STAKEHOLDER COOPERATION IN CIRCULAR ECONOMY ADOPTION FOR MUNICIPAL SOLID WASTE MANAGEMENT

By

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Abstract

The current global pattern of systematic use and disposal of resources, combined with the ever-growing urban population increasingly demanding more goods and services, has resulted in vast amounts of resources being extracted and waste generated. A circular economy aims to capture the remaining value in waste through several disruptive actions such as reuse, recycle, recover and regenerate. However, stakeholders in this transition often find themselves in conflict due to their different objectives and priorities. Cooperation is a critical feature in the circular economy implementation, but in practice it is not easily achieved. There is a shortfall of studies and tools that attempt to facilitate stakeholder cooperation in developing a circular economy.

This doctoral research addresses this gap by establishing an instrument as a questionnaire to analyse the cooperation features in stakeholders, and by developing a Game Theory-hybrid tool that can help to induce cooperation or to make discord clear. Such a methodology consists of six steps: 1) define stakeholders, scope and objectives; 2) select indicators and construct future scenarios for municipal solid waste management; 3) survey stakeholders on cooperation features and to rank the evaluation indicators; 4) determine the weightings for the scenarios criteria; 5) reveal the preference order of the scenarios; and 6) analyse the preferences to study cooperation. The questionnaire was sent to stakeholder groups of the circular economy with interest in the adoption in the municipal solid waste management of Birmingham, UK. The cohorts consisted of 101 MSc students and 27 businesses. The efficiency of the proposed game theory method was tested using a case study with 14