Panama City. Its total area is about 130 ha including administration, operation and other non-disposal zones, of which the net disposal area was 53 ha in 2002 (JICA, 2003) and 63 ha in 2016 (AAUD, 2016a). CP receives various waste fractions: MSW (including street sweeping, household waste, and commercial waste assimilable to household waste), sewage and industrial sludge, used tires, clinical waste and construction/demolition (C&D) waste; approximately 60% of this waste is biodegradable (AAUD, 2016b).

Waste disposal has increased by an average of 3.5% per year since CP opened in 1986. From 1986 to 2007, the increment estimates were based on the design stage for achieving its planned lifespan: an average of 1% per year (Weitz et al., 2008). The accelerated immigration and economic growth that began in late 2007/early 2008 (CEPAL, 2009; INEC, 2008) caused a rise in resource consumption that increased the MSW generation rate to an average of 7%. By 2016, waste reception had reached approximately 2,300 tons per day, 40% more than expected for the same year according to its initial design (**Figure 1**).

The initially planned closure date by design was 2037, but actual waste deposited in CP exceeds the design forecast and this rate is expected to continue until at least 2022, the date to which CP closure has been advanced following recent studies of its capacity (AAUD, 2016a). The degree of saturation of CP is evident from a comparison of the maximum elevation of waste slopes reached in 2002 (106 m) to that reached in 2016 (126 m) (JICA, 2003). This was the maximum permitted until a new maximum of 145 m was approved for the same year in order to fulfill the city's increasing needs for landfill capacity (AAUD, 2016a), despite the augmented risk of hazardous gas dispersion for nearby communities (Paraskaki and Lazaridis, 2005).



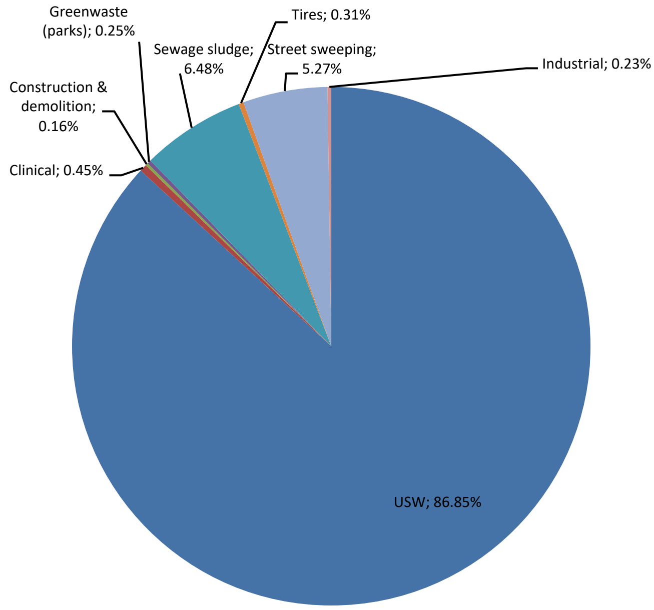


Figure 1. Expected (red line) vs. real data (green line) of the daily waste disposal in tons throughout the lifespan of CP (left), and waste composition in 2016 (right)

2.2. Local and global environmental pressures derived from Cerro Patacón

Biodegradable materials in landfills are decomposed by microbes under anaerobic conditions. This microbial action is highly complex due to unpredictable differences in the degradation rates of the materials that make up solid wastes (Farquhar and Rovers, 1973). The degradation process starts with hydrolysis of solid materials, such as hemicellulose and cellulose, into larger soluble organic molecules, fermentation of which yields organic acids that give rise to methanogenesis. Simple sugars, fats and hemicellulose are easily degraded; cellulose has a moderate degradability, while lignin is resistant to biodegradation under anaerobic conditions. Depending on its availability to bacteria, it can also influence cellulose degradation (Chandler and Jewell, 1980). The intermediate products of landfill waste biodegradation, such as carboxylic acids (R–COOH), carbon dioxide (CO_2) and hydrogen (H_2), generate liquid and gaseous emissions, leachate, and Landfill Gas (LFG) respectively, producing negative environmental and societal impacts (Bogner and Matthews, 2003).

2.2.1.Global Environmental Pressures

2.2.1.1. Methane emissions

The atmosphere is being polluted by LFG acting as a greenhouse gas (GHG). LFG is a combination of methane (CH_4) and carbon dioxide in approximately equal proportions, such that total LFG flow can be assumed to be twice the methane flow. However, traces of other gases have also been found, which constitute no more than 2% of the flow but sum to more than 160 compounds, such as non-methane organic compounds (NMOC), reduced sulfur, and speciated organics (US EPA, 2008). Some NMOCs contain volatile organic compounds (VOC) that can be organic HAPs. Notably, methane and the NMOC nitrous oxide have a Global Warming Potential (GWP) of 21- and 298-times that of CO2 (Frischknecht et al., 2007; Majdinasab et al., 2017).

2.2.2.Local Environmental Pressures

2.2.2.1. Diffusion of toxic gases traces

Local environmental pollution by the waste management sector is now one of the most sensitive social issues in many DCs including Panama (US EPA, 2006a). However, throughout the lifetime of CP, the surrounding community has only been aware of the impacts that their senses can perceive, such as bad smells, noise, vibrations from machines, and surface fires (ATSDR, 2004). The proportion of HAPs present in LFG varies with the local weather conditions and the characteristics of the disposed waste such as the quantity, age, and organic waste content (Paraskaki and Lazaridis, 2005; Sarptaş, 2016). Several NMOCs have been studied to evaluate their HAP properties at the low concentrations at which they are emitted from landfills (Saral et al., 2009). These compounds contribute to air quality deterioration (US EPA, 2006b, 2008), and long–term inhalation throughout life is harmful but imperceptible to people in nearby communities (US EPA, 2011).

2.2.2.2. Landfill surface fires

The lack of proper waste acceptance policies observed in CP is a common problem in DCs (Powell et al., 2016). The combination of uncontrolled waste disposal and inappropriate landfill management (Blais et al., 2010) derives in undesired events like that which occurred in March 2013, when LFG and stockpiles of waste tires combined to produce a heat-generating reaction that caused the worst surface fire seen to date at CP. LFG accumulated in the void spaces in the waste tires (75% volume) and boosted the combustion energy to 28% higher than that of coal, which made the fire difficult to quench both with water and by suffocation (Islam et al., 2009; Pennington, 1996). This fire occupied an area of 30 ha and burned continuously for 10 days, releasing airborne fumes to a radius of 13 km (La Prensa, 2013). No report has yet been published on the environmental damage that resulted from this fire, but studies of similar events have reported increased levels of NMOC, particulate matter, nitrogen oxide, sulfur dioxide, carbon monoxide, polycyclic aromatic hydrocarbon, benzene and dioxin/furan (US EPA, 2008); for the latter, levels reached up to 66 times higher during burning (Weichenthal et al., 2015).

2.2.2.3. Nearby infrastructure explosion risks

As a result of this fire, local authorities concluded that there was a need to assess various issues, including the topography of the landfill's high slopes, where the waste was neither compacted nor covered (AAUD, 2016a). This issue highlighted an environmental pressure resulting from the inappropriate landfill management: risk of explosion by methane migration because the waste was not properly covered with soil.

When LFG is generated, it can be emitted directly into the atmosphere, oxidized to carbon dioxide via an aerobic soil cover, retained within the landfill volume, or migrated laterally to the subsurface. As for the latter case, migration can extend to >300 m in poorly engineered landfills (Kjeldsen, 1996). The most important parameter that controls LFG migration to the surrounding zones is soil permeability to air, which has been found to be strongly influenced by the soil's permeability to water: higher water content results in lower gas migration due to reduced soil porosity (Poulsen et al., 2001).

The soil in CP has a low water permeability (AAUD, 2016a), so despite the high levels of rainfall risk of LGF migration increases during the 3-month dry season (Poulsen et al., 2003). CP is located adjacent to a 4,000-ha protected national park, and the closest residential community is at 50 m distance (Calle 50 squatter settlement) (**Figure 2**). Migration of LFG through soil may result in societal impacts such as explosion hazards in nearby civilian structures, and damage to vegetation due to high concentrations of LFG (Blais et al., 2010; Poulsen et al., 2003).

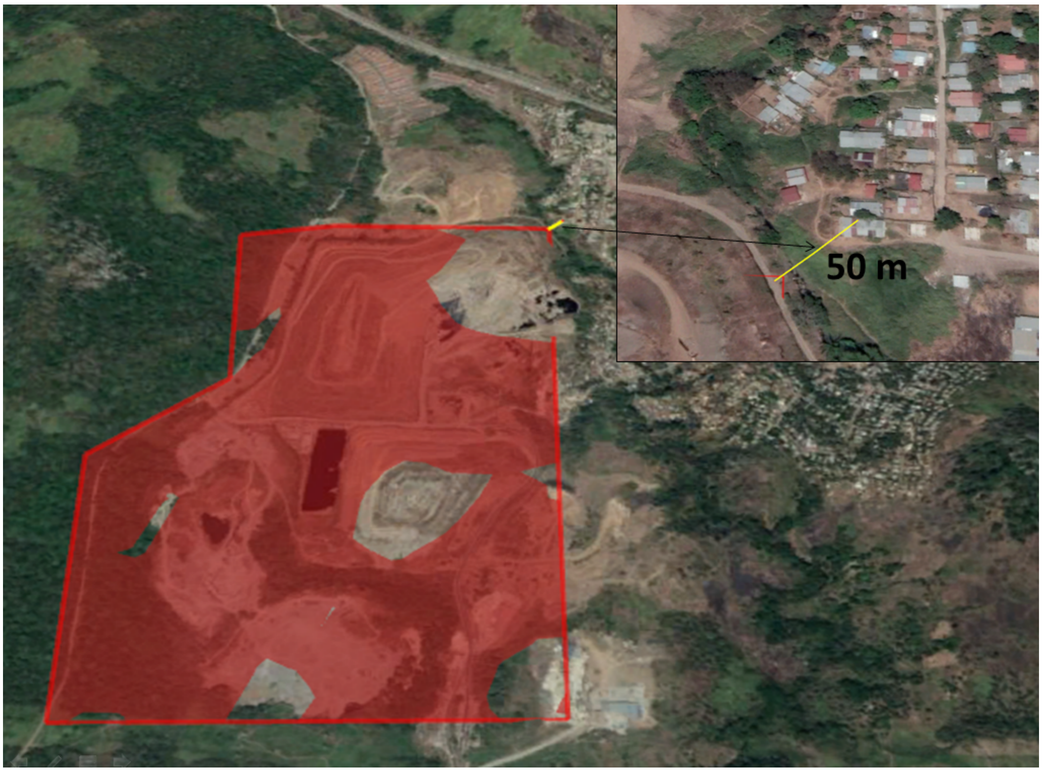


Figure 2. CP landfill area is located adjacent to a protected national park (green zones) and 50 meters from the nearest community.

2.2.2.4. Sludge spills and leachate infiltration in ground and surface water

CP lies in a tropical weather zone, with annual rainfall of 3000 mm and evaporation of 1500 mm. These characteristics are important for CP's waterproofing system, which is not adapted to avoid leachate infiltration to groundwater. Older areas are covered by a 40 to 80 cm layer of clay, while recently constructed areas have a geomembrane and a geotextile, which lacks appropriate systems for gas collection and leachate recirculation (AAUD, 2016a).

Sludge is directly disposed of in a pit, from which a stream flows into a nearby river located no more than 200 m from CP, and from which some communities are supplied with daily-use water. Recent field studies found annual leachate accumulation of >450,000 m^3 in the ponds, with concentrations well above legal limits for various water quality control parameters such as cadmium, lead, nitrate/nitrite, and chlorides in groundwater, and Biological/Chemical Oxygen Demand (BOD5, COD), cadmium, copper, iron, chromium, lead, and sodium in surface water (AAUD, 2016a). The amount and composition of landfill leachate depend on waste type and compaction, landfill hydrology, climate and landfill age, and treatment methods are chosen accordingly (Aziz et al., 2018; Roudi et al., 2018).

2.3. DOC in the waste disposed in CP

As mentioned above, MSW represents approximately 87% of the total waste in CP (**Figure 1**). It is composed of commingled waste, i.e. bulk waste, collected in PD and SMD. The overall composition of MSW when landfilled is 4% metals, 16% paper/cardboard, 18% plastics, 27% organics and 35% others (AAUD, 2016b). It has 80% humidity and 45% carbon content (AAUD, 2016a). The fractions of MSW that contain DOC, which ultimately generates LFG and leachate (IPCC, 2006a), are paper/cardboard, organics (food waste and green-waste) and some materials of the “others” fraction. This is composed of 32 different identifiable fractions, including wood, cellulose, diapers, textiles, glass, etc.

In addition to MSW, DOC containing waste also includes sludge, non-hazardous industrial waste, and street sweeping waste (Sarptaş, 2016). Of the total waste in CP, 73% contains DOC, of which 82% comes from MSW, and the rest from other fractions. Local conditions such as soil cover and weather conditions determine how much of the DOC contained in the waste is available for degradation as methane, as not all biodegradable material can be converted to LFG, and methane accounts for approximately 50% (Oonk, 2010).

3. Materials and methods

Figure 3 shows the methodology applied in this study.

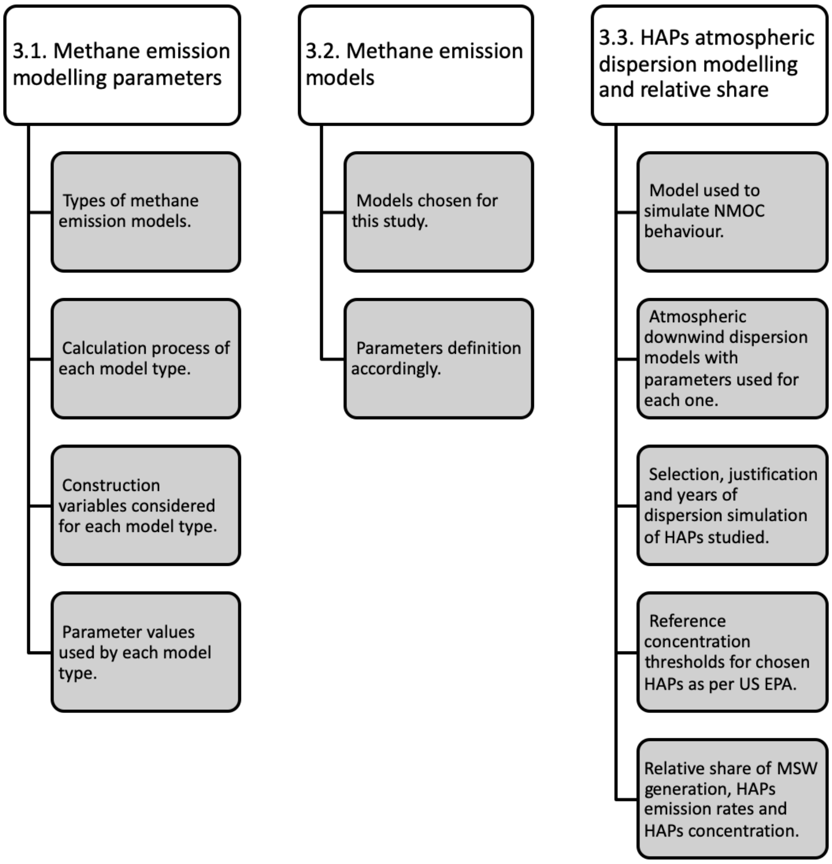


Figure 3. Methodological pathway of this study

3.1. Methane emission modelling parameters

Methane emissions are generally calculated from the methane mass-balance, which is the difference between methane generated and that recovered plus oxidized methane. Oxidation is ~10% of the total methane generation (IPCC, 2006b), and most landfills in DC, including CP, do not have LFG recovery (JICA, 2002; Machado et al., 2009).

Since the extreme complexity of landfill processes makes it impossible to obtain precise data on their outputs, methane emission models are used to assess landfill outputs using field-collected data on a yearly basis, such as the waste disposal volumes and landfill conditions. By modelling the behavior of a landfill site, we can attempt to interpret its environmental pressure (Powrie and White, 2004). Models are constructed using data from different waste categories, which, depending on the country, can differ depending on local definitions of the various waste fractions –e.g. MSW- (Scharff and Jacobs, 2006). There is no perfect model that accurately predicts methane emissions within narrow limits (Oonk, 2010).

Existing models can be empirical, mathematical or numerical. The most well developed and widely used models are the ZOD and FOD empirical models. Second Order Decay empirical models are much less widely used because they are less accurate regarding their complexity (Oonk, 1994), and the reliability of the available mathematical and numerical models (El-Fadel et al., 1989) depends on the availability of input data which is very specific (Majdinasab et al., 2017).

ZOD models are generally used in DC, where there is little or no data on the amount, age and composition of the waste (Oonk, 2010). FOD models are often used in developed countries (Zacharof and Butler, 2004). ZOD models assume that waste produces a fixed amount of LFG for a fixed number of years (Peer et al., 1992), while FOD models assume that LFG forms after waste deposition and that emissions begin to decrease by a given methane generation rate k [yr^{-1}] per half-life $t_{1/2}$ [yr] over a fixed number of years. In this sense, data temporal resolution in this work will be given in a yearly basis. The assumed value of $t_{1/2}$ is 0.693 k^{-1} [yr], in which 50% of the original amount of DOC in waste is biodegraded as methane, depending on the level of moisture, pH, local weather conditions, and the availability of nutrients for methane-generating bacteria, etc. (Ludwig, 2007).

The input for FOD models is usually a “single-phase” or bulk waste amount, -e.g. MSW with homogenous characteristics (Scharff and Jacobs, 2006)-, and thanks to the increasing availability of this type of data, FOD models are increasingly preferred over ZOD models in DCs landfills (Bogner and Matthews, 2003). Moreover, by conducting waste characterization studies, FOD “multi-phase” models can be used to assign parametric values for k and methane generation potential L_0 for each waste fraction characterized (Mou et al., 2015). In this case, depending on the model, both parameters can be assigned for different material decay rates, for which the characterized waste proportions must be adapted according to the model’s specific waste input categories -e.g. slow-, medium- and fast-degrading-, and local weather conditions -i.e. wet, dry, tropical, temperate, etc.- (Krause et al., 2016).

The methane generation potential L_0 [m^3 CH_4 Mg^{-1} waste] indicates the total amount of methane emitted from DOC during the methanogenesis phase of waste degradation for bulk waste with a particular composition (i.e. ZOD and FOD models), or for different fractions of waste -i.e. FOD multi-phase models-. Some models express L_0 in terms of mass as Biochemical Methane Potential (BMP) [Kg CH_4 Mg^{-1} waste] (Mou et al., 2014). Others express methane yield as a variable that describes the percentage of carbon actually degraded depending on waste composition, the Biodegradable Carbon (BDC) [kg C Mg^{-1} waste]. In this study, methane generation potential for all models used is expressed as L_0 [m^3 CH_4 Mg^{-1} waste] using a conversion factor of 1.33 kg CH_4 kg C^{-1} to convert carbon mass to methane mass and 0.714 kg CH_4 m^{-3} CH4 to convert methane mass to methane volume (Krause et al., 2016).

In CP, ~73% of DOC contained in disposed waste is biodegradable from which ~10% is aerobically degraded by oxidation occurring in landfill soil cover, and ~90% is anaerobically degraded through the methanogenesis process (IPCC, 2006b). Not all anaerobically converted DOC is bioavailable, it is defined by landfill conditions (Krause et al., 2016). However, suitable landfill conditions in CP allow all anaerobically degraded DOC to be considered bioavailable. Only ~2% of bioavailable anaerobically biodegraded DOC from disposed waste is trace gases, the rest is methane and carbon dioxide in equivalent proportions (**Figure 4**). ZOD and FOD models use the Bioavailable Carbon Factor (BAC_f), dissimilation factor (Ϛ) or the Methane Conversion Factor (MCF), all of which account for the availability of the degradable material due to external conditions (Krause et al., 2016). This value is taken as 100% for anaerobic unmanaged solid waste wet disposal sites (IPCC, 2006a; Scharff and Jacobs, 2006), which is the case of CP.

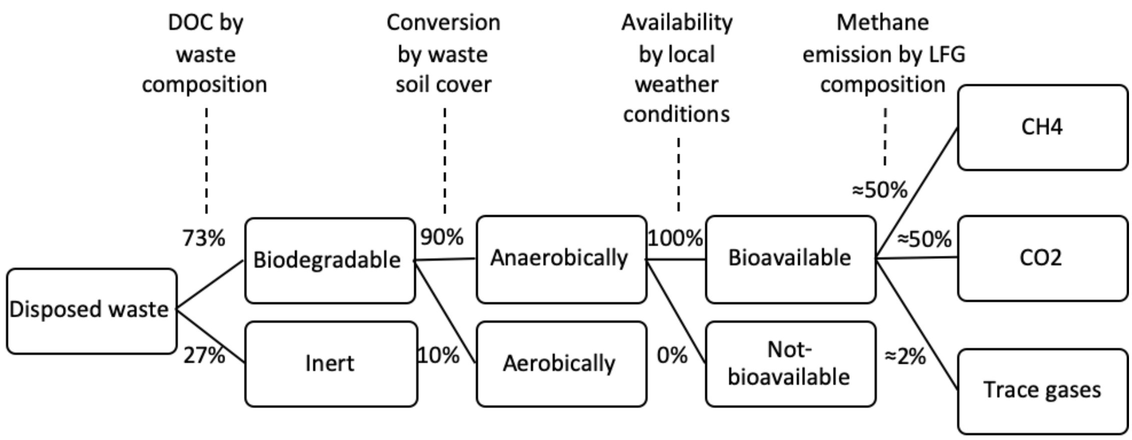


Figure 4. Conditions defining methane emission proportions according to the DOC content of waste disposed in Cerro Patacón.

3.2. Methane emission models

In this study, 2 ZOD, 4 FOD and 4 FOD multi-phase models were used to estimate the average methane generation for CP (**Table 1**). The waste characterization study performed in 2016 was used to benchmark the waste composition for all years modelled since 1986; no other characterization study had previously been carried out in CP (AAUD, 2016b).

For one FOD model (the TNO-model) and all four FOD multi-phase models, waste categories were re-coded to match the input format required by each model and are given as a proportion of the total disposed waste. Parameters *k* and L_0 were obtained from default values according to each model (Krause et al., 2016; Majdinasab et al., 2017; Mou et al., 2014), for which a weighted-average has been obtained for bulk waste representing 100% of the waste disposed in CP –i.e. commingled waste-; the value obtained serves as a guide for future modeling with no characterization study available.

We computed the yearly average L_0 for the weighted-averages of the bulk waste input values of the five models mentioned above (97 m^3 CH4 Mg^{-1} of waste), and used this as the L_0 value for the remaining models (T&R, LandGem, SWANA FOD, SWANA ZOD, and EPER Germany), as their input is a bulk waste value. Others studies have reported similar L_0 values for bulk waste in wet/tropical landfills (Bentley et al., 2005; Faour et al., 2007; Machado et al., 2009); their *k* values are the default (Krause et al., 2016; Oonk, 2010; SWANA, 1997).

Table 1. Methane emission models and parameters used for CP

Model		**Waste**		**Parameters**	
Name and reference	*Type*	*Categories*	*Proportions*	*k (y-1)*	*L0 (m3 CH4/Mg Waste)*
GasSim (Attenboroμgh et al., 2002)	FOD multi-phase	*Weighted-average for bulk waste*	*100%*	*0.28*	*78*
		Paper/Cardboard	19%	0.12	116
		Textiles	6%	0.12	113
		Miscellaneous	6%	0.12	113
		Putrescible	28%	0.69	115
		Fines	8%	0.08	111
		Sludge	6%	0.69	34
		Non-degradable	27%	0.00	0
IPCC (Pipatti et al., 2006)	FOD multi-	*Weighted-average for bulk waste*	*100%*	*0.13*	*80*
		Food	18%	0.40	70
		Garden	6%	0.17	93

	phase	Paper	19%	0.07	187
		Wood	5%	0.04	201
		Textiles	6%	0.07	112
		Disposable nappies	4%	0.17	112
		Sludge	12%	0.17	23
		Industrial	1%	0.17	70
		Plastics, other inert	28%	0.00	0
Afvalzorg (Mou et al., 2015)	FOD multi-phase	*Weighted-average for bulk waste*	*100%*	*0.13*	*78*
		C&D waste	1%	0.03	15
		Street cleaning	5%	0.03	27
		Coarse household waste	1%	0.03	112
		Sludge and composting waste	7%	0.21	35
		Refuse	2%	0.03	88
		Household waste	46%	0.21	127
		Vegetable, fruit and garden waste	6%	0.21	66
		Wood	5%	0.10	177
		Inorganic	27%	0.00	0
Central America (Weitz et al., 2008)	FOD multi-phase	*Weighted-average for bulk waste*	*100%*	*0.12*	*84*
		Food Waste	16%	0.23	68
		Fast-decaying green waste	6%	0.23	68
		Other fast-decay organic waste	25%	0.23	68
		Slower-decay green waste	2%	0.03	207
		Paper and Cardboard	14%	0.03	207
		Wood Waste	3%	0.03	207
		Rubber, Leather, Textiles, Bones	7%	0.03	207
		Inorganic waste	28%	0.00	0
TNO (Oonk, 1994)	FOD	*Weighted-average for bulk waste*	*100%*	*0.07*	*164*
		C&D waste	1%	0.10	20
		Street cleaning	5%	0.10	168
		Coarse household waste	1%	0.10	242
		Sludge and composting waste	7%	0.10	168
		Refuse	2%	0.10	168
		Household waste	46%	0.10	242

		Vegetable, fruit and garden waste	6%	0.10	242
		Wood	5%	0.10	242
		Inorganic	27%	0.00	0
T & R (Tabasaran and Rettenberger, 1987)	FOD	Bulk waste	100%	0.03	97
LandGem (US EPA, 2001)	FOD	Bulk waste	100%	0.70	97
SWANA (SWANA, 1997)	FOD	Bulk waste	100%	0.15	97
SWANA (SWANA, 1997)	ZOD	Bulk waste	100%		97
EPER Germany (Scharff and Jacobs, 2006)	ZOD	Bulk waste	100%		97

3.3. HAP atmospheric dispersion modelling and relative share

The Gaussian Plume Model of Atmospheric Dispersion AERMOD (US EPA, 2018) was used to simulate NMOC behavior and atmospheric downwind dispersion based on local meteorological data according to local weather conditions up to 10 km around CP, which is considered as an area-shaped air polluting source. The annual average concentrations of six long-term standard hazardous landfill-derived NMOCs that are considered VOC and HAP are reported in Table 2: Hydrogen Sulphide (H_2S), Vinyl Chloride ($H_2C{=}CHCl$), trichloroethene or trichloroethylene (TCE)(C_2HCl_3), Benzene (C_6H_6), Dichloromethane or methylene chloride (CH_2Cl_2) and Chloroform ($CHCl_3$) (Gioia et al., 1995; Kanabkaew et al., 2014; Paraskaki and Lazaridis, 2005; US EPA, 1991, 1995, 2000).

HAP emission rates from the FOD model GasSim [$g\ s^{-1}$] were used as input for AERMOD per m^2 of net waste disposal area at CP for the years 2002, 2018 and 2022. GasSim was preferred over other models because it has been designed with a special inclination toward the potential health effects on the population living near and working on landfills (Golder Associates, 2012). This is of interest given the reported statistical relationship between landfill proximity and adverse effects on human health (Elliott et al., 2001). The resulting concentrations were compared to exposure threshold values of RfC (Dankovic et al., 2015; NITE, 2017; US EPA, 2003) (**Table 2**).

Table 2. Name, formula, RfC [μg m^{-3}] (uncertainty factor spanning three orders of magnitude), relative proportion of the total landfill HAPs emitted and emission rates [g s^{-1}] (at 1 Atm and 25ºC) for the years 2002, 2018 and 2022 of simulated HAPs at Cerro Patacón.

HAP				**Year of simulation**		
				2002	**2018**	**2022**
Name	*Formula*	*RfC*	*Proportion*	*Emission rates*		
Hydrogen Sulphide	H_2S	10	5%	0.1071	0.2	0.262
Vinyl Chloride	$H_2C{=}CHCl$	100	2%	0.0398	0.075	0.097
Trichloroethene	C_2HCl_3	600	2%	0.0321	0.06	0.078
Benzene	C_6H_6	30	4%	0.075	0.14	0.183
Dichloromethane	CH_2Cl_2	600	5%	0.1038	0.194	0.254
Chloroform	$CHCl_3$	100	0.01%	0.0003	6E-04	8E-04

Meteorological data input for AERMOD was obtained from the Albrook station (WMO, 2001); others parameters are described in **Table 3**.

Table 3. Site-specific and meteorological parameters for AERMOD simulation

Parameter	**Value**
CP approximate location (UTM)	17P 656961E 1000248N
Sensible heat flux (W/m2)	40 (Hamza and Muñoz, 1996)
Surface friction velocity (m/s)	0.72 (Cheng and Georgakakos, 2011)
Bowen ratio	0.48 (Lewis, 1995)
Albedo	0.17 (McEvoy et al., 2012)
Average wind speed (m/s)	1.67 (Hidromet, 2017)
Average wind direction (degrees)	315 (Hidromet, 2002)
Average relative humidity (%)	90 (Hidromet, 2017)
Average cloud cover (tenths)	5 (Hidromet, 2017)
Precipitation (mm/hr)	0.34 (Hidromet, 2017)
Monin-Obukhov length (m)	92.39 (Pino et al., 2006)

Relative contributions to MSW generation and related HAPs emission rates from CP by the 32 towns making up Panama City were assessed. HAPs concentrations within affected communities close to CP were allocated by population relative share to assess environmental pressures within the same year.

4. Results and discussion

Results on methane emission behaviour are shown for the 10 models used from the opening of CP in 1986 to 2086; an overall model average behaviour is also presented (**Figure 5**). The behaviour of the total NMOC emissions (**Figure 6**) and 6 major HAPs (**Figure 7**) is shown for a period of 46 years (1986-2032). Simulations of HAP atmospheric dispersion over the area surrounding CP are shown (**Figure 8**) for the years 2002, 2018 and 2022, along with the total population at risk and the HAP concentrations in the affected communities. Radar plots to allocate the MSW generation and HAP emission rates from CP by towns and to allocate EP through HAP concentrations by towns and affected communities were forecasted to 2022 (**Figures 9 and 10).**

4.1. Methane emissions

Oonk (2010) reported differences between model estimations of more than 10-fold. The Central America model reached its highest methane levels by 2023, 92 Gg CH_4, while the TNO model reached its highest value by 1998, 9 Gg CH_4 (**Figure 5**). The LandGEM model behaved in a similar way to that reported by Plocoste et al., (2016) when applied to a tropical area.

The methane emissions of the TNO, GasSIM and LandGEM models had the same order of magnitude to the results reported by Scharff and Jacobs, (2006) for the same landfill; the same is observed for the AFVALZORG, IPCC and LandGEM models in Mou et al., (2015), and for the T&R, TNO, IPCC and LandGEM models in Sarptaş (2016).

Since EPER Germany estimates methane emissions independent of the amount of the methane already generated (Majdinasab et al., 2017), the methane emission curve falls to 0 Gg CH_4 by 2022, the year reported for landfill closure. Similar behavior can be observed in another ZOD model, SWANA, although methane emissions did not fall so dramatically, but rather remained almost constant after the highest peak of 43 Gg CH_4 in 2022, which is the typical behavior of ZOD models (Oonk, 2010).

The SWANA FOD model reaches its peak long before the other models because it considers the effect of waste age on methane emissions by simulating a direct relationship between the methane generation potential (L_0) and the waste decay rate (*k*). Thus, L_0 becomes over-sensitive to *k*, and reaches its maximum in the last year in which the interaction between L_0 and *k* shows a curve-increasing result (Majdinasab et al., 2017).

The behavior of the average curve is similar to that of the LandGEM model, and the peak value by 2022 is very close to the last peak (46.81 Gg CH_4) reported in 2011 by the National Environmental Authority of Panama in their Second National Communication to the United Nations Framework Convention on Climate Change (UNFCCC); however, there is difference of eleven years between the results (ANAM, 2011).

Globally, over 60% of methane emissions comes directly from human activities such as coal mining, the petroleum industry, and MSW landfills, with the remainder being accounted for by other indirect activities and natural sources (US EPA, 2010, 2002). In Panama, cattle raising, manure management, and wetlands account for 40% (80 Gg $year^{-1}$) of methane emissions (Dennehy et al., 2017; Goopy et al., 2018; INEC, 2014a, 2014b; Philippe and Nicks, 2015). There is no coal mining or petroleum industry, so direct anthropogenic methane emissions, which represent 60% (120 Gg $year^{-1}$), come from landfills alone; ~45% is emitted by the CP metropolitan landfill (AAUD, 2016b).

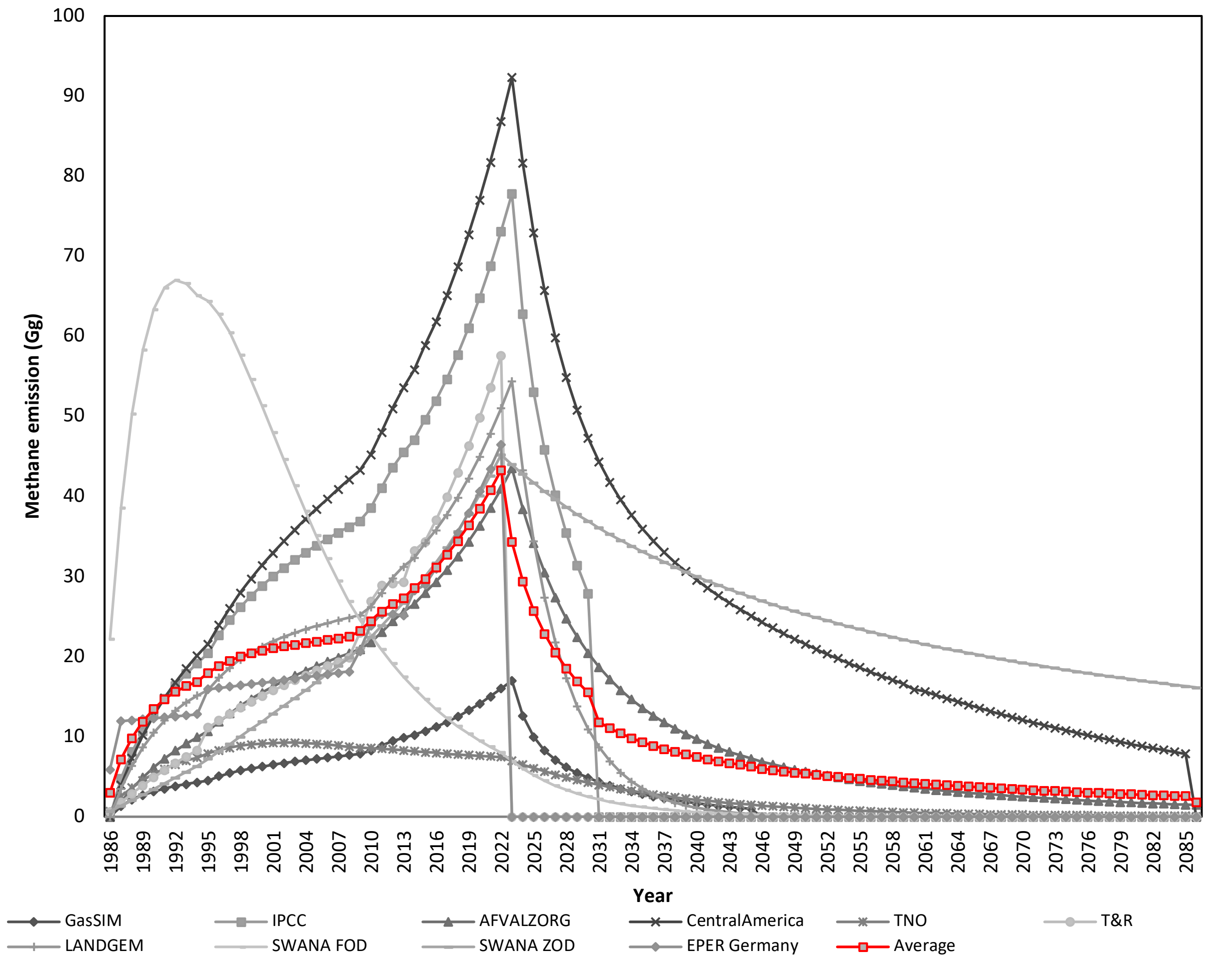


Figure 5. Annual methane emission rates for the ten models used and the average curve

4.2. HAP emissions

According to the US EPA (2005), landfills with NMOC emissions of >50 Mg yr^{-1} require an LFG capturing mechanism. At CP, the total HAP emission per year, which represent 52% of all NMOC generated, reaches a peak of 194 Mg by 2022 (**Figure 6**), so CP should have had an LFG capture system since its opening in 1986. The 6 HAPs simulated in this study account for more than 18% of the total HAP per year, and less than 1% of the total LFG. Hydrogen Sulphide and Dichloromethane had the highest emissions in 2022, both with a peak of ~9 Mg, followed by Benzene, Vinyl Chloride and Trichloroethene, with 13, 4 and 2 Mg, respectively. Chloroform had the lowest emission for 2022 (26 kg, **Figure 7**).

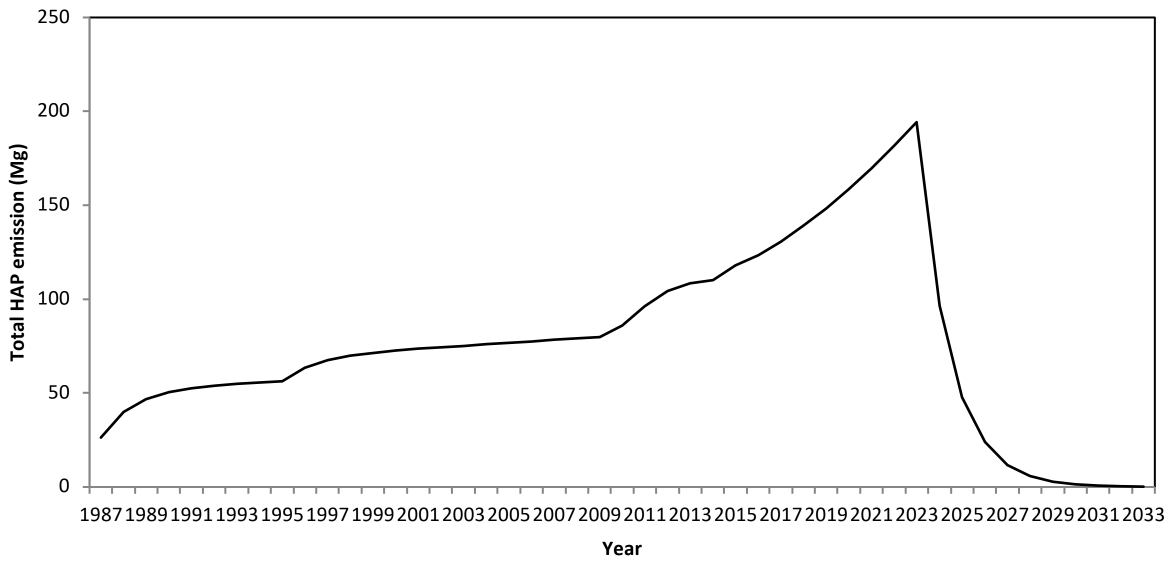


Figure 6. Total HAP emission (Mg) per year in Cerro Patacón.

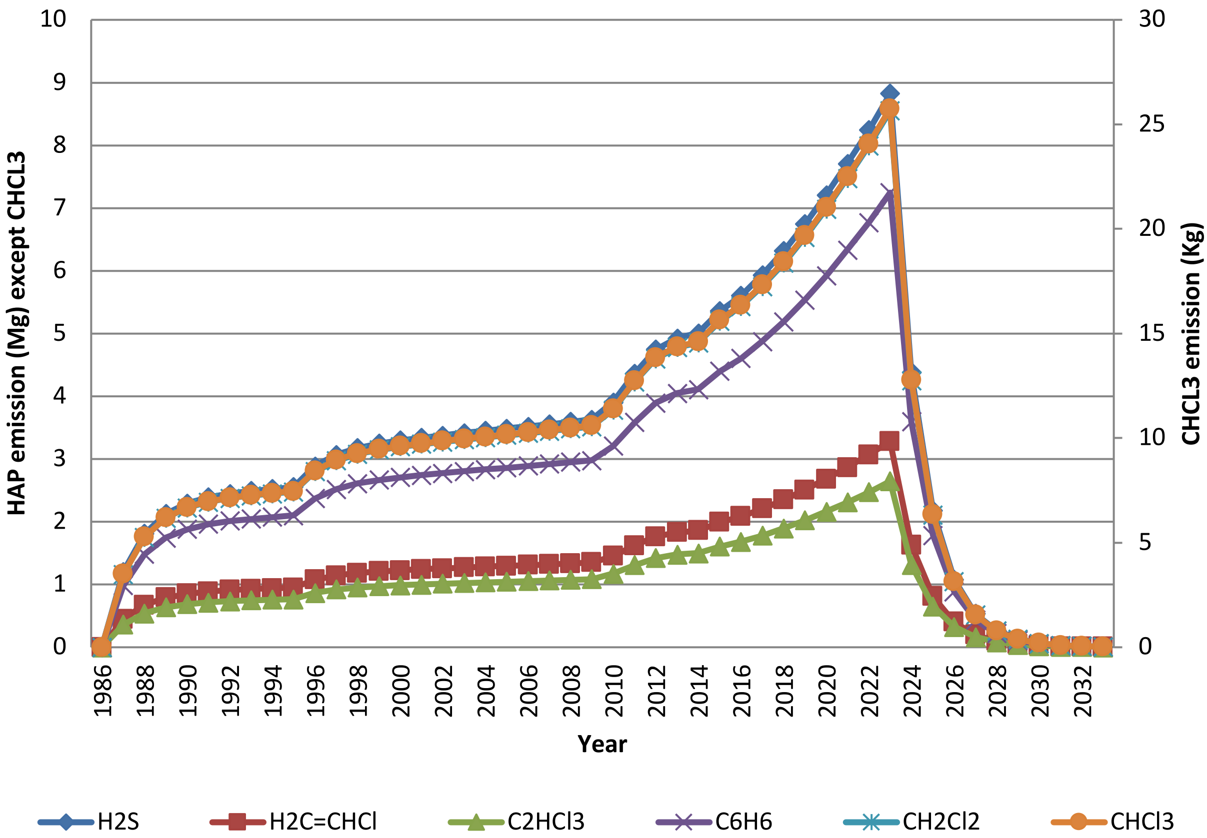


Figure 7. Emissions per year in Cerro Patacón for the six HAPs simulated for the period 1986-2032.

4.2.1.HAP concentrations

A total of 16 communities close to CP, with ~73,600 inhabitants, are affected by low-concentration, long-term HAP emissions (**Table 4**). Communities 1 and 2 are squatter settlements very close to CP, while community 3 is an old low-income rural community that was settled before CP came into existence. Communities 4–8 are recently settled middle-high income condos, while the remainder are older middle-income communities.

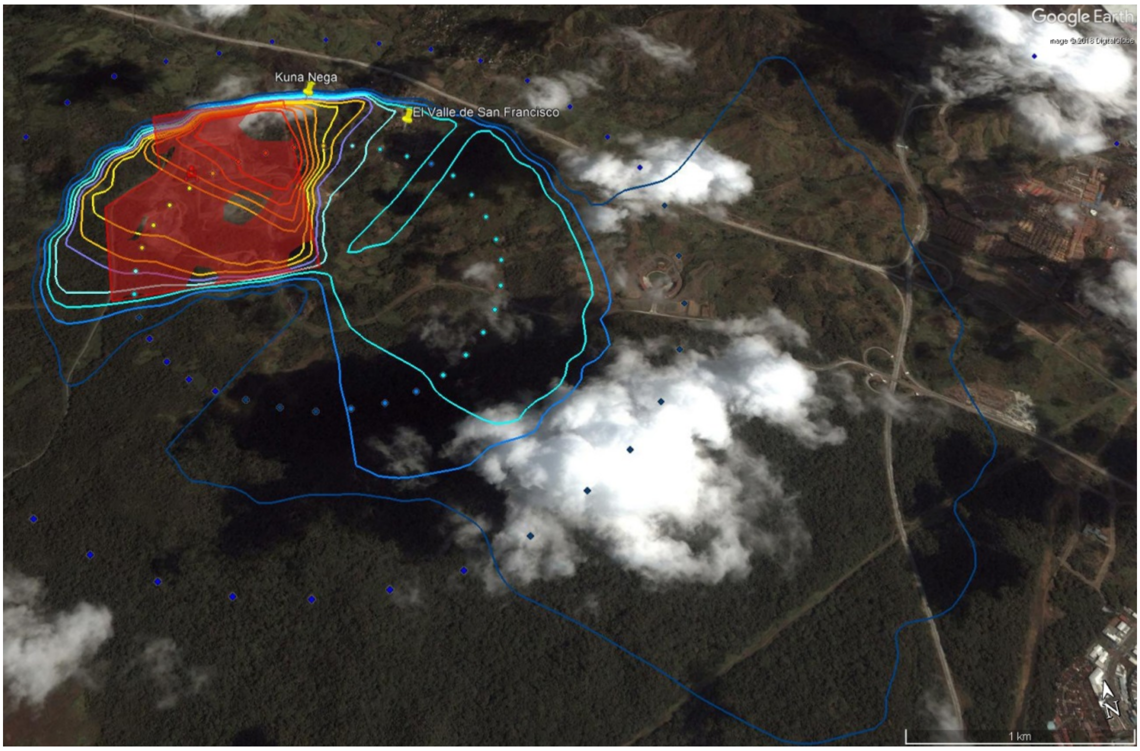
Table 4. Approximate population size of nearby communities, and their distance from Cerro Patacón (INEC, 2010)

#	Community	Population	Distance range (m)
1	Kuna Nega	2000	<250
2	Calle 50	100	<250
3	El Valle de San Francisco	3000	<250
4	P.H. Altamira Gardens	500	1000-2000
5	P.H. Las Huacas	500	2000-4000
6	P.H. 4 Horizontes	500	5000-7000
7	Paseo Dorado	500	2000-4000
8	Dorado Lakes	500	5000-7000
9	Carrasquilla	5000	5000-7000
10	La Loma	1000	5000-7000
11	El Ingenio	5000	5000-7000
12	Club X	5000	5000-7000
13	Betania	40000	5000-7000
14	Hato Pintado	5000	5000-7000
15	Panacasa	3000	5000-7000
16	Villa de las Fuentes 1	2000	5000-7000
	Total	*73600*	

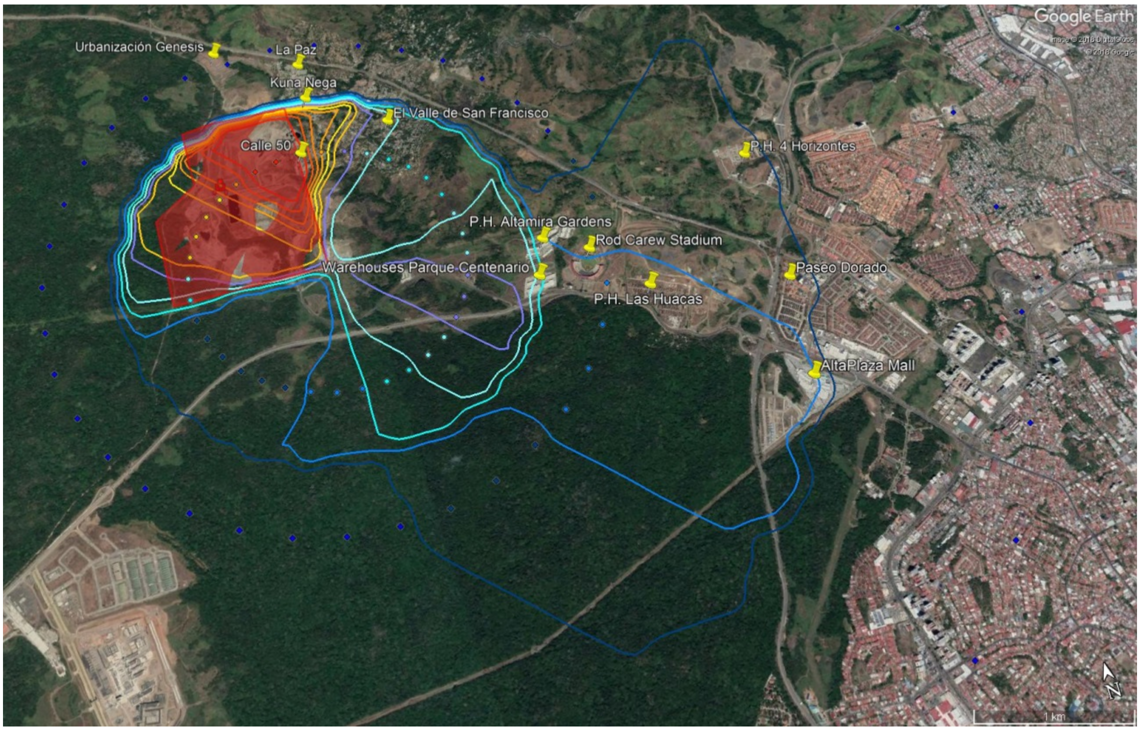
Table 5 show the concentration of the 6 HAPs studied in the 16 communities close to CP. Community numbering refers to **Table 4**.

Figure 8 shows simulations of the HAP atmospheric dispersion derived from CP (red spotted area) up to 10 km around for the years 2002, 2018 and 2022. HAP dispersion is shown from the highest to the lowest concentration according to average air direction patterns, where the orange pattern is the highest concentration and the blue one is the lowest.

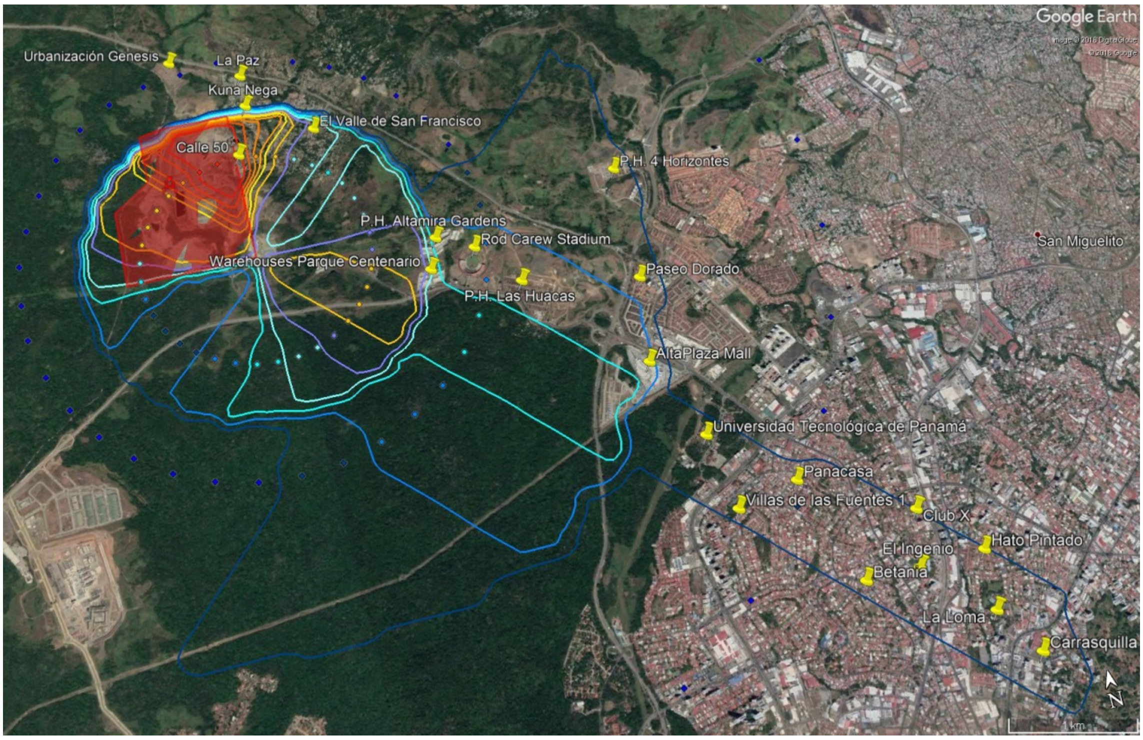
In 2002, the waste disposed of in CP emitted HAPs that affected communities 1 and 3 (these were the only communities existing at that time, **Table 5**), with HAP dispersion extending as far as 4 km from CP to the inhabited areas (**Figure 8a**). In 2018, there was a well-marked difference in population growth around this area (**Figure 8b**), and in this year the landfill produced HAPs emissions that dispersed within the same distance as in 2002; although the concentrations were higher in some of the earlier populated areas (**Table 5**). By 2022, HAP emissions may extend as far as 10 km from CP (**Figure 8c**), thus affecting many more communities (**Table 5**).



a)



b)



c)

Figure 8. AERMOD Dispersion patterns of HAP according to average local meteorological conditions for the years 2002 (a), 2018 (b), and 2022 (c).

The concentration of Hydrogen Sulfide in 2002 is consistent with the field measurement results from JICA (2003b) and is over the RfC (**Table 2**) for all communities and years simulated

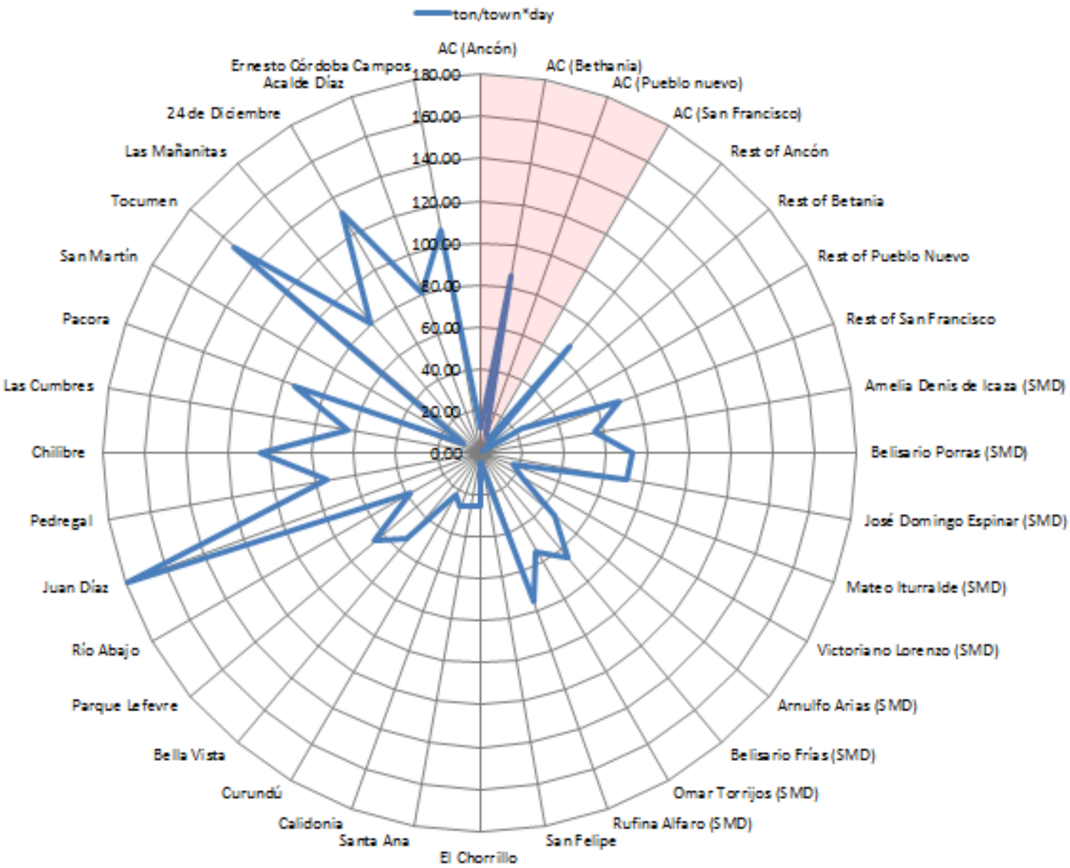
(**Table 5**). The concentration of Vinyl Chloride is over the RfC for all communities and years simulated, except for communities 5, 6, 7 and 8 to 16 by 2018. The concentration of Benzene is over the RfC for all communities and years simulated. The concentration of Dichloromethane is over the RfC for community 2 in 2018 and 2022. The concentration of Trichloroethene and Chloroform are under RfC for all communities and years simulated. Risk of falling over RfC values beyond 2022 for some HAPs increases with rapid population growth and unpredictable political decision-making that could postpone the closure of CP or continue its operation until the closure year planned under the original design (2037).

Table 5. HAP concentrations in communities close to CP per year [μg m^{-3}].

HAP	*Hydrogen Sulphide*	*Vinyl Chloride*	*Trichloroethene*	*Benzene*	*Dichloromethane*	*Chloroform*
Community #	*Concentrations*					
			2002			
1/3	**0.4129**	**0.1535**	0.1376	**0.3213**	0.4446	0.0134
			2018			
1/3	**0.5834**	**0.2169**	0.1749	**0.4086**	0.5655	0.0015
2	**0.7001**	**0.2603**	0.2099	**0.4903**	**0.6786**	0.0020
4	**0.2917**	**0.1085**	0.0875	**0.2043**	0.2827	0.0009
5/7	**0.1750**	0.0651	0.0525	**0.1226**	0.1696	0.0005
6/8-16	**0.1167**	0.0434	0.0350	**0.0817**	0.1131	0.0003
			2022			
1/3	**0.6114**	**0.2274**	0.1834	**0.4282**	0.5926	0.0018
2	**0.7337**	**0.2729**	0.2200	**0.5138**	**0.7112**	0.0021
4	**0.3057**	**0.1137**	0.0917	**0.2141**	0.2963	0.0009
5/7	**0.1834**	**0.6822**	0.0550	**0.1285**	0.1778	0.0005
6/8-16	**0.1223**	**0.4548**	0.0367	**0.0856**	0.1185	0.0004

4.2.2. Attribution of landfill emission rates to MSW generation by town and town exposure to dispersed HAPs.

Figure 9 shows the forecasted MSW generation from PD and SMD in 2022 and the corresponding HAPs emission rates from CP by town. Approximately 95% of the MSW expected to be generated by the 32 towns from PD and SMD (1.5 million inhabitants) in 2022 will exert environmental pressure on 16 communities belonging to 4 towns (73,600 inhabitants) of the PD through HAPs atmospheric dispersion. By weighing the HAPs emission rates with the expected MSW generated by town, it is observed that the highest emission rates are for Hydrogen Sulphide and Dichloromethane from the MSW generation of Juan Diaz and Tocúmen followed by Chilibre, Pacora, 24 de Diciembre and Ernesto Córdoba Campos. Within the affected communities, the HAP emission rates from the MSW generated by community 13 exert the highest EP.



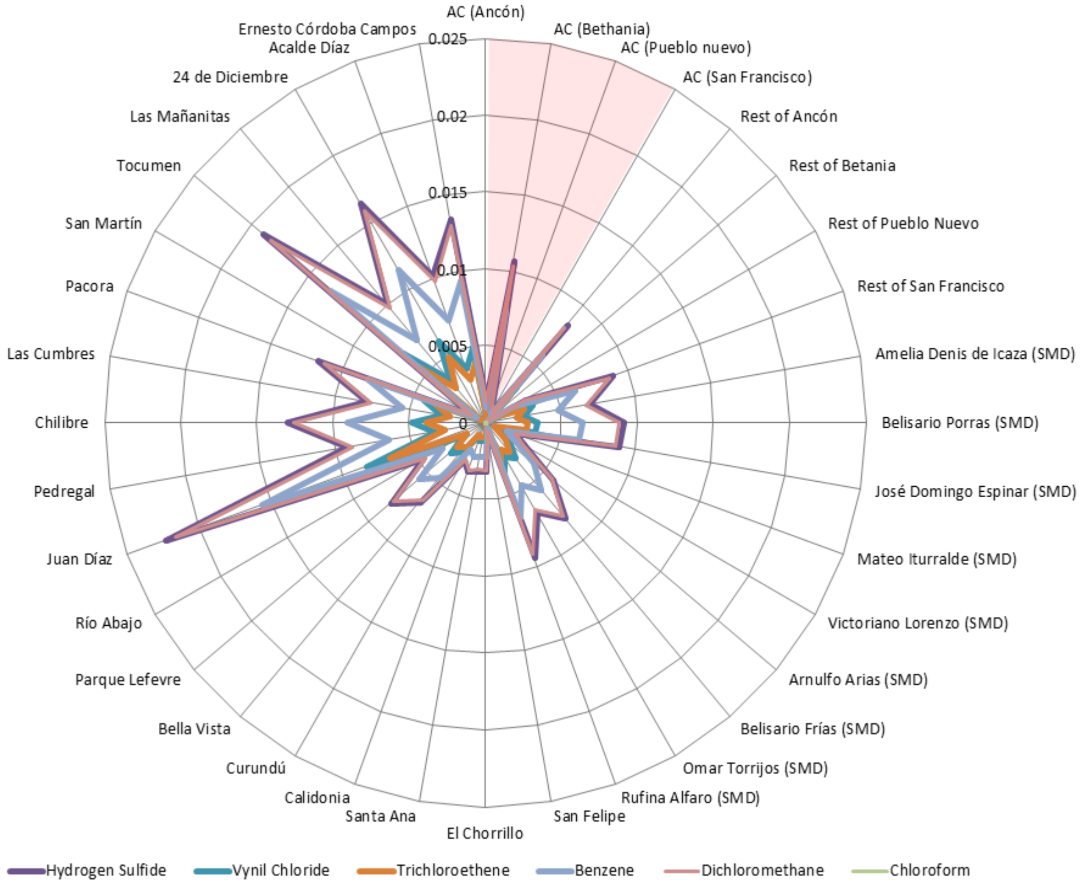


Figure 9. Expected MSW generation in 2022 (ton town^{-1} day^{-1}) (upper graph) and corresponding HAPs emission rates (g s^{-1}) from CP by Panama City towns. Towns marked with SMD in parenthesis belong to the San Miguelito District, all the others to the Panama District. The reddish zone marks communities (AC) closest to the landfill.

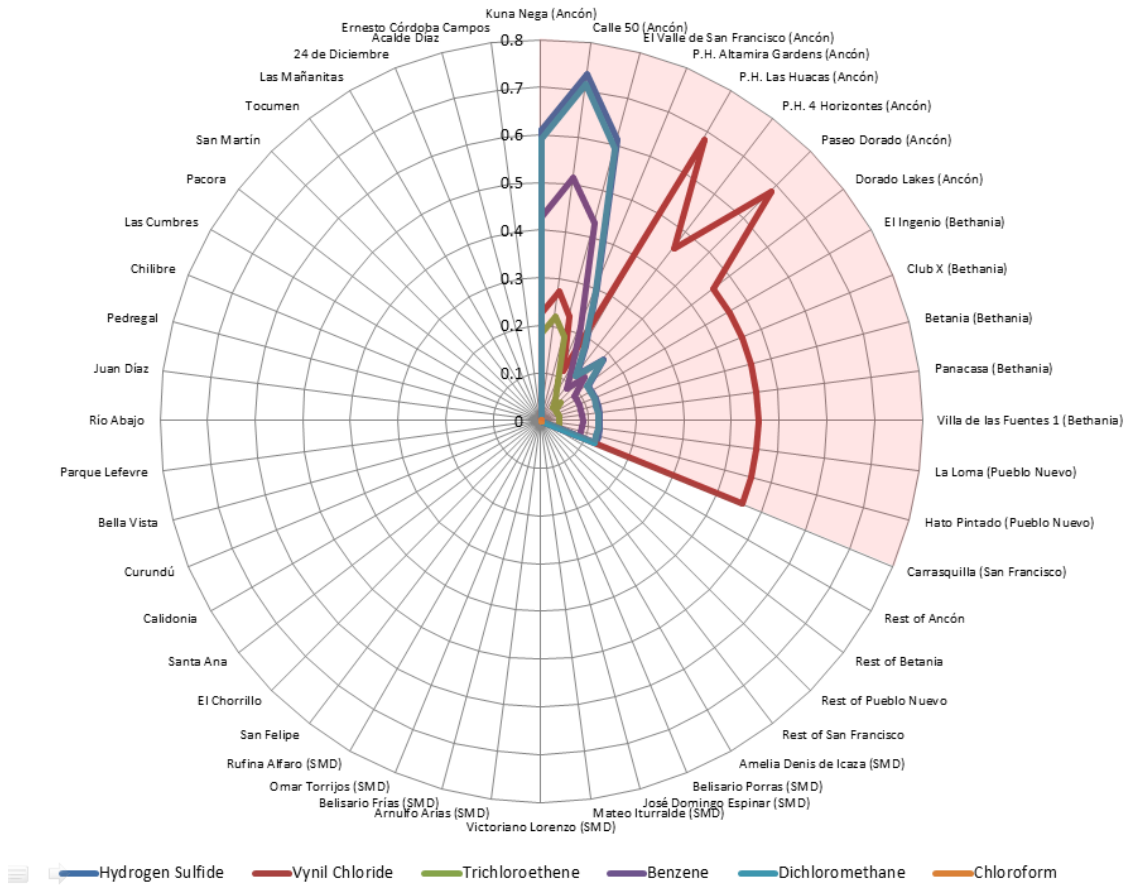


Figure 10. Expected community exposure to dispersed HAPs (in µg m^{-3}) (upper graph) in 2022. Only towns with an exposure exceeding the RF are shown. Towns with SMD in parenthesis belong to the SMD, all the others to the PD.

Figure 10 shows expected exposure to dispersed HAPs emitted from the landfill in 2022 for affected communities of the PD (HAPs concentration exceeding RfC). Community 2, located in the town Ancón, is subject to the highest environmental pressure from exposure to dispersed Hydrogen Sulphide and Dichloromethane, while the communities 5 and 7, located in the same town, are exposed to the highest concentration of Vinyl Chloride. The community 2 is also exposed to the highest concentration of Benzene.

5. Conclusions and recommendations

To reduce global environmental pressures, many DCs including Panama, ratified the Paris Agreement with an action plan based on a carbon pricing mechanism mostly applied to energy generation (Elkahwagy et al., 2017), but waste generation is often left aside because, contrary to energy, measurement mechanisms are rare. Climate change awareness is high but it works in a short life natural attention cycle difficult to engage with for long time because there are not sensible strategies for engagement (Spence et al., 2012). Taking actions on landfills will be necessary to reduce the global environmental pressures exerted.

People engage better with health than with environmental issues, this study presents quantitative results to relate societal impacts with global environmental impacts –e.g. Climate Change- through local environmental pressures –e.g. health hazards- as an alternative to raise awareness in population on the global harms their lifestyles contribute to. With the right engagement tools, awareness on the personal repercussion could contribute to long-term global environmental awareness.

It was found that CP will average a methane emission rate of ~47 Gg by 2022, thus generating ~45% of the total countrywide methane emissions. Waste generated by 1.5 million inhabitants directly impacts 73,600 inhabitants of the Panama district through the dispersion of HAPs derived from landfill. The highest emission rates were from Hydrogen Sulfide and Dichloromethane, allocated to the waste generated by the communities of Juan Diaz and Tocúmen. Calle 50, a squatter settlement nearby CP, bears the highest environmental pressure with the highest concentration of Hydrogen Sulphide and Dichloromethane; it also receives environmental pressures from the highest concentration of Benzene.

Landfill sites will become even more necessary during the coming years due to rapid urbanization in DCs. However, as an alternative to open dumping, restructuring entire waste management systems by introducing waste separated collection, treatment before final disposal, efficient waste transport logistic and better engineered landfills and their appropriate management are required to support healthy socio-economic growth (Bogner and Matthews, 2003).

Despite the fact that local environmental pressures and societal impacts derived are directly proportional to the waste generating society; the path to reliable waste management systems in DCs is a technical and political issue that hardly depends on the society but on the government Will to solve the issue. However, waste generation is it source; the part of the waste management system that society bear responsibility for.

Same way, landfills are the sink of waste management systems, perceived by society as the main cause of environmental pressures, whereas it is merely the source. Societal impacts-mitigating actions are likely to be ineffective if they only target the source of the environmental pressure, rather than its underlying cause.

Environmental justice (Martínez-Alier, 1997) is possible with information mechanisms in place for each inhabitant to acknowledge from their personal perspective the impacts they exert each other with their non-deliberate waste generation. Deep understanding of impacts each inhabitant receive will contribute to opening informed consultation spaces between society and government to foster a solution-oriented decision-making process on the waste management systems.

This study is limited to Panama City, more case studies will be necessary to explore the issue of societal impacts caused by environmental pressures produced in landfills of DCs. It is recommended further research on methods to quantify societal impacts produced by landfill surface fires and nearby infrastructure explosions due to the discrete occurrence of these events. Also, on societal impacts caused by leachate infiltration in groundwater since only communities close to surface water bodies will be affected and different approaches will be necessary. Further research is needed to understand societal impacts from landfills of DCs, not only from an environmental pressure standpoint but multidimensionally, where other criteria to assess societal impacts can be taken into account -e.g. economic, socio-political, cultural-.

This study lacks an uncertainty and sensitivity analysis to verify the quality of the results of the models used, this limitation could be approached in further studies by using only open models allowing variables to be manipulated and understanding their interactions. RfC values uncertainty factors present great variability as per source and reference update. This could affect the interpretation of results, especially when studies are based on models, like in this case. LFG direct field data collection and analysis is recommended in further studies to decrease result uncertainty and increase the reliability degree of the present study.

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References

AAUD, 2016a. 20170731 -E 1.6.4.10 -Reformulacion-ANEJOS [WWW Document]. URL http://gestionderesiduos.com.pa/EstudioAAUD/AAUD - 2016 - 20170731 -E 1.6.4.10 -Reformulacion-ANEJOS.pdf (accessed 9.1.19).

AAUD, 2016b. PLAN NACIONAL DE GESTIÓN INTEGRAL DE RESIDUOS 2017-2027 Análisis y Diagnóstico de la Situación Actual (TOMO I) [WWW Document]. URL http://aaud.gob.pa/plangestion//Docs/ANEXOS/20170731_E 1.3.3.3.5_Propuesta Nuevo Modelo de Gestion_v3.pdf (accessed 9.1.19).

ANAM, 2011. SEGUNDA COMUNICACIÓN NACIONAL: Ante la convención marco de las Naciones Unidas sobre el cambio climático [WWW Document]. URL https://unfccc.int/resource/docs/natc/pannc2.pdf (accessed 11.8.18).

ATSDR, 2004. Health Consultation: A Note of Explanation [WWW Document]. URL http://www.atsdr.cdc.gov (accessed 1.25.19).

Attenborough, G.M., Hall, D.H., Gregory, R.G., McGoochan, L., 2002. Development of a landfill gas risk assessment model: GasSim [WWW Document]. Twenty-Fifth Annu. Landfill Gas Symp. URL https://www.lqm.co.uk/uploads/general/files/GasSim SWANA 2002.pdf (accessed 1.25.19).

Aziz, H.A., Rahim, N.A., Ramli, S.F., Alazaiza, M.Y.D., Omar, F.M., Hung, Y.T., 2018. Potential use of Dimocarpus longan seeds as a flocculant in landfill leachate treatment. Water (Switzerland) 10. https://doi.org/10.3390/w10111672

Bentley, H., Smith, S., Schrauf, T., 2005. Baro-pneumatic estimation of landfill gas generation rates at four landfills in the southeastern United States [WWW Document]. Proc. from SWANA 28th Annu. Landfill Gas Symp. URL https://www.researchgate.net/publication/268398035

Blais, A., Ritch, E., Berlin, R., Clima, R., Glendening, J., Gutierrez, V., Izard, J., Mallow, C., Nelson, R., Swigert, P., 2010. Managing Trash in Colón , Panama : A Case Study of Selected Strategies A Report of the Panama Initiative [WWW Document]. URL https://panama.evsc.virginia.edu/docs/team_panama_report_100621.pdf

Bogner, J., Matthews, E., 2003. Global methane emissions from landfills: New methodology and annual estimates 1980-1996. Global Biogeochem. Cycles 17, n/a-n/a. https://doi.org/10.1029/2002GB001913

Caprile, M.D., Ripa, M., 2014. A Life Cycle Assessment of Landfilled Municipal Solid Waste in Argentina: The Influence of Waste Composition on Greenhouse Gases Emissions and Other Impacts. J. Environ. Account. Manag. 2, 145–162. https://doi.org/10.5890/JEAM.2014.06.005

CEPAL, 2009. PANAMÁ. Evolución Económica durante 2008 y perspectiva para 2009 [WWW Document]. URL https://repositorio.cepal.org/bitstream/handle/11362/25885/1/LCmexL916_es.pdf (accessed 1.24.19).

Chandler, J.A., Jewell, W.J., 1980. Predicting methane fermentation biodegradability. Final report [WWW Document]. Biotechnol. Bioeng. Symp. No. 10. URL https://www.osti.gov/biblio/6810537-predicting-methane-fermentation-biodegradability (accessed 1.25.19).

Cheng, F.Y., Georgakakos, K.P., 2011. Wind speed interpolation in the vicinity of the Panama Canal. Meteorol. Appl. 18, 459–466. https://doi.org/10.1002/met.237

Chifari, R., Lo Piano, S., Bukkens, S.G.F., Giampietro, M., 2016. A holistic framework for the integrated assessment of urban waste management systems. Ecol. Indic. https://doi.org/10.1016/j.ecolind.2016.03.006

Coleman, G., Kalish, I., Konigsburg, D., 2014. Competitiveness: Catching the next wave Panama [WWW Document]. Deloitte. URL https://www2.deloitte.com/content/dam/Deloitte/global/Documents/About-Deloitte/gx-panama-competitiveness-report-08042014.pdf (accessed 1.20.19).

Dankovic, D.A., Naumann, B.D., Maier, A., Dourson, M.L., Levy, L.S., 2015. The Scientific Basis of Uncertainty Factors Used in Setting Occupational Exposure Limits. J. Occup. Environ. Hyg. 12, S55–S68. https://doi.org/10.1080/15459624.2015.1060325

DEFRA, 2010. Waste acceptance at landfills: Guidance on waste acceptance procedures and criteria [WWW Document]. URL www.environment-agency.gov.uk (accessed 9.26.18).

Dennehy, C., Lawlor, P.G., Jiang, Y., Gardiner, G.E., Xie, S., Nghiem, L.D., Zhan, X., 2017. Greenhouse gas emissions from different pig manure management techniques: a critical analysis. Front. Environ. Sci. Eng. https://doi.org/10.1007/s11783-017-0942-6

El-Fadel, M., Findikakis, A.N., Leckie, J.O., 1989. A numerical model for methane production in managed sanitary landfills. Waste Manag. Res. 7, 31–42. https://doi.org/10.1177/0734242X8900700105

Elkahwagy, R., Gyanchandani, V., Piselli, D., 2017. UNFCCC Nationally Determined Contributions: Climate Change and Trade, SSRN. https://doi.org/10.2139/ssrn.2919692

Elliott, P., Morris, S., Briggs, D., Hoogh, C. De, Hurt, C., Jensen, T.K., Maitland, I., Lewin, A., Richardson, S., Wakefield, J., Lars, J., 2001. Birth outcomes and selected cancers in populations living near landfill sites [WWW Document]. URL https://cot.food.gov.uk/sites/default/files/cot/dhlandfillaug01.pdf (accessed 1.28.19).

Faour, A.A., Reinhart, D.R., You, H., 2007. First-order kinetic gas generation model parameters for wet landfills. Waste Manag. 27, 946–953. https://doi.org/10.1016/j.wasman.2006.05.007

Farquhar, G.J., Rovers, F.A., 1973. Gas production during refuse decomposition. Water, Air, Soil Pollut. 2, 483–495. https://doi.org/10.1007/BF00585092

Frischknecht, R., Editors, N.J., Althaus, H.-J., Bauer, C., Doka, G., Dones, R., Hischier, R., Hellweg, S., Köllner, T., Loerincik, Y., Margni, M., 2007. Implementation of Life Cycle Impact Assessment Methods [WWW Document]. Am. Midl. Nat. URL www.ecoinvent.org

GALLUP, 2014. Country Well-Being Varies Greatly Worldwide [WWW Document]. URL https://news.gallup.com/poll/175694/country-varies-greatly-worldwide.aspx (accessed 2.1.19).

Gioia, F., Murena, F., Savino, G., Saha, P., 1995. The release into the atmosphere of hazardous volatiles Part I. Release from porous solids imbued with a liquid mixture in which the volatiles are dissolved. J. Hazard. Mater. 40, 213–235. https://doi.org/10.1016/0304-3894(94)00083-S

Golder Associates, 2012. GasSim 2.5 User Manual [WWW Document]. URL http://www.gassim.co.uk/documents/GasSim User Manual v2.5.8.pdf (accessed 9.26.18).

Goopy, J.P., Onyango, A.A., Dickhoefer, U., Butterbach-Bahl, K., 2018. A new approach for improving emission factors for enteric methane emissions of cattle in smallholder systems of East Africa – Results for Nyando, Western Kenya. Agric. Syst. 161, 72–80. https://doi.org/10.1016/j.agsy.2017.12.004

Hamza, V., Muñoz, M., 1996. Heat flow map of South America [WWW Document]. Geothermics. URL https://www.researchgate.net/profile/Miguel_Munoz19/publication/222894266_Heat_Flow_Map_of_South_America/links/5a07c7ebaca272ed279e6731/Heat-Flow-Map-of-South-America.pdf (accessed 11.21.18).

Hidromet, 2017. Viento - Hidrometeorología de ETESA [WWW Document]. URL http://www.hidromet.com.pa/viento.php (accessed 1.28.19).

Hidromet, 2002. Mapa_Frecuencia_Direccion_Viento_Panama [WWW Document]. URL http://www.hidromet.com.pa/Mapas/Mapa_Frecuencia_Direccion_Viento_Panama.pdf (accessed 1.28.19).

Hoornweg, D., Bhada, P., 2012. What a Waste. A Global Review of Solid Waste Management. Urban Dev. Ser. Knowl. Pap. 281, 44 p. https://doi.org/10.1111/febs.13058

INEC, 2014a. Cuadro 312-04. Total de reses, promedio de reses por hectarea y pastos en la República, según provincia y comarca indígena: Septiembre de 2014 [WWW Document]. URL https://www.contraloria.gob.pa/inec/archivos/P6701312-04.pdf (accessed 1.20.19).

INEC, 2014b. Cuadro 312-07. Existencia de ganao porcino en la República por actividad, según provincia y comarca indígena: año 2014 [WWW Document]. URL https://www.contraloria.gob.pa/inec/archivos/P6701312-07.pdf (accessed 1.20.19).

INEC, 2010. Población en el Distrito de Panamá, por sexo, según corregimiento y grupos de edad: Censo 2010 [WWW Document]. URL https://www.contraloria.gob.pa/inec/Publicaciones/Publicaciones.aspx?ID_SUBCATEGORIA=59&ID_PUBLICACION=362&ID_IDIOMA=1&ID_CATEGORIA=13 (accessed 1.8.18).

INEC, 2008. Comentarios sobre la economía panameña: año 2008 [WWW Document]. URL https://www.contraloria.gob.pa/inec/archivos/P4511COMENTARIO.pdf (accessed 1.24.19).

INEC, 2000. Volumen I: Lugares Poblados: Año 2000 [WWW Document]. 1. URL https://www.contraloria.gob.pa/inec/Publicaciones/Publicaciones.aspx?ID_SUBCATEGOR

IA=53&ID_PUBLICACION=542&ID_IDIOMA=1&ID_CATEGORIA=9 (accessed 3.6.19).

INECO, 2017. Plan Nacional de gestión integral de residuos 2017 - 2027 [WWW Document]. URL http://aaud.gob.pa/plangestion//Docs/ANEXOS/20170731_E 1.3.3.3.5_Propuesta Nuevo Modelo de Gestion_v3.pdf (accessed 4.29.18).

IPCC, 2006a. 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Solid Waste Disposal [WWW Document]. URL https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf (accessed 11.8.18).

IPCC, 2006b. Good practice guidance and uncertainty management in national greenhouse inventories -waste [WWW Document]. URL https://www.ipcc-nggip.iges.or.jp/public/gp/english/5_Waste.pdf (accessed 1.26.19).

Islam, M.R., Haniu, H., Fardoushi, J., 2009. Pyrolysis kinetics behavior of solid tire wastes available in Bangladesh. Waste Manag. https://doi.org/10.1016/j.wasman.2008.04.009

JICA, 2003. Evaluación de Impacto Ambiental del Sistema de Disposición Final [WWW Document]. URL http://open_jicareport.jica.go.jp/pdf/11712841_01.pdf

JICA, 2002. Characteristics of Solid Waste Problems in Developing Countries [WWW Document]. Support. Capacit. Dev. Solid Waste Manag. Dev. Ctries. URL https://www.jica.go.jp/jica-ri/IFIC_and_JBICI-Studies/english/publications/reports/study/topical/waste/pdf/waste_02.pdf (accessed 6.21.18).

Kanabkaew, T., Rakmak, N., Choosaeng, S., 2014. Assessment of Hydrogen Sulfide Dispersion from Dumpsite Using AERMOD Modeling System. Adv. Mater. Res. 931–932, 650–654. https://doi.org/10.4028/www.scientific.net/AMR.931-932.650

Kinnaman, T.C., 2009. The economics of municipal solid waste management. Waste Manag. 29, 2615–2617. https://doi.org/10.1016/j.wasman.2009.06.031

Kjeldsen, P., 1996. Landfill gas migration in soil. Chapter 3.1 [WWW Document]. Landfilling of waste: Biogas. URL http://orbit.dtu.dk/en/publications/landfill-gas-migration-in-soil(7f5b6676-c9a8-42c7-9eaf-29236ec35dd2)/export.html (accessed 1.20.19).

Krause, M.J., Chickering, G.W., Townsend, T.G., 2016. Translating landfill methane generation parameters among first-order decay models. J. Air Waste Manag. Assoc. 66, 1084–1097. https://doi.org/10.1080/10962247.2016.1200158

La Prensa, 2013. AAUD: El peor incendio en 10 años en Cerro Patacón [WWW Document]. URL https://www.prensa.com/manuel_vega_loo/AAUD-peor-incendio-Cerro-Patacon_2_3619158050.html (accessed 12.17.18).

Lewis, J.M. (National S.S.L., 1995. The Story behind the Bowen Ratio. Bull. Am. Meteorol. Soc. 76, 2433–2443. https://doi.org/10.1175/1520-0477(1995)076<2433:TSBTBR>2.0.CO;2

Ludwig, V., 2007. User's Manual Central America Landfill Gas Model [WWW Document]. URL https://www.globalmethane.org/documents/models/pdfs/UsersManualCentralAmerica_LFG_model_final_English_REV1.pdf (accessed 9.30.18).

Machado, S.L., Carvalho, M.F., Gourc, J.P., Vilar, O.M., do Nascimento, J.C.F., 2009. Methane generation in tropical landfills: Simplified methods and field results. Waste Manag. 29, 153–161. https://doi.org/10.1016/j.wasman.2008.02.017

Majdinasab, A., Zhang, Z., Yuan, Q., 2017. Modelling of landfill gas generation: a review. Rev. Environ. Sci. Biotechnol. https://doi.org/10.1007/s11157-017-9425-2

Martínez-Alier, J., 1997. Environmental justice (local and global). Capital. Nature, Social. 8, 91–109. https://doi.org/10.1080/10455759709358725

McEvoy, A.J. (Augustin J., Markvart, T., Castañer, L., 2012. Practical handbook of photovoltaics : fundamentals and applications [WWW Document]. URL https://www.elsevier.com/books/practical-handbook-of-photovoltaics/mcevoy/978-0-12-385934-1 (accessed 1.28.19).

Mou, Z., Kjeldsen, P., Scheutz, C., 2014. Landfill gas generation and emission at Danish waste disposal sites receiving low-organic waste [WWW Document]. DTU Environ. URL http://orbit.dtu.dk/files/100551929/Zishen_Mou_PhD_Thesis_WWW_Version.pdf (accessed 11.16.18).

Mou, Z., Scheutz, C., Kjeldsen, P., 2015. Evaluation and application of site-specific data to revise the first-order decay model for estimating landfill gas generation and emissions at Danish landfills. J. Air Waste Manag. Assoc. 65, 686–698. https://doi.org/10.1080/10962247.2015.1008653

NITE, 2017. Risk Assessment on chemicals-For Better Understanding-5 | Chemical Management | National Institute of Technology and Evaluation (NITE) [WWW Document]. URL https://www.nite.go.jp/en/chem/shiryo/ra/about_ra7.html (accessed

11.23.19).

OECD, 2008. Key environmental indicators, OECD Environment Directorate. https://doi.org/10.2110/pec.72.02.0001

Oonk, H., 2010. Literature review: methane from landfills methods to quantify generation, oxidation and emission. Final report [WWW Document]. URL www.oonkay.nl (accessed 1.25.19).

Oonk, H., 1994. Validation of landfill gas formation models [WWW Document]. URL https://www.rvo.nl/sites/default/files/2013/10/Oonk 1994 %28EN%29 Validation of landfill gas formation models.pdf (accessed 1.25.19).

Pan, S.Y., Du, M.A., Huang, I. Te, Liu, I.H., Chang, E.E., Chiang, P.C., 2014. Strategies on implementation of waste-to-energy (WTE) supply chain for circular economy system: A review. J. Clean. Prod. 108. https://doi.org/10.1016/j.jclepro.2015.06.124

Paraskaki, I., Lazaridis, M., 2005. Quantification of landfill emissions to air: A case study of the Ano Liosia landfill site in the greater Athens area. Waste Manag. Res. 23, 199–208. https://doi.org/10.1177/0734242X05054756

Peer, R.L., Epperson, D.L., Campbell, D.L., Brook, P. Von, 1992. Development of an Empirical Model of Methane Emissions from Landfills [WWW Document]. URL https://cfpub.epa.gov/si/si_public_record_Report.cfm?Lab=NRMRL&dirEntryID=126308 (accessed 1.25.19).

Pennington, D.G., 1996. Effects of Waste Tires, Waste Tire Facilities, and Waste Tire Projects on The Environment [WWW Document]. URL www.ciwmb.cagov

Philippe, F.X., Nicks, B., 2015. Review on greenhouse gas emissions from pig houses: Production of carbon dioxide, methane and nitrous oxide by animals and manure. Agric. Ecosyst. Environ. 199, 10–25. https://doi.org/10.1016/j.agee.2014.08.015

Pino, D., de Arellano, J.V.G., Kim, S.W., 2006. Representing sheared convective boundary layer by zeroth- and first-order-jump mixed-layer models: Large-eddy simulation verification. J. Appl. Meteorol. Climatol. 45, 1224–1243. https://doi.org/10.1175/JAM2396.1

Pipatti, R., Svardal, P., Wagner Silva Alves, J., Gao, Q., López Cabrera, C., Mareckova, K., Oonk, H., Scheehle, E., Sharma, C., Smith, A., Yamada, M., 2006. IPCC Guidelines for National Greenhouse Gas Inventories [WWW Document]. URL https://www.ipcc-nggip.iges.or.jp/SBSTA24/sb24_2006GL_waste_6.ppt

Plocoste, T., Jacoby-Koaly, S., Petit, R.-H., Roussas, A., 2016. Estimation of Methane Emission from a Waste Dome in a Tropical Insular Area. Int. J. Waste Resour. 6. https://doi.org/10.4172/2252-5211.1000211

Poulsen, T., Christophersen, M., Moldrup, P., Kjeldsen, P., 2003. Relating landfill gas emissions to atmospheric pressure using numerical modelling and state-space analysis [WWW Document]. URL http://journals.sagepub.com/doi/pdf/10.1177/0734242X0302100408 (accessed 9.20.18).

Poulsen, T.G., Christophersen, M., Moldrup, P., Kjeldsen, P., 2001. MODELING LATERAL GAS TRANSPORT IN SOIL ADJACENT TO OLD LANDFILL. J. Environ. Eng. 127, 145–153. https://doi.org/doi:10.1061/(ASCE)0733-9372(2001)127:2(145)

Powell, J.T., Townsend, T.G., Zimmerman, J.B., 2016. Estimates of solid waste disposal rates and reduction targets for landfill gas emissions. Nat. Clim. Chang. 6, 162–165. https://doi.org/10.1038/nclimate2804

Powrie, W., White, J., 2004. Landfill process modelling, in: Waste Management. pp. 225–226. https://doi.org/10.1016/j.wasman.2004.02.001

Rigamonti, L., Sterpi, I., Grosso, M., 2016. Integrated municipal waste management systems: An indicator to assess their environmental and economic sustainability. Ecol. Indic. 60, 1–7. https://doi.org/10.1016/j.ecolind.2015.06.022

Roudi, A.M., Chelliapan, S., Mohtar, W.H.M.W., Kamyab, H., 2018. Prediction and optimization of the Fenton process for the treatment of landfill leachate using an artificial neural network. Water (Switzerland) 10. https://doi.org/10.3390/w10050595

Saral, A., Demir, S., Yildiz, Ş., 2009. Assessment of odorous VOCs released from a main MSW landfill site in Istanbul-Turkey via a modelling approach. J. Hazard. Mater. 168, 338–345. https://doi.org/10.1016/j.jhazmat.2009.02.043

Sarptaş, H., 2016. Assessment of Landfill Gas (Lfg) Energy Potential Based on Estimates of Lfg Models. Deu Muhendis. Fak. Fen ve Muhendis. 18, 491–491. https://doi.org/10.21205/deufmd.2016185416

Scharff, H., Jacobs, J., 2006. Applying guidance for methane emission estimation for landfills, in: Waste Management. pp. 417–429. https://doi.org/10.1016/j.wasman.2005.11.015

Spence, A., Poortinga, W., Pidgeon, N., 2012. The Psychological Distance of Climate Change. Risk Anal. 32, 957–972. https://doi.org/10.1111/j.1539-6924.2011.01695.x

SWANA, 1997. Comparison of models for predicting landfill methane recovery [WWW Document]. URL https://www.nrel.gov/docs/legosti/fy97/26041.pdf (accessed 11.12.18).

Tabasaran, O., Rettenberger, G., 1987. Grundlage zur Planung von Entgasungsanlagen [WWW Document]. Müllhandbuch. URL http://wirtschaftsrechtdigital.info/_sid/ZHHL-524258-3Lrx/978-3-503-11666-9 (accessed 9.26.18).

The World Bank, 2018. New country classifications by income level: 2018-2019 | The Data Blog [WWW Document]. URL https://blogs.worldbank.org/opendata/new-country-classifications-income-level-2018-2019 (accessed 7.9.18).

US EPA, 2018. User's Guide for the AMS/EPA Regulatory Model (AERMOD) [WWW Document]. URL https://www3.epa.gov/ttn/scram/models/aermod/aermod_userguide.pdf (accessed 10.7.18).

US EPA, 2011. Integrated Risk Information System (IRIS) Glossary [WWW Document]. URL https://ofmpub.epa.gov/sor_internet/registry/termreg/searchandretrieve/glossariesandkeywordlists/search.do?details=&glossaryName=IRIS Glossary (accessed 1.24.19).

US EPA, 2010. Methane and Nitrous Oxide Emissions From Natural Sources [WWW Document]. URL http://www.epa.gov/methane/sources.html (accessed 9.26.18).

US EPA, 2008. Background Information Document for Updating AP42 Section 2.4 for Estimating Emissions from Municipal Solid Waste Landfills [WWW Document]. URL https://www3.epa.gov/ttn/chief/ap42/ch02/draft/db02s04.pdf (accessed 9.26.18).

US EPA, 2006a. Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks [WWW Document]. URL https://nepis.epa.gov (accessed 1.24.19).

US EPA, 2006b. AP 42, Fifth Edition, Volume I - Chapter 2 Solid Waste Disposal (2-4 Municipal Solid Waste Landfills) DRAFT [WWW Document]. URL https://www3.epa.gov/ttn/chief/ap42/ch02/draft/d02s04.pdf (accessed 1.24.19).

US EPA, 2005. US EPA First-Order Kinetic Gas Generation Model Parameters for Wet Landfills [WWW Document]. URL https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100ADRJ.TXT (accessed 9.26.18).

US EPA, 2003. Toxicological Review of Hydrogen Sulfide [WWW Document]. EPA/635/R-03/005. URL www.epa.gov/iris (accessed 12.11.18).

US EPA, 2002. U.S. Greenhouse Gas Emissioms and Sinks, 1990-2016 [WWW Document]. EPA 430-R-18-003. URL https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks (accessed 1.20.19).

US EPA, 2001. Volume III: Chapter 15. LANDFILLS Revised Final [WWW Document]. URL https://www.epa.gov/sites/production/files/2015-08/documents/iii15_apr2001.pdf (accessed 1.25.19).

US EPA, 2000. Chloroform [WWW Document]. URL https://www.epa.gov/sites/production/files/2016-09/documents/chloroform.pdf (accessed 12.11.18).

US EPA, 1995. 2.4 Municipal Solid Waste Landfills [WWW Document]. Compil. Air Pollut. Emiss. Factors AP-42. URL http://www.epa.gov/ttn/chief (accessed 1.24.19).

US EPA, 1991. Dichloromethane; CASRN 75-09-2 [WWW Document]. URL https://cfpub.epa.gov/ncea/iris/iris_documents/documents/subst/0070_summary.pdf#nameddest=rfc (accessed 11.23.19).

Weichenthal, S., Van Rijswijk, D., Kulka, R., You, H., Van Ryswyk, K., Willey, J., Dugandzic, R., Sutcliffe, R., Moulton, J., Baike, M., White, L., Charland, J.P., Jessiman, B., 2015. The impact of a landfill fire on ambient air quality in the north: A case study in Iqaluit, Canada. Environ. Res. 142, 46–50. https://doi.org/10.1016/j.envres.2015.06.018

Weitz, M., Coburn, J.B., Salinas, E., 2008. Estimating national landfill methane emissions: An application of the 2006 Intergovernmental Panel on Climate Change Waste Model in Panama. J. Air Waste Manag. Assoc. 58, 636–640. https://doi.org/10.3155/1047-3289.58.5.636

Wilson, D.C., Rodic, L., Scheinberg, A., Velis, C.A., Alabaster, G., 2012. Comparative analysis of solid waste management in 20 cities. Waste Manag. Res. 30, 237–254. https://doi.org/10.1177/0734242X12437569

WMO, 2001. International current condition weather stations [WWW Document]. URL https://www.wunderground.com/about/faq/international_cities.asp (accessed 1.28.19).

Zacharof, A.I., Butler, A.P., 2004. Stochastic modelling of landfill processes incorporating waste heterogeneity and data uncertainty, in: Waste Management. pp. 241–250. https://doi.org/10.1016/j.wasman.2003.12.001

Ziout, A., Azab, A., Atwan, M., 2014. A holistic approach for decision on selection of end-of-life products recovery options. J. Clean. Prod. 65, 497–516. https://doi.org/10.1016/j.jclepro.2013.10.001

6.4 Paper #4 - "Robust information for effective municipal solid waste policies: Identifying behavior of waste generation across spatial levels of organization"

Robust information for effective municipal solid waste policies: identifying behaviour of waste generation across spatial levels of organization

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Abstract

Existing studies have studied influencing factors of MSW generation behaviour at different spatial levels of organization, but always one at a time and not simultaneously. Income is a strong influencing factor, affecting MSW generation from the individual to the country level, capable of hiding the effects of the others. This study shows that when MSW generation behaviour is holistically analysed across multiple levels of organization (individuals, households, and communities) hierarchically organized as functional units of MSW generation within a specific study area, it is possible to identify influencing factors in addition to income (education, demographic, health, ethnic, economic activity and financial types) as explanatory variables. Increasing the number of influencing factors of MSW generation makes it possible to create a robust knowledge base for MSW management policies in fast-growing urban areas of developing countries, improving the information used to select proper policies and plans within their MSW management systems and avoiding overlapping policies causing legal gaps. Betania, an urban area of the Panama City district, has been chosen as a case study area. The results show that the household income explains 86% of its members´ MSW generation and the community indigenous population explains 21% of households´ MSW generation. It is concluded that MSW generation is not linear across levels, it has as many degrees of freedom as influencing factors shaping the levels of organization where functional units generating waste exist. Influencing factors appearing at each spatial level affects MSW generation in an interdependent manner in variable degrees of magnitude.

Keywords

Municipal solid waste generation; Multi-scale analysis; Influencing factors; Waste policies developing countries; Panama district.

Highlights

- Sudden changes in MSW generations behaviours are common to developing countries.
- Determined by social practices at multiple hierarchical spatial levels of organization.
- Different influencing factors of MSW generation behaviour appear at each level.
- Income is mostly the main influencing factor of MSW generation behaviour.
- Most studies conclude this from analyzing this link one spatial level at a time.
- Simultaneous analysis can reveal influencing factors others than income.

1. Introduction

Municipal Solid Waste (MSW) management is a major concern in developing countries experiencing uncontrolled rapid growth of urban areas (Zohoori and Ghani, 2017). Economic development in these countries is expected to further exacerbate the already high pressure on the MSW management system through increased consumption (and concomitant waste generation) and a change in waste composition (Adamović et al., 2017). Marked spatial heterogeneity in the socio-economic characteristics of urban dwellers presents further challenges as the disparity in income level and expenditure results in different behaviours of MSW generation -i.e., quantity and quality of waste outflows- and, hence, places spatially differentiated requirements on the MSW management system to implement.

Proper governance plays an important role in the MSW management system (Leal Filho et al., 2016) and requires a careful integration of physical/technological components (the “hardware”) with effective mechanisms of monitoring and control (the “software”) (Seadon, 2010). In developing countries, several public agencies, from the central to municipal governments, are involved in waste management. Their functions often overlap because they are unclear; there is no single agency designated to coordinate or assume responsibility for MSW management (Manaf et al., 2009; Periathamby et al., 2009). This has led to weak implementation and enforcement of laws and regulations of MSW management (Meidiana and Gamse, 2010) and hinders effective waste management planning (Mmereki, 2018). In general, at a given level of technology, it is the lack of pro-active policies, not considering the multiple factors influencing MSW generation, that most negatively affects the final performance of MSW management systems (Wilson et al., 2012).

In fact, understanding information on influencing factors of MSW generation is important for two reasons. Firstly, to create policies aimed at changing the materials´ resource consumption habits and MSW generation behaviour of urban dwellers in order to reduce the quantity of waste generated and enable the implementation of source-separated MSW collection to improve the quality of the waste received by the MSW management system (Liu and Wu, 2010). Secondly, to properly plan, develop and organize the processes and the infrastructures associated with an efficient MSW management, such as waste collection frequencies, human and technological resources, payment rates and treatment facilities (Cargo, 1978; Wertz, 1976).

Mazzanti and Zoboli (2008) point out that it is important not to wait to implement waste generation reduction policies until consumption levels and resulting MSW generation — both in quantity and quality— arrive at a point where they overwhelm the capacity of local MSW management systems. Hence there is an urgent need to benchmark the experiences of developing countries in MSW management and take adequate actions studying the influencing factors of MSW generation (Leal Filho et al., 2016; Wilson et al., 2015; Zaman et al., 2016) to anticipate future troubles, implement effective policies and plan for due processes and infrastructures. This requires the availability of useful data for characterizing relevant aspects of the process to be controlled.

Influencing factors, such as income, education, sociodemographic characteristics, health, ethnicity, and religion are widely used to correlate MSW generation behaviour and to try to anticipate future states of the MSW management system (Bandara et al., 2007; Barr, 2007; Matsumoto, 2011; Mohammed, 2018). However, results obtained are mostly biased because of the adoption of only one hierarchical level of analysis of the socio-economic organization -i.e., individual, household, community, town, district, province, country, etc.-; mostly the individual level (Hoornweg and Bhada, 2012), and per capita MSW generation average values are simply aggregated to obtain MSW generation figures at other hierarchical levels (Kawai and Tasaki, 2016). The lack of waste studies supporting updated data collection in developing countries, forces: (i) correlation results obtained at the individual level to be used at other levels without considering MSW generation behaviour constraints; and (ii) misconceived policies and technological improvements applied to hierarchical levels, others than the individual level for which correlations were obtained, thus misspending human, technical and economic resources.

Given the complexity of urban systems and the heterogeneity of cultural, economic and geographic contexts, an effective analysis of the influencing factors affecting the behaviour of MSW generation is challenging (Mazzanti and Zoboli, 2008). An assessment of the effects of an influencing factor studied at a specific hierarchical level of socio-economic organization cannot provide a useful description of the overall performance of complex MSW management systems (Seadon, 2010). Proper governance requires the analysis of an integrated set of criteria of performance. The study of influencing factors can only fulfil its purpose when it is simultaneously carried out at different spatial levels.

For instance, values describing MSW generation behaviour, obtained from correlations with influencing factors at the household level, provides useful information for policies regulating waste storage and separation (source-/post-separation) and collection (curb-side/drop-off) (Bing et al., 2014); correlations at community (or town) level provides useful information for determining collection routes, types and dimensions of collection vehicles, street sweeping routines and the balance between manual or automatic MSW management actions (Bras et al., 2009); correlations at district level can inform policies governing waste management subsystems functions used in centralized MSW management systems (-e.g. treatment options, final disposal choices, etc- (Chua et al., 2011; Desa et al., 2011).

The selection of a specific spatial level depends on the specific purpose of the analysis. For example, in Italy, the waste management tariff is calculated by pricing the full cost of MSW management services based on the total MSW generated at the provincial level, whereas the waste management tax is calculated based on the household living space (Mazzanti and Zoboli, 2008).

The complex nature of social-ecological systems, organized across different hierarchical levels, entails the expression of features and behaviours that can only be observed at the different hierarchical levels (Ahl and Allen, 1999; Allen and Starr, 1983). Depending on the pre-analytical choice of level, MSW generation can be measured per person (but will be different for different types of persons), per household (but will be different for different types of households), per community (but will be different for different types of communities), and so on. At any given level, the observed waste generation behaviour is the result of a combination of interactions and influences across processes, simultaneously taking place at higher and lower levels of socio-economic organization.

Individuals generating waste operate inside families that share a common boundary of the household. Households share a common boundary in the form of a building or community where they are located, and so on. The heterogeneous distribution of different typologies of households in space add further complexity: a given community can host different typologies of households, and a city can host different typologies of communities.

This paper presents results of a secondary analysis of existing data from a study on MSW generation in Betania, a culturally diversified urban area of Panama City, This study was commissioned by the Municipality of Panama City (MUPA, 2018a) with the specific aim to exploratorily study the degree of magnitude that influencing factors affect household MSW generation, and understand their simultaneous effect across multiple hierarchical levels of socio-economic organization. The broader scope of the paper is to create a robust knowledge base for MSW management policies in fast growing urban areas in Latin America and other developing areas.

2. Materials and methods

2.1. Conceptual framework

A multi-level analysis of the series of processes of waste generation and management taking place in a defined social-ecological system requires the definition of "functional units" (Garb and Friedlander, 2014; Kampis, 1987; Klerkx et al., 2012) identifying relevant agents at different hierarchical levels of organization inside the system. Two broad types of agent can be distinguished in a MSW management system: (i) "functional units of MSW generation" expressing behaviours of waste generation in space and time at different hierarchical levels (generating the throughput of waste to be processed); and (ii) "functional units of MSW management" (determined by a combination of workers and technology) such as collection, transport, valorisation and treatment (recycling, incineration, anaerobic digestion, composting, etc.) and final disposal (processing the throughput of waste in space and time).

Functional units of MSW generation can be defined across different levels of organization from "individuals" to "countries". Obviously, the larger the size of the unit considered, the larger the heterogeneity of the waste generation behaviours it will contain. Individuals are the smallest identifiable functional unit of MSW generation given that, in biophysical sense, resources of the economic system are consumed by people (Burger et al., 2017). Measuring daily MSW generation at individual level would be the most rigorous way to obtain the real amount of waste generated from city dwellers but it is both impractical and does not provide relevant information for the functional units of MSW management. Other definitions of functional units of MSW generation are more useful to study predictable characteristics (expected behaviour) of MSW generation (Redko et al., 2004).

An important one is the household, which represents the constrained space of individuals, their nesting level of organization, and the immediate functional unit of their MSW generation (Kampis, 1987). It is possible to study and identify specific influencing factors for typologies of household associated with the typologies of individuals living in it and use them as independent variables in models that estimate behaviours of household MSW generation. In turn, larger boundary entities (communities) determine the functional unit of the households within. Indeed, the constrained-constrainer relationship between entities making up functional units of MSW generation can be repeated across multiple levels of organization: households—community, communities—town, towns—districts, etc.

From the point of view of hierarchy theory (Ahl and Allen, 1999), the functional units of MSW generation observed at their specific level -i.e. households generating solid waste (a problem) to be disposed- represent the final causes of the functional units of the MSW management system -i.e. those in charge of eliminating the problem-, but at the same time they represent the efficient cause -i.e. entities which MSW generation behaviour determines the pattern of MSW management- when considering the whole process of MSW metabolism (Wolfram, 2002).

Nested systems, like socio-economic systems, are affected by an 'extensional complexity' determined 'by the fact that at any local at any level in this hierarchy there could be a mixture of different kinds of information coming from different levels constraining the dynamics' (Salthe, 2012).

In the case of MSW management systems, functional units of *MSW management* have to guarantee the expected functions -i.e., the handling of wastes- for the functional units of *MSW generation*, that are operating at the lower level. Thus, there is an *impredicative* relation between the characteristic of the functional units of *MSW generation* and those of *MSW management*: functional units generating waste affect the characteristics of those managing waste by posing new challenges, and those managing waste constraint the possible generation of waste by setting limits to what can be managed (Clayton, 1996; Seadon, 2010). This chain of reciprocal influence operates across all the different hierarchical levels of organization and emphasizes the need for a multi-scale approach when trying to assess the factors influencing the behaviours of MSW generation across different levels of organization.

2.2. The case study

A case study is presented for Betania, an urban area (administrative level of *'corregimiento'* or town) of Panama City. With an estimated population of 59,765 inhabitants (INEC, 2010a, 2006), Betania accounts for approximately 1% of the country's total population. Although Panama City is one of the fastest growing urban areas of Latin America (IMF, 2018), Betania experienced a population growth rate of only 5% in the period 1980-2010 (INEC). Nonetheless, Betania was selected for study because of its location and cultural diversification, presenting widely varying resource consumption habits and MSW generation behaviours (JICA, 2003). Although other towns of Panama City have grown up to 541% in the same period -e.g., Pacora, Tocúmen, Las Cumbres, Juan Díaz-, they are located in the outskirts of the city as satellite or dormitory towns and exhibit limited cultural diversification. Betania, on the other hand, is located in the southeast part of the Panama district centre, surrounded by other towns with a considerably wide socio-economic diversity. The 33 communities that make up Betania combine traces of these socio-economic features -e.g. education, financial, demographic, ethnic, economic activity and health- that characterize Betania´s surrounding metropolitan towns. Household size in Betania increased from an average of 2.9 to 3.1 members in 8 years from 2010 to 2018.

The case study area has been carefully chosen to represent the socio-economic diversity of most communities in developing countries, which are well stratified and present different attributes on influencing factors of MSW generation behaviours within the same area (Jordan, 1982).

In the Panama district, of which Betania forms part, no source waste separation is formally implemented for collecting MSW. A small proportion of families use the recycling stations offered by the Zero Waste program of the Panama district to increase the material recovery of recyclable MSW (MUPA, 2018b). However, there are less than 10 stations and with insufficient capacity to receive MSW from the whole district, even from the few families that bother to segregate and carry their waste to the closer station. This fact is evident from the overflow of waste observed in some stations (EFE, 2019). This program runs more to foster recycling consciousness in population than to collect separately a significant quantity of MSW (MUPA, 2018c). In this sense, the term MSW generation refers to the combined waste fractions of materials present in the MSW streams.

MSW generated in the entire district is collected mainly mixed through a "Curbside" collection: in houses, it is collected in metal basket-like outer containers; in popular sectors, public containers are used; and in building apartments concrete structures with a metal door are implied (Linowes and Brown, 2006). MSW represents approximately 87% of the total waste generated in the Panama district and it is constituted by 53% of waste from households and 34% from commercial sector. Even if both waste flows are transported separately, at the end they are landfilled mixed without any previous treatment (AAUD, 2016) creating serious environmental consequences that could be limited if at least part of the organic fraction of MSW was first source separated and then valorized. In this paper, the focus is made on MSW generated from households in Betania town since it contains 58% of organic fraction (MUPA, 2018a) whose correct management requires urgent attention and novel approaches to improve the current status.

2.3. Data sources

A data set of MSW values per household and day, obtained from a study commissioned by the Municipality of Panama City (MUPA, 2018a), was used to represent the MSW generation of upper, middle-upper, lower-middle and lower income level communities –i.e. communities 30, 8, 3, 23- (see **Table A.1** of the Appendix for the identification (ID) indexes of the communities of Betania). MSW generation was measured (weighted) during one week for 600 randomly selected sample households in 4 out of the 33 communities that make up Betania (150 per community). Data was represented as observed median values per household and day of the 4 communities to which they belong $(\boldsymbol{diag}(\boldsymbol{Whh_{44}})_{\boldsymbol{hh-obs}})$ (see **Table A.2** of the Appendix for acronyms and variables description).

2.4. Statistical analysis

Given the correlation of MSW generation behaviour to resource consumption habits (Adamović et al., 2017), linear regression models were used to correlate the individuals' functional unit of MSW generation with the IF of the households' functional unit, and household's functional unit of MSW generation with the IF of the community functional unit. IFs considered in this study (**Table 1**) were taken from the available database of the last National Census (2010) and Statistic Institute of Panama (INEC, 2010b) and classified by education, demographic, health, ethnic, economic activity and financial type of variables.

2.5. Correlation of functional units of MSW generation and the IF of their functional unit

An average value of MSW generated per individual per day was estimated from $(\boldsymbol{diag}(\boldsymbol{Whh_{44}})_{\boldsymbol{hh-obs}})$ divided by surveyed values of total individuals living in each household, as shown in **Equation 1**.

$$\boldsymbol{diag}(\boldsymbol{Wind_{44}})_{\boldsymbol{hh-est}} = (\boldsymbol{diag}(\boldsymbol{Whh_{44}})_{\boldsymbol{hh-obs}}) \times (\boldsymbol{diag}(\boldsymbol{Pind^{-1}}_{\boldsymbol{44}})_{\boldsymbol{hh-obs}})$$

(1)

A linear regression model (RStudio Team, 2015) was used to correlate individuals´ functional unit of MSW generation with the IF “household median monthly income” of the households´ functional unit to assess its effect size on the MSW generation at this level (**Equation 2**).

$$\boldsymbol{diag(Wind_{44})_{hh-est} \sim diag(Ihh_{44})_{hh-ava}}$$
(2)

The MSW generation per individual and day for the other 27 communities was calculated ($\boldsymbol{diag(Wind_{133})_{hh-cal}}$) and a value of MSW generation per household and day (**Equation 3**) has been inferred for all 33 communities with the aggregation of the MSW generation values per individual and day by the average total individuals per household, available as official data (INEC, 2010b).

$$\boldsymbol{diag(Whh_{133})_{ind-cal}} = (\boldsymbol{diag(Wind_{133})_{hh-cal}}) \times (\boldsymbol{diag(Pind_{133})_{hh-ava}})$$
(3)

A linear regression model was used to correlate households’´ functional unit of MSW generation with the IFs “Community indigenous population”, “Community median monthly income of active population”, “Community population without social security”, “Community population with less than 3rd grade of primary school approved” and “Community illiterate population” of the communities´ functional unit to assess their effect sizes on the MSW generation at the household level (**Equation 4**). The Stepwise method (Graham, 2015; RStudio Team, 2015) was used to select the most representative variables from **Table 1** with the application of the Akaike Information Criterion (AIC) (Akaike, 1974) by removing and/or adding at each step the variable that keeps the AIC value as low as possible. This process is iteratively repeated until it can no longer be reduced (Gallardo et al., 2012).

$$\boldsymbol{diag(Whh_{133})_{ind-cal} \sim diag(IND_{133})_{com-ava} + diag(Icom_{133})_{com-ava} + diag(NOSS_{133})_{com-ava} + diag(LTG_{133})_{com-ava} + diag(ILL_{133})_{com-ava}}$$
(4)

The MSW generation per household and day for the other 27 communities was calculated ($\boldsymbol{diag}(\boldsymbol{Whh}_{\mathbf{133}})_{\boldsymbol{com-cal}}$) and a value of MSW generation per community and day (**Equation 5**) then inferred for all 33 communities with the aggregation of the MSW generation values per household and day by the average total households per community, available as official data (INEC, 2010b). Consideration of functional unit IF was kept for the individual and household levels, the MSW generation at the community level has been calculated for illustrative purposes.

$$\boldsymbol{diag}(\boldsymbol{Wcom}_{\mathbf{133}})_{\boldsymbol{hh-cal}} = (\boldsymbol{diag}(\boldsymbol{Whh}_{\mathbf{133}})_{\boldsymbol{com-cal}}) \times (\boldsymbol{diag}(\boldsymbol{Phh}_{\mathbf{133}})_{\boldsymbol{com-ava}})$$
(5)

Finally, **Equation 6** shows the total daily MSW generation per day for the town of Betania, which is a scalar value obtained with the trace –i.e. aggregation of values- of the diagonal matrix that represents the daily MSW generation of all its 33 communities of **Equation 5**.

$$(\boldsymbol{Wtown})_{\boldsymbol{hh-cal}} = \boldsymbol{Tr}(\boldsymbol{diag}(\boldsymbol{Wcom}_{\mathbf{133}})_{\boldsymbol{hh-cal}}) \qquad (6)$$

Equation 7 and 8 represent the correlation between the MSW generation of the individuals´ and households´ functional units obtained from the linear regression model with the IF of the households´ and communities´ functional unit.

$$\boldsymbol{diag}(\boldsymbol{Wind}_{\boldsymbol{ii}})_{\boldsymbol{hh-reg}} = (\boldsymbol{\beta_o J}_{\boldsymbol{ii}})_{\boldsymbol{hh}} + (\boldsymbol{\beta}_{\mathbf{1}})_{\boldsymbol{hh}}\, \boldsymbol{diag}(\boldsymbol{Ihh}_{\boldsymbol{ii}})_{\boldsymbol{hh-ava}};\ \text{where } i = 1 \ldots, n$$
(7)

$$\boldsymbol{diag}(\boldsymbol{Whh}_{\boldsymbol{ii}})_{\boldsymbol{com-reg}} = (\boldsymbol{\beta_o J}_{\boldsymbol{ii}})_{\boldsymbol{com}} + (\boldsymbol{\beta}_{\mathbf{1}})_{\boldsymbol{com}}\, \boldsymbol{diag}(\boldsymbol{IND}_{\boldsymbol{ii}})_{\boldsymbol{com-ava}} + (\boldsymbol{\beta}_{\mathbf{2}})_{\boldsymbol{com}}\, \boldsymbol{diag}(\boldsymbol{Icom}_{\boldsymbol{ii}})_{\boldsymbol{com-ava}} + (\boldsymbol{\beta}_{\mathbf{3}})_{\boldsymbol{com}}\, \boldsymbol{diag}(\boldsymbol{NOSS}_{\boldsymbol{ii}})_{\boldsymbol{com-ava}} + (\boldsymbol{\beta}_{\mathbf{4}})_{\boldsymbol{com}}\, \boldsymbol{diag}(\boldsymbol{LTG}_{\boldsymbol{ii}})_{\boldsymbol{com-ava}} + (\boldsymbol{\beta}_{\mathbf{5}})_{\boldsymbol{com}}\, \boldsymbol{diag}(\boldsymbol{ILL}_{\boldsymbol{ii}})_{\boldsymbol{com-ava}};\ \text{where } i = 1 \ldots, n$$
(8)

P-values under the conventionally predefined level of significance 0.05 are desirable to validate statistical hypothesis tests (Bhattacharya and Habtzghi, 2002). *P-values* over 0.05 are a typical result for small sample size linear regressions (Ioannidis, 2005), as in our case. The effect size is used for statistical validation of the model instead of the *p-value* because null hypothesis significant testing is a dichotomous measure of evidence showing whether explanatory variables influence MSW generation or not, but not indicating the degree of magnitude explanatory variables are expected to influence MSW generation (Lee, 2016; Verhagen P et al., 2004). The absolute value of the Pearson's correlation coefficient is used as the effect size value, interpreted for the independent variable as explaining certain percentage (R^2) of the dependent variable response.

2.6. Clustering communities by MSW generation values´ similarities looking for IF causality

The double clustering methodology (Matuszewski, 2002) was used for the discovery of causality of MSW generation between communities by assessing their similarities at different levels of organization. Hierarchical Agglomerative Cluster (HAC) analysis (Kassambara, 2015), commonly used to associate relatively "natural" homogenous groups in a statistic population (Gentle et al., 1991), was used twice to cluster communities by their MSW generation values, first in the individual´s functional unit, then in the household´s. Hierarchical clustering is an algorithm that groups similar objects to create a set of clusters where each one is distinct from each other, while keeping the objects within each cluster the most similar to each other as possible.

The main output of Hierarchical Clustering is a dendrogram, a structured tree that shows the hierarchical relationship among clusters, where each leaf corresponds to an observation. As it is moved up the tree, observations that are similar to each other are combined into branches, which are themselves fused at a higher height. The height of the fusion, provided on the vertical axis, indicates the (dis)similarity between two observations. The higher the height of the fusion, the less similar the observations are. The *distance* between two clusters is computed based on length of the straight line drawn from one cluster to another; commonly referred to as the *Euclidean distance.* Results are presented as dendrograms formed according to MSW generation values of the 33 communities of Betania in order to show community affinity with the effect of causality.

Average distances of members within the same cluster were used in order to yield the highest Cophenetic correlation coefficients (CCC). The CCC is a measure of the extent at which a dendrogram preserves the pairwise distances between the original unmodeled data points (Sokal and Rohlf, 1962). A CCC value of 0.75 can be interpreted as acceptable (Mather, 1976). This analysis was performed using the package "stats" (RStudio Team, 2015).

2.7. Clustered communities´ membership variation among the levels of individuals and households

As MSW generation values change from the individual to the household functional unit due to different IF affecting the MSW generation at each level, membership of communities also does within cluster dendrograms at both levels. In order to understand the extent at which this variation is present, the quality of the alignment between both cluster trees was measured using the entanglement coefficient (Galili, 2018; RStudio Team, 2015; Ryota Suzuki, 2015; Soetaert, 2013). The entanglement coefficient is a measure between 1 (100% entanglement) and 0 (0% entanglement) interpreted as the correspondence of community´s arrangements by the MSW generation between the individual and household level. Less entanglement represents a good quality alignment, which means high correspondence between trees.

3. Results

The effect size that the variable *"Household median monthly income"* exerts over the MSW generation of individual functional unit is |0.93|, which means that it explains 86% of the MSW generation of the individual functional unit (see statistical results and coefficients values in **Table A.2**). The variable *"Community indigenous population"*, with the higher effect size (r = |0.46|), is the one better explaining the MSW generation of household functional units over the rest of independent variables, with 21% of the dependent variable response.

Columns 2 and 3 of **Table A.3** of the Appendix section show results of MSW generation of functional units 'individuals' and 'households' for the 33 communities that make up Betania. **Figures 2 and 3** show dendrograms of clustered communities performed according to the MSW generation values of the individual and household functional units from the **Table A.4** of the Appendix section, respectively. The CCC values for the clusters formed from the MSW generation of the individuals' functional unit is 0.80 and 0.78 for the MSW generation of households´ functional unit, which exceed the minimum acceptable of 0.75. Communities presented in each dendrogram were divided in 5 clusters (red framework) to emphasize the community membership as per the similarity of their MSW generation intervals at each level.

Figure 2 shows upper (La Alameda) and middle-upper (Condado del Rey) income level communities in the same cluster (cluster 4), and lower (La Gloria) and lower-middle (Villa Soberanía) income level communities in the same cluster (cluster 3).

Figure 3 shows the upper income level community (La Alameda) in cluster 4, the middle-upper-income level community (Condado del Rey) in cluster 5, the lower (La Gloria) and lower-middle (Villa Soberanía) income level communities in the same cluster (cluster 3). Whilst the double clustering methodology was used for the discovery of causality of MSW generation, the small sample size used for the linear regressions may alter the reliability of results interpretation, especially when more than one independent variable is present.

Figure 4 confronts the dendrograms of **Figure 2 and 3** to assess the alignment quality between both dendrograms with the entanglement coefficient. An entanglement coefficient value of 0.56 is obtained, interpreted as a 56% lack of alignment; which represents the overall change of community membership from one dendrogram to the other, leaving a remaining 44% alignment.

In **Figure 4,** left side dendrogram, community (9) is clustered alone (cluster 5) as the highest

MSW generator per individual and day, far from other cluster MSW generation values. However, the same community is found in the right side dendrogram of **Figure 4** clustered with six communities (13, 26, 29, 27, 22, and 30), five (26, 29, 27, 22, 30) of which comes from cluster 4 of the left side dendrogram and one community (13) from cluster 3.

The integrated representation of MSW generation at multiple levels of organization is shown in **Figure 5.** This figure presents an integrated 3-dimensional profile picture of the MSW generation of the 33 communities that make up the town of Betania, to simultaneously assess the MSW generation picture at the levels of individuals, households and communities. This profile picture was built with MSW generation data of **Table A.3** and serves as a guiding tool to create appropriate policies at several levels of organization of the same community to yield successful interactions among them. The higher MSW generation per individual and day (1.09 kg) is from community (9), however community (8) has the highest MSW generation per household and day (2.98 kg). The fact that community (9) has a higher MSW generation rate per individual and day than community (8) does not mean that it will behave the same at the household level, since IFs shaping these levels are different. Community (31) has the highest MSW generation per community and day with 2564 kg.

4. Discussion and recommendations

Correlation of MSW generation was directly obtained simultaneously for individual´s and household´s functional units of MSW generation in function of the "*Household median monthly income"* and *"Community indigenous population"* IF, respectively. At the individuals' level, the income of the household, as a whole entity, affects the average MSW generation of its members beyond their individual incomes; the higher the household income, the larger is the MSW generation of its members. Household income is a stronger determinant of resource consumption habits than inhabitants´ individual incomes, and consequently better shows causality of their MSW generation behaviour (De Feo et al., 2017; Karlsson et al., 2004; Oribe-Garcia et al., 2015). However, at the household level, indigenous population of communities had a higher effect size over MSW generation of households than other IF. This can be directly interpreted as the more indigenous inhabitants in communities, the higher is the MSW generation of communities´ households because of higher consumption of organic waste derived from food scraps. Consumption habits of indigenous communities in Panama are well-known to be high in raw food goods (AAUD, 2016) and the organic fraction, mainly made up of food scraps, is commonly the most abundant of the MSW stream in DC (Taboada-González et al., 2011). However, a low 21% of dependent variable response shows that the causality interpretation entailed in this correlation maybe improved with the availability of more data to correlate variables.

A still remaining 44% alignment between dendrograms of communities clustered as per individual and household functional units is interpreted as the behavioural trace that the *"Household median monthly income"* IF (used to explain the MSW generation of the individuals´ functional unit) left over the MSW generation of the higher level, the households´ functional unit. "Household median monthly income" and "Community median monthly income of active population" may be the cause of this alignment remaining trace since both variables refer to income, which is a direct cause of resource consumption, each at their respective level of organization.

Community (9), as per its correlation with MSW generation, appears as an upper income level community at the individual level and as a middle-upper income level community at the household level. Community (13), as per its correlation with MSW generation, appears as a lower income level community at the individual level, and as a lower-middle income level community at the household level. The trending to cluster with same or similar communities from the lower level (26, 29, 27, 22, and 30) is a sign of the community "memory" when other functional unit IF, corresponding to the higher level, are shaping the new context of their MSW generation. Income, as a known IF of MSW generation at multiple spatial levels, varies not only among levels of organization but also within them.

The memory of behavioural trend traces remains from one level to the other and are mixed together with the IF representing the context of the new level in unknown proportions that should be surveyed specifically according to the case study. Absolute income level apparently represented at each level, cannot be generalized to all the spatial level at which MSW generation is analysed.

Understanding the extent to which influencing factors simultaneously affect MSW generation allows for volumetric rather than linear representations at several spatial levels at a time. The integrated three-dimensional profile picture of the MSW generation offers a graphical understanding of the extent at which the *X* axis, representing the MSW generation per individual and day (kg/inhabitant*day), is chiefly the only dimension taken into account when policies are created and implemented at several levels. The *Y* and *Z* axis, representing MSW generation per household (Kg/household*day) and community (Kg/community*day) are normally imperceptible for policy makers. This simple graphical representation shows that the current view of MSW generation as a scalar value is insufficient for policymaking and novel vector and matrix representations are needed. The relationship between the MSW generation of functional units at different levels of organization is not linear, but most are differentiable to the extent that can be approximated with the aggregation of linear functions that are given per level and can be graphically represented with tensor-like figures. MSW generation has as many degrees of freedom as IF shaping each level where functional units exists, a tensor-like representation of MSW generation is a reliable way to understand how MSW generation behave at the many levels that are relevant (Jeffreys et al., 1969).

The use of the Principal Component Analysis (PCA) technique or similar is recommended in further studies to determine, not only MSW generation behaviour specific influencing factors, but also the extent at which they are a cause of municipal solid waste generation at higher hierarchical levels of organization, where functional units rely on more than one influencing factor.

The effect size parameter used in this paper shows the extent at which discrete independent variables explain the response of the dependent variable independently of the sample size. Larger sample sizes are recommended for further studies to understand interactions among independent variables and elaborate more reliable interpretation of results.

5. Conclusion

Existing studies have studied influencing factors of MSW generation behaviour at different spatial levels of organization, but always one at a time and not simultaneously. Income is a strong influencing factor, affecting MSW generation from the individual to the country level, capable of hiding the effects of the others. However, this study shows that when MSW generation behaviour is analysed across multiple hierarchical levels of organization, it is possible to identify influencing factors others than income as explanatory variables. In this way, by increasing the number of influencing factors of MSW generation become possible to improve the information used to select proper policies and plans in developing countries MSW management systems in a holistic manner.

When policies are not developed on a proper analysis of the complexity of the relation between units of MSW generation and units of MSW management across hierarchical levels of organization policy overlapping may cause legal gaps. In this situation by considering the influencing factors of the functional unit at each hierarchical level of organization we can generate a better assessment of the effectiveness of MSW.

The approach presented here could also be applied to individual fractions of the municipal solid waste stream –e.g. metal, plastic, paper, organic- so as to understand the extent at which influencing factors affects their generation at different levels in function of the materials composing the municipal solid waste stream. As source separation is not common in developing countries, waste characterization activities have to be performed first; otherwise local actions for policy creation are not viable.

Solid waste management systems of developing countries mostly use landfills in which all solid waste streams are mixed without previous treatment. The approach presented in this paper could be used to understand simultaneous generation behaviour at multiple hierarchical levels of spatial organization of other solid waste streams -e.g., commercial municipal solid waste, tires, clinical waste and construction & demolition waste- in order to be able to plan actions to improve their solid waste management systems.

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7. References

AAUD, 2016. PLAN NACIONAL DE GESTIÓN INTEGRAL DE RESIDUOS 2017-2027 Análisis y Diagnóstico de la Situación Actual (TOMO I) [WWW Document]. URL http://aaud.gob.pa/plangestion//Docs/ANEXOS/20170731_E 1.3.3.3.5_Propuesta Nuevo Modelo de Gestion_v3.pdf (accessed 9.1.19).

Adamović, V.M., Antanasijević, D.Z., Ristić, M., Perić-Grujić, A.A., Pocajt, V. V, 2017. Prediction of municipal solid waste generation using artificial neural network approach enhanced by structural break analysis. Environ. Sci. Pollut. Res. 24, 299–311. https://doi.org/10.1007/s11356-016-7767-x

Ahl, V., Allen, T.F.H., 1999. Hierarchy theory: A Vision, Vocabulary, and Epistemology, Complexity. Columbia University Press. https://doi.org/10.1002/(SICI)1099-0526(199907/08)4:6<29::AID-CPLX6>3.0.CO;2-B

Akaike, H., 1974. A New Look at the Statistical Model Identification. Springer, New York, NY, pp. 215–222. https://doi.org/10.1007/978-1-4612-1694-0_16

Allen, T.F.H., Starr, T.B., 1983. Hierarchy: Perspectives for ecological complexity. Behav. Sci. 28, 305–306. https://doi.org/10.1002/bs.3830280407

Bandara, N.J.G.J.G.J., Hettiaratchi, J.P.A., Wirasinghe, S.C., Pilapiiya, S., 2007. Relation of waste generation and composition to socio-economic factors: A case study. Environ. Monit. Assess. 135, 31–39. https://doi.org/10.1007/s10661-007-9705-3

Barr, S., 2007. Factors Influencing Environmental Attitudes and Behaviors A U.K. Case Study of Household Waste Management. https://doi.org/10.1177/0013916505283421

Bhattacharya, B., Habtzghi, D., 2002. Median of the p value under the alternative hypothesis. Am. Stat. 56, 202–206. https://doi.org/10.1198/000313002146

Bing, X., de Keizer, M., Bloemhof-Ruwaard, J.M., van der Vorst, J.G.A.J., 2014. Vehicle routing for the eco-efficient collection of household plastic waste. Waste Manag. 34, 719–729. https://doi.org/10.1016/j.wasman.2014.01.018

Bras, A., Berdier, C., Emmanuel, E., Zimmerman, M., 2009. Problems and current practices of solid waste management in Port-au-Prince (Haiti). Waste Manag. 29, 2907–2909. https://doi.org/10.1016/j.wasman.2009.07.015

Burger, J.R., Weinberger, V.P., Marquet, P.A., 2017. Extra-metabolic energy use and the rise in human hyper-density. Sci. Rep. 7, 43869. https://doi.org/10.1038/srep43869

Cargo, D.B., 1978. Solid Wastes: Factors Influencing Generation Rates: Issue 174.

University of Chicago, Dept. of Geography.

Chua, S.C., Oh, T.H., Goh, W.W., 2011. Feed-in tariff outlook in Malaysia. Renew. Sustain. Energy Rev. 15, 705–712. https://doi.org/10.1016/j.rser.2010.09.009

Clayton, T., 1996. Sustainability : a systems approach. Earthscan.

De Feo, G., Polito, A.R., Ferrara, C., Zamballetti, I., 2017. Evaluating opinions, behaviours and motivations of the users of a MSW separate collection centre in the town of Baronissi, Southern Italy. Waste Manag. https://doi.org/10.1016/j.wasman.2017.06.045

Desa, A., Ba'yah Abd Kadir, N., Yusooff, F., 2011. A study on the knowledge, attitudes, awareness status and behaviour concerning solid waste management, in: Procedia - Social and Behavioral Sciences. pp. 643–648. https://doi.org/10.1016/j.sbspro.2011.05.095

EFE, 2019. El reciclaje se enfrenta a una dura batalla para imponerse en Panamá [WWW Document]. URL https://www.efeverde.com/noticias/reciclaje-panama/ (accessed 8.21.19).

Galili, T., 2018. Title Extending "dendrogram" Functionality in R.

Gallardo, A., Bovea, M.D., Colomer, F.J., Prades, M., 2012. Analysis of collection systems for sorted household waste in Spain. Waste Manag. 32, 1623–1633. https://doi.org/10.1016/j.wasman.2012.04.006

Garb, Y., Friedlander, L., 2014. From transfer to translation: Using systemic understandings of technology to understand drip irrigation uptake. Agric. Syst. 128, 13–24. https://doi.org/10.1016/j.agsy.2014.04.003

Gentle, J.E., Kaufman, L., Rousseeuw, P.J., 1991. Finding Groups in Data: An Introduction to Cluster Analysis. Biometrics 47, 788. https://doi.org/10.2307/2532178

Giampietro, M., Mayumi, K., Ramos-Martin, J., 2009. Multi-scale integrated analysis of societal and ecosystem metabolism (MuSIASEM): Theoretical concepts and basic rationale. Energy 34, 313–322. https://doi.org/10.1016/j.energy.2008.07.020

Graham, J., 2015. Package “stepwise” Title Stepwise detection of recombination breakpoints.

Hoornweg, D., Bhada, P., 2012. What a Waste. A Global Review of Solid Waste Management. Urban Dev. Ser. Knowl. Pap. 281, 44 p. https://doi.org/10.1111/febs.13058

IMF, 2018. World Economic Outlook: Cyclical Upswing, Structural Change [WWW Document]. Int. Monet. Fund. URL https://www.imf.org/external/pubs/ft/weo/2009/01/pdf/text.pdf

INEC, 2010a. Volumen I: Lugares Poblados de la República:2010 [WWW Document]. URL https://www.contraloria.gob.pa/inec/Publicaciones/Publicaciones.aspx?ID_SUBCATEGORIA=59&ID_PUBLICACION=355&ID_IDIOMA=1&ID_CATEGORIA=13 (accessed 2.21.19).

INEC, 2010b. Población en el Distrito de Panamá, por sexo, según corregimiento y grupos de edad: Censo 2010 [WWW Document]. URL https://www.contraloria.gob.pa/inec/Publicaciones/Publicaciones.aspx?ID_SUBCATEGORIA=59&ID_PUBLICACION=362&ID_IDIOMA=1&ID_CATEGORIA=13 (accessed 1.8.18).

INEC, 2006. Estimación de la población en la provincia de Panamá, por sexo, según distrito y corregimiento [WWW Document]. URL https://www.contraloria.gob.pa/inec/SINAMP/pdf/Panama.pdf (accessed 1.8.18).

Ioannidis, J.P.A., 2005. 12. Significant p-values in small samples [WWW Document]. PLoS Med. https://doi.org/10.1371/journal.pmed.0020124

Jeffreys, B., Borisenko, A.I., Tarapov, I.E., Silverman, R.A., 1969. Vector and Tensor Analysis with Applications. Math. Gaz. 53, 451. https://doi.org/10.2307/3612533

JICA, 2003. The Study on Solid Waste Management Plan for Municipality of Panama in the

Republic of Panama [WWW Document]. URL http://open_jicareport.jica.go.jp/pdf/11712841_01.pdf (accessed 4.29.18).

Jordan, R., 1982. Spatial population distribution and development: notes on urban settlements in Latin America. Notas Poblacion 10, 9–42.

Kampis, G., 1987. Some problems of system descriptions I: Function. Int. J. Gen. Syst. https://doi.org/10.1080/03081078708934964

Karlsson, N., Dellgran, P., Klingander, B., Gärling, T., 2004. Household consumption: Influences of aspiration level, social comparison, and money management. J. Econ. Psychol. 25, 753–769. https://doi.org/10.1016/j.joep.2003.07.003

Kassambara, A., 2015. Practical Guide To Cluster Analysis in R (preview) 1–38.

Kawai, K., Tasaki, T., 2016. Revisiting estimates of municipal solid waste generation per capita and their reliability. J. Mater. Cycles Waste Manag. 18, 1–13. https://doi.org/10.1007/s10163-015-0355-1

Klerkx, L., van Bommel, S., Bos, B., Holster, H., Zwartkruis, J. V., Aarts, N., 2012. Design process outputs as boundary objects in agricultural innovation projects: Functions and limitations. Agric. Syst. 113, 39–49. https://doi.org/10.1016/j.agsy.2012.07.006

Leal Filho, W., Brandli, L., Moora, H., Kruopiene, J., Stenmarck, Å., 2016. Benchmarking approaches and methods in the field of urban waste management. J. Clean. Prod. https://doi.org/10.1016/j.jclepro.2015.09.065

Lee, D.K., 2016. Alternatives to P value: Confidence interval and effect size. Korean J. Anesthesiol. 69, 555–562. https://doi.org/10.4097/kjae.2016.69.6.555

Linowes, R., Brown, M., 2006. The Tropical Waste Dilemma: waste management in Panama. Int. J. Emerg. Mark. 1, 101–112. https://doi.org/https://doi.org/10.1108/17468800610674453//

Liu, C., Wu, X.-W., 2010. Factors influencing municipal solid waste generation in China: A multiple statistical analysis study. Waste Manag. Res. 29, 371–378.

https://doi.org/10.1177/0734242X10380114

Manaf, L.A., Samah, M.A.A., Zukki, N.I.M., 2009. Municipal solid waste management in Malaysia: Practices and challenges. Waste Manag. 29, 2902–2906. https://doi.org/10.1016/j.wasman.2008.07.015

Mather, P.M., 1976. Computational methods of multivariate analysis in physical geography. Wiley.

Matsumoto, S., 2011. Waste separation at home: Are Japanese municipal curbside recycling policies efficient? Resour. Conserv. Recycl. 55, 325–334. https://doi.org/10.1016/j.resconrec.2010.10.005

Matuszewski, A., 2002. Double clustering: A data mining methodology for discovery of causality, in: Intelligent Information Systems 2002. Physica-Verlag HD, Heidelberg, pp. 227–236. https://doi.org/10.1007/978-3-7908-1777-5_24

Mazzanti, M., Zoboli, R., 2008. Waste generation, waste disposal and policy effectiveness. Evidence on decoupling from the European Union. Resour. Conserv. Recycl. 52, 1221–1234. https://doi.org/10.1016/j.resconrec.2008.07.003

Meidiana, C., Gamse, T., 2010. Development of Waste Management Practices in Indonesia. Eur. J. Sci. Res. 40, 199–210. https://doi.org/http://www.eurojournals.com/ejsr.htm

Mmereki, D., 2018. Current status of waste management in Botswana: A mini-review. Waste Manag. Res. https://doi.org/10.1177/0734242X18772097

Mohammed, A., 2018. The Factors That Influence the Environmental Sanitation on People ' s Health in Nigeria. IOSR J. Environ. Sci. Toxicol. Food Technol. 12, 73–76. https://doi.org/10.9790/2402-1202027376

MUPA, 2018a. Estudio de caracterización puntual y dinámica de la generación y composición de los residuos sólidos urbanos por conglomerados de lugares poblados del corregimiento de Betania según sus características sociodemográficas [WWW

Document]. URL http://gestionderesiduos.com.pa/caracterizacion/EstudioBethania.pdf (accessed 7.10.18).

MUPA, 2018b. PUNTOS LIMPIOS | BASURA CERO [WWW Document]. URL https://www.basuracerocambiatubarrio.org/puntos_limpios.php (accessed 8.21.19).

MUPA, 2018c. BASURA CERO - CAMBIA TU BARRIO [WWW Document]. URL https://www.basuracerocambiatubarrio.org/basura_cero.php (accessed 8.21.19).

Oribe-Garcia, I., Kamara-Esteban, O., Martin, C., Macarulla-Arenaza, A.M., Alonso-Vicario, A., 2015. Identification of influencing municipal characteristics regarding household waste generation and their forecasting ability in Biscay. Waste Manag. 39, 26–34. https://doi.org/10.1016/j.wasman.2015.02.017

Periathamby, A., Hamid, F.S., Khidzir, K., 2009. Evolution of solid waste management in Malaysia: Impacts and implications of the solid waste bill, 2007. J. Mater. Cycles Waste Manag. 11, 96–103. https://doi.org/10.1007/s10163-008-0231-3

Redko, V., Prokhorov, D., Burtsev, M., 2004. Theory of Functional Systems, Adaptive Critics and Neural Networks.

RStudio Team, 2015. RStudio: Integrated Development for R. RStudio, Inc.

Ryota Suzuki, A., 2015. Title Hierarchical Clustering with P-Values via Multiscale Bootstrap Resampling.

Seadon, J.K., 2010. Sustainable waste management systems. J. Clean. Prod. 18, 1639–1651. https://doi.org/10.1016/j.jclepro.2010.07.009

Soetaert, K., 2013. plot3D : Tools for plotting 3-D and 2-D data .

Sokal, R.R., Rohlf, F.J., 1962. The Comparison of Dendrograms by Objective Methods. Taxon 11, 33. https://doi.org/10.2307/1217208

Taboada-González, P., Aguilar-Virgen, Q., Ojeda-Benítez, S., Armijo, C., 2011. Waste characterization and waste management perception in rural communities in Mexico: A case study. Environ. Eng. Manag. J. 10, 1751–1759. https://doi.org/10.30638/eemj.2011.238

Verhagen P, A., Ostelo, R.W., Rademaker, A., 2004. Is the p value really so significant?*. Autralian J. Physiother. 50, 2.

Wertz, K.L., 1976. Economic factors influencing households' production of refuse. J. Environ. Econ. Manage. 2, 263–272. https://doi.org/10.1016/S0095-0696(76)80004-6

Wilson, D.C., Rodic, L., Cowing, M.J., Velis, C.A., Whiteman, A.D., Scheinberg, A., Vilches, R., Masterson, D., Stretz, J., Oelz, B., 2015. "Wasteaware" benchmark indicators for integrated sustainable waste management in cities. Waste Manag. 35, 329–342. https://doi.org/10.1016/j.wasman.2014.10.006

Wilson, D.C., Rodic, L., Scheinberg, A., Velis, C.A., Alabaster, G., 2012. Comparative analysis of solid waste management in 20 cities. Waste Manag. Res. 30, 237–254. https://doi.org/10.1177/0734242X12437569

Wolfram, S., 2002. A new kind of science - The Principle of Computational Equivalence, in: A New Kind of Science. p. 1197.

Zaman, A.U., Shahidul, M., Swapan, H., 2016. Performance evaluation and benchmarking of global waste management systems. Resour. Conserv. Recycl. 114, 32–41. https://doi.org/10.1016/j.resconrec.2016.06.020

Zohoori, M., Ghani, A., 2017. Municipal Solid Waste Management Challenges and Problems for Cities in Low-Income and Developing Countries. Int. J. Sci. Eng. Appl. 6, 039–048. https://doi.org/10.7753/IJSEA0602.1002

Table. 1. Available independent variables as IF of the MSW generation at the household and community level from official data of the National Census and Statistic Institute of Panama (INEC, 2010b)

Type	*Independent variables*
Education	- Population with less than 3rd grade of primary school approved - Illiterate population - Average higher grade approved
Demographic	- Average inhabitants per household - Median age
Health	- Handicap population - Population without social security
Ethnic	- Indigenous population
Economic Activity	- Active population (from 15 to 64 years old) - Population employed in agricultural activities - Unemployed population - Not economically active population
Financial	- Community median monthly income of active population - Household median monthly income

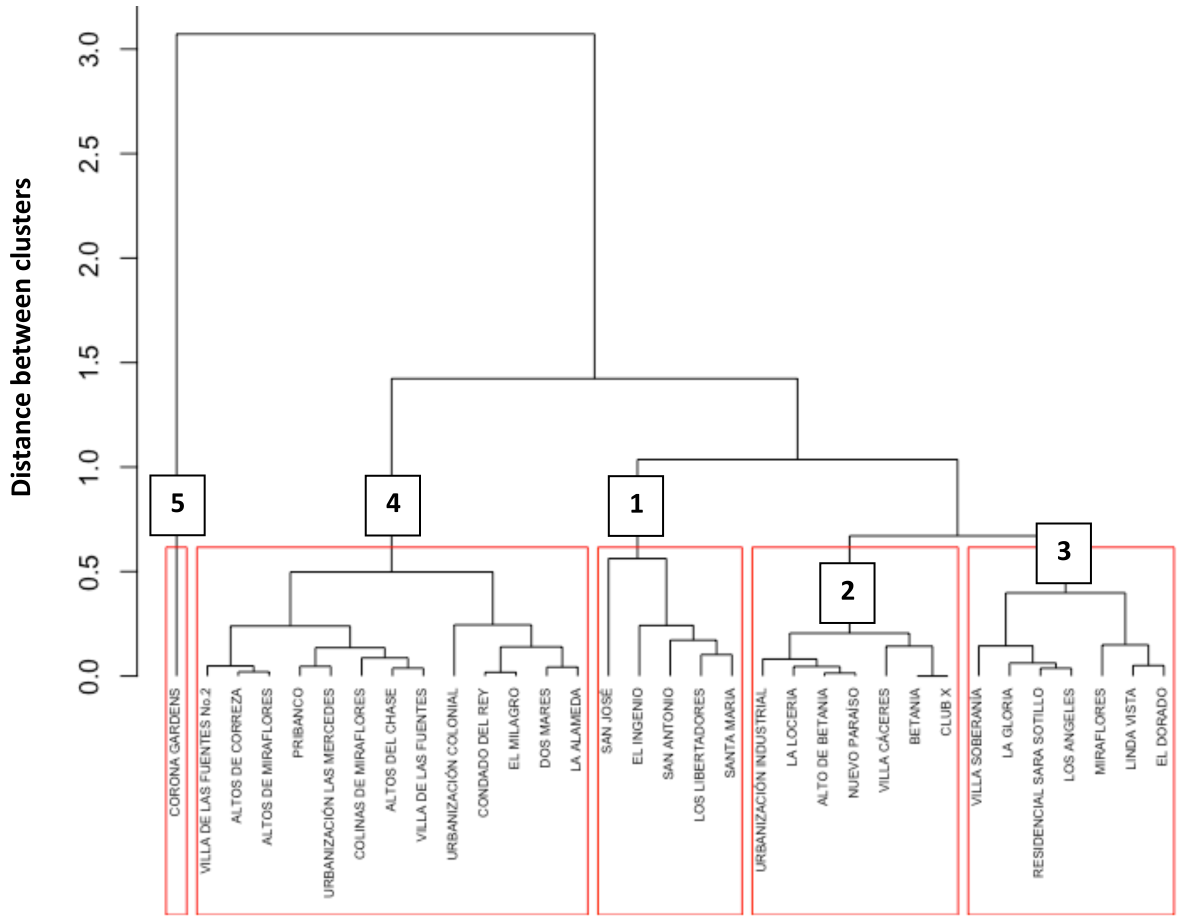

Figure 2. Dendrogram of communities obtained with the similarities of their MSW generation at the level of individuals. Statistical tools derived from several sources (Galili, 2018; RStudio Team, 2015; Ryota Suzuki, 2015; Soetaert, 2013)

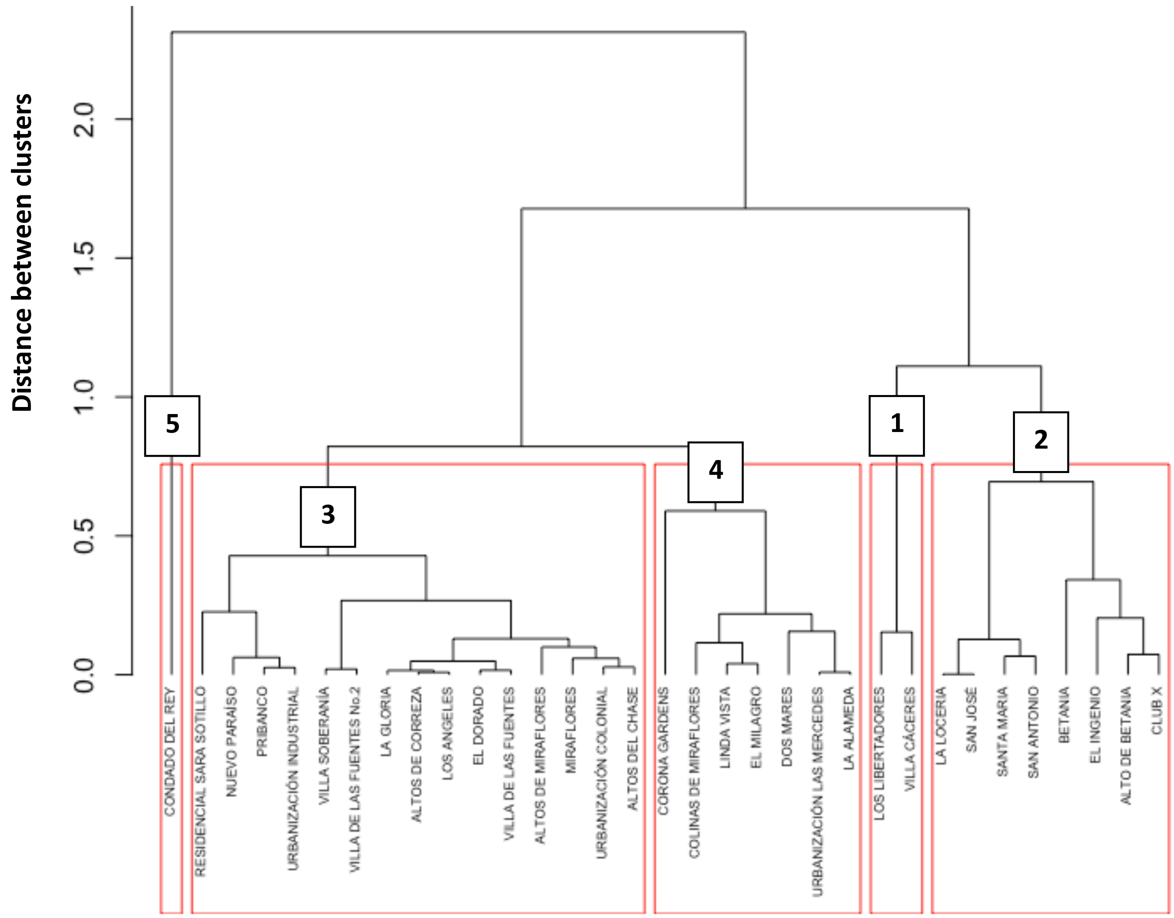

Figure 3. Dendrogram of communities obtained with the similarities of their MSW generation at the household level. Statistical tools derived from several sources (Galili, 2018; RStudio Team, 2015; Ryota Suzuki, 2015; Soetaert, 2013).

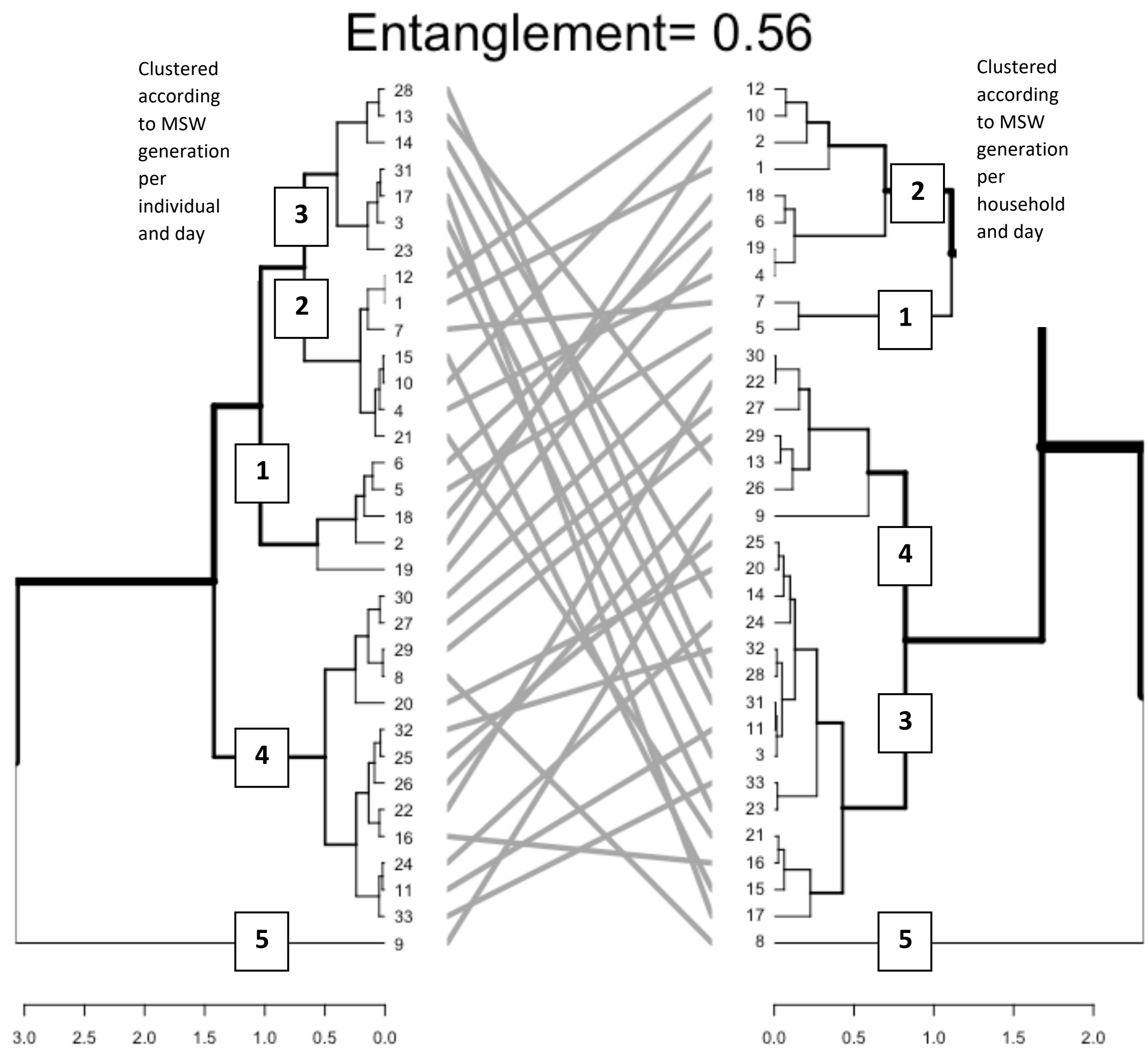

Figure 4. Community membership entanglement from the *individual – household* to the *household – community* functional unit relationship

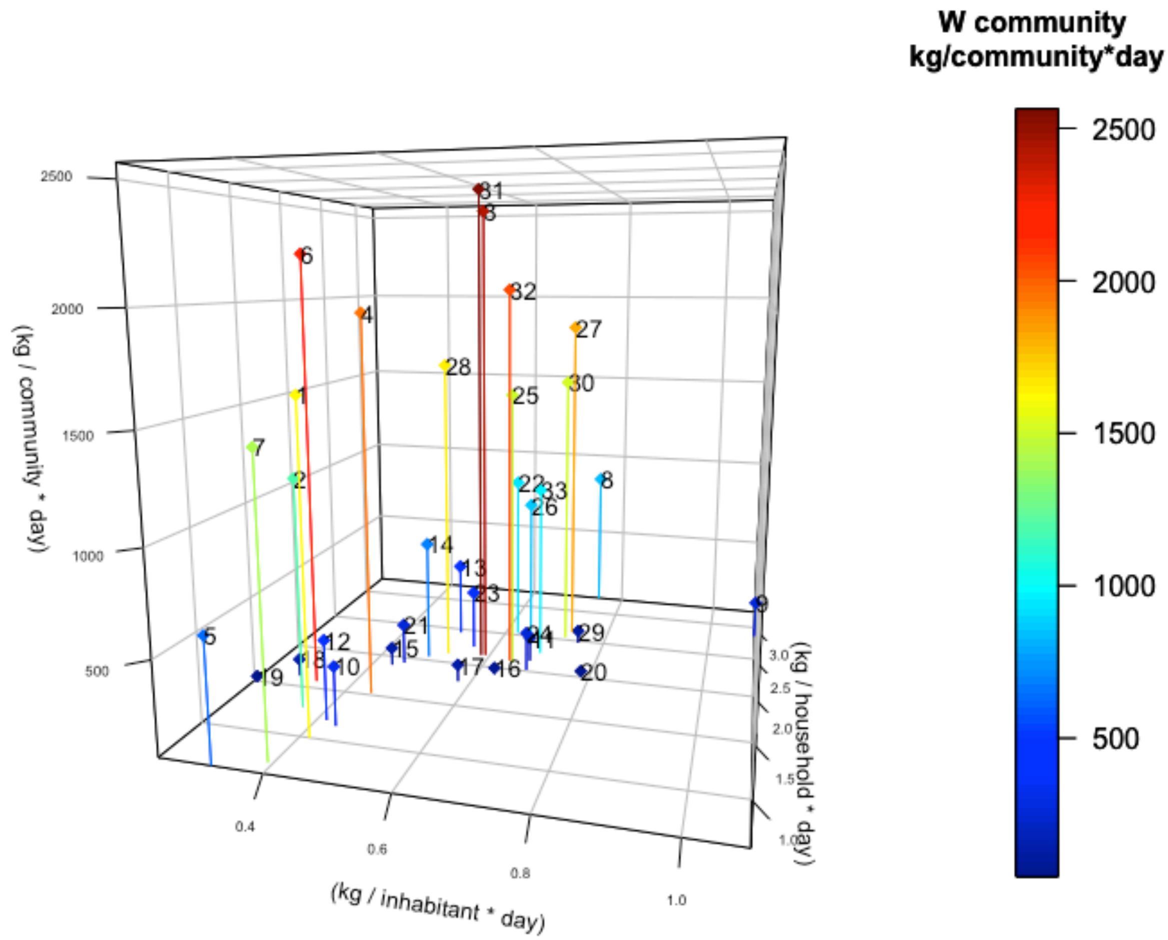

Figure. 5. Integrated three-dimensional profile picture of the MSW generation of the town of Betania composed by the MSW generation values in kg per day of its sub-levels of organization -e.g. inhabitant, household and community-.

A. Appendix

Table A.1. Numbered communities of Betania to be used along this paper as Community ID indexes

1	Betania	12	Club X	23	Villa Soberanía
2	El Ingenio	13	Linda Vista	24	Altos De Miraflores
3	La Gloria	14	Miraflores	25	Altos Del Chase
4	La Loceria	15	Nuevo Paraíso	26	Colinas De Miraflores
5	Los Libertadores	16	Pribanco	27	Dos Mares
6	Santa Maria	17	Residencial Sara Sotillo	28	El Dorado
7	Villa Cáceres	18	San Antonio	29	El Milagro
8	Condado Del Rey	19	San José	30	La Alameda
9	Corona Gardens	20	Urbanización Colonial	31	Los Angeles
10	Alto De Betania	21	Urbanización Industrial	32	Villa De Las Fuentes
11	Altos De Correza	22	Urbanización Las Mercedes	33	Villa De Las Fuentes No.2

Table A.2. Acronyms, statistical results and coefficient values for the variables used in **Equations 1 to 8**. Variables names referring to individual *(ind)*, household *(hh),* community *(com)*, observed *(obs)*, available *(ava)*, calculated *(cal)*, estimated *(est),* regressed *(reg).*

$\boldsymbol{diag(Wind_{44})_{hh-est}}$	*4x4* size diagonal matrix describing the MSW generation per individual and day, estimated from the observed — i.e. measured — median MSW generation values per household per day of the 4 communities for which they belong to $\boldsymbol{diag(Whh_{44})_{hh-obs}}$ divided by the observed — i.e. surveyed — total individuals living in each household ($\boldsymbol{diag(Pind_{44})_{hh-obs}}$.)
$\boldsymbol{diag(Whh_{44})_{hh-obs}}$	*4x4* size diagonal matrix representing the observed — i.e. measured — median MSW generation values per household per day for 600 households in 4 communities of Betania, 150 per community.
$\boldsymbol{diag(Pind_{44})_{hh-obs}}$	*4x4* size diagonal matrix representing the observed — i.e. surveyed — total individuals per household in the 4 sampled communities of the town of Betania.
$\boldsymbol{diag(Ihh_{44})_{hh-ava}}$	*4x4* size diagonal matrix representing the *"Household median monthly income"* officially available data for the 4 communities sampled in the town of Betania.
$\boldsymbol{diag(Wind_{ii})_{hh-reg}}$	*ii* size diagonal matrix representing the MSW generation values per individual and day of the linear regression model obtained with $\boldsymbol{diag(Wind_{44})_{hh-est}}$ as dependent variable and $\boldsymbol{diag(Ihh_{ii})_{44-ava}}$ as independent variable for the *i* communities of the town to which households belong.
$\boldsymbol{(\beta_o J_{ii})_{hh}}$	*ii* size diagonal matrix for the intercept value of the linear regression model obtained for

	$\boldsymbol{diag(Wind_{ii})_{hh-reg}}$ *p-value: 0.62, std. error: 1.63e-01.*
$(\boldsymbol{\beta_1})_{hh}$	Scalar coefficient for the independent variable $\boldsymbol{diag(Ihh_{ii})_{hh-ava}}$ of the linear regression model obtained for $\boldsymbol{diag(Wind_{ii})_{hh-reg}}$. *p-value: 0.07, std. error: 5.15e-05, confidence interval: (-4.33e-05, 4.00e-05).*
$\boldsymbol{diag(Ihh_{ii})_{hh-ava}}$	*ii* size diagonal matrix representing the variable *"Household median monthly income"* for the *i* communities of the town to which households belong. *r (effect size): 0.93, Min.: 2.60e03, 1st Qu.: 2.81e03 , Median: 3.15e03, Mean: 3.14e03, 3rd Qu.: 3.47e03 , Max.: 3.66e03.*
$\boldsymbol{diag(Wind_{133})_{hh-cal}}$	*1x33* size diagonal matrix representing the MSW generation values per individual and day for the 33 communities that make up the town of Betania, calculated from $\boldsymbol{diag(Wind_{ii})_{hh-reg}}$ **.**
$\boldsymbol{diag(Pind_{133})_{hh-ava}}$	*1x33* size diagonal matrix representing the total individuals living in each household for the 33 communities that make up the town of Betania.
$\boldsymbol{diag(Whh_{133})_{ind-cal}}$	*1x33* size diagonal matrix representing the MSW generation values per household and day for the 33 communities that make up the town of Betania, calculated from the aggregation of $\boldsymbol{diag(Wind_{133})_{hh-cal}}$ by $\boldsymbol{diag(Pind_{133})_{hh-ava}}$.

$diag(IND_{133})_{com-ava}$	*1x33* size diagonal matrix representing the variable *"Community indigenous population"* for the 33 communities that make up the town of Betania. *r (effect size): -0.46, Min.: 0.00, 1st Qu.: 2.60, Median: 14.36, Mean: 18.97, 3rd Qu.: 23.35, Max.: 65.07.*
$diag(Icom_{133})_{com-ava}$	*1x33* size diagonal matrix representing the variable *"Community median monthly income of active population"* for the 33 communities that make up the town of Betania. *r (effect size): -0.12, Min.: 1.25e05, 1st Qu.: 7.18e05 , Median: 2.41e06, Mean: 3.06e06, 3rd Qu.: 5.66e06, Max.: 7.95e06*
$diag(NOSS_{133})_{com-ava}$	*1x33* size diagonal matrix representing the variable *"Community population without social security"* for the 33 communities that make up the town of Betania. *r (effect size): -0.31, Min.: 12.96, 1st Qu.: 59.64 , Median: 260.43, Mean: 423.23, 3rd Qu.: 701.19, Max.: 1411.12*
$diag(LTG_{133})_{com-ava}$	*1x33* size diagonal matrix representing the variable *"Community population with less than 3rd grade of primary school approved"* for the 33 communities that make up the town of Betania. *r (effect size): -0.34, Min.: 0.000, 1st Qu.: 3.89 , Median: 14.26, Mean: 23.49, 3rd Qu.: 33.70, Max.: 102.38*
$diag(ILL_{133})_{com-ava}$	*1x33* size diagonal matrix representing the variable *"Community illiterate population"* for the 33

	communities that make up the town of Betania. r (effect size): -0.36, Min.: 0, 1st Qu.: 1.30, Median: 6.48, Mean: 10.13, 3rd Qu.: 16.85, Max.: 44.06
$\boldsymbol{diag(Whh_{ii})_{com-reg}}$	*ii* size diagonal matrix representing the MSW generation values per household and day of the linear regression model obtained with $\boldsymbol{diag(Whh_{133})_{ind-cal}}$ as dependent variable and $\boldsymbol{diag(IND_{133})_{com-ava}}$ $\boldsymbol{diag(Icom_{133})_{com-ava}}$, $\boldsymbol{diag(NOSS_{133})_{com-ava}}$, $\boldsymbol{diag(LTG_{133})_{com-ava}}$ and $\boldsymbol{diag(ILL_{133})_{com-ava}}$ as independent variable for the *i* communities of the town to which households belong.
$\boldsymbol{diag(IND_{ii})_{com-ava}}$	*ii* size diagonal matrix representing the formalization of the variable *"Community indigenous population"* for the community where the MSW generating households are located.
$\boldsymbol{diag(Icom_{ii})_{com-ava}}$	*ii* size diagonal matrix representing the formalization of the variable *"Community median monthly income of active population"* for the community where the MSW generating households are located.
$\boldsymbol{diag(NOSS_{ii})_{com-ava}}$	*ii* size diagonal matrix representing the formalization of the variable *"Community population without social security"* for the community where the MSW generating households are located.
$\boldsymbol{diag(LTG_{ii})_{com-ava}}$	*ii* size diagonal matrix representing the formalization of the variable *"Community population with less than 3rd*

	grade of primary school approved" for the community where the MSW generating households are located.
$\boldsymbol{diag(ILL_{ii})_{com-ava}}$	*ii* size diagonal matrix representing the formalization of the variable *"Community illiterate population"* for the community where the MSW generating households are located.
$\boldsymbol{(\beta_0 J_{ii})_{com}}$	*ii* size intercept value diagonal matrix of the linear regression model obtained for $\boldsymbol{diag(Whh_{ii})_{com-reg}}$. *p-value: 3.50e-13, std. error: 1.39e-01, confidence interval: (1.53, 2.11)*
$\boldsymbol{(\beta_1)_{com}}$	Scalar coefficient for the independent variable $\boldsymbol{diag(IND_{ii})_{com-ava}}$ of the linear regression model obtained for $\boldsymbol{diag(Whh_{ii})_{com-reg}}$. *p-value: 0.003 , std. error: 7.88e-03, confidence interval: (-4.16e-02, -9.31e-03), VIF´S = 2.93*
$\boldsymbol{(\beta_2)_{com}}$	Scalar coefficient for the independent variable $\boldsymbol{diag(Icom_{ii})_{com-ava}}$ of the linear regression model obtained for $\boldsymbol{diag(Whh_{ii})_{com-reg}}$. *p-value: 6.43e-5, std. error: 1.09e-07, confidence interval: (2.91e-07, 7.38e-07), VIF´S = 10.80*
$\boldsymbol{(\beta_3)_{com}}$	Scalar coefficient for the independent variable $\boldsymbol{diag(NOSS_{ii})_{com-ava}}$ of the linear regression model obtained for $\boldsymbol{diag(Whh_{ii})_{com-reg}}$. *p-value: 0.0006, std. error: 9.62e-04, confidence interval: (-5.69e-03, -1.74e-03), VIF´S = 21.13*

$(\boldsymbol{\beta}_4)_{com}$	Scalar coefficient for the independent variable $\boldsymbol{diag(LTG_{ii})_{com-ava}}$ of the linear regression model obtained for $\boldsymbol{diag(Whh_{ii})_{com-reg}}$. *p-value: 0.006, std. error: 1.99e-02, confidence interval: (1.87e-02, 1.01e-01), VIF´S = 34.16*
$(\boldsymbol{\beta}_5)_{com}$	Scalar coefficient for the independent variable $\boldsymbol{diag(ILL_{ii})_{com-ava}}$ of the linear regression model obtained for $\boldsymbol{diag(Whh_{ii})_{com-reg}}$. *p-value: 0.025, std. error: 3.98e-02, confidence interval: (-1.76e-01, -1.31e-02), VIF´S = 25.64*
$\boldsymbol{diag(Whh_{133})_{com-cal}}$	*1x33* size diagonal matrix representing the MSW generation values per household and day for the 33 communities that make up the town of Betania, calculated from $\boldsymbol{diag(Whh_{ii})_{com-reg}}$.
$\boldsymbol{diag(Phh_{133})_{com-ava}}$	*1x33* size diagonal matrix representing the total households located in each of the 33 communities of the town of Betania.
$\boldsymbol{diag(Wcom_{133})_{hh-cal}}$	*1x33* size diagonal matrix representing the MSW generation values per community and day for the 33 communities that make up the town of Betania, calculated from the aggregation of $\boldsymbol{diag(Whh_{133})_{com-cal}}$ by $\boldsymbol{diag(Phh_{133})_{com-ava}}$.
$\boldsymbol{(Wtown)_{hh-cal}}$ =	Scalar value representing the total MSW generation per town, calculated from the trace of

$\boldsymbol{Tr(diag(Wcom_{133})_{hh-cal})}$	$\boldsymbol{diag(Wcom_{133})_{hh-cal}}$ which is the aggregation of the MSW generation values per community and day for the 33 communities that make up the town of Betania.

Table A.3. Daily median MSW generation calculated for the individuals´ and households´ LOO from the correlations obtained and for the communities´ LOO obtained from the aggregation of household MSW generation by the total households located in each of the 33 communities of the town of Betania.

Community ID index[1]	$\boldsymbol{diag(Wind_{133})_{hh-cal}}$	$\boldsymbol{diag(Whh_{133})_{com-cal}}$	$\boldsymbol{diag(Wcom_{133})_{hh-cal}}$
1	0.42	0.92	1625
2	0.36	1.20	1192
3	0.59	2.02	2454
4	0.45	1.43	1956
5	0.32	0.60	638
6	0.33	1.45	2232
7	0.39	0.71	1438
8	0.75	2.98	845
9	1.09	2.59	251
10	0.44	1.07	342
11	0.68	1.94	178

12	0.42	1.09	447
13	0.51	2.21	454
14	0.49	1.88	691
15	0.44	1.71	142
16	0.63	1.73	81
17	0.58	1.62	136
18	0.29	1.47	137
19	0.23	1.38	59
20	0.78	1.88	46
21	0.46	1.74	262
22	0.62	2.29	957
23	0.56	2.04	368
24	0.68	1.83	254
25	0.65	1.91	1518
26	0.66	2.19	864
27	0.73	2.40	1844
28	0.52	1.93	1661
29	0.75	2.23	119
30	0.72	2.32	1544
31	0.58	1.96	2563

32	0.64	1.94	2057
33	0.69	2.06	981
Town of Betania $= (\boldsymbol{Wtown})_{\boldsymbol{hh-cal}} = \boldsymbol{Tr}(\boldsymbol{diag}(\boldsymbol{Wcom}_{133})_{\boldsymbol{hh-cal}}) = 30338$ (Kg/town*day)			

[1] Community ID index referring to **Table A.1.**

Table A.4. HAC membership of communities per interval of MSW generation at the individuals´ and households´ LOO

Cluster membership				
1	2	3	4	5
Individual level (kg/individual*day)				
(0.22, 0.36)	(0.39, 0.46)	(0.49, 0.59)	(0.62, 0.78)	1.09
(2)	(1)	(3)	(8)	(9)
(5)	(4)	(13)	(11)	
(6)	(7)	(14)	(16)	
(18)	(10)	(17)	(20)	
(19)	(12)	(23)	(22)	
	(15)	(28)	(24)	
	(21)	(31)	(25)	
			(26)	
			(27)	

			(29)	
			(30)	
			(32)	
			(33)	

Household Level (kg/household*day)				
(0.65, 0.75)	(1.00, 1.62)	(1.78, 2.27)	(2.39, 2.85)	3.28
(5)	(1)	(3)	(9)	(8)
(7)	(2)	(11)	(13)	
	(4)	(14)	(22)	
	(6)	(15)	(26)	
	(10)	(16)	(27)	
	(12)	(17)	(29)	
	(18)	(20)	(30)	
	(19)	(21)		
		(23)		
		(24)		
		(25)		
		(28)		
		(31)		
		(32)		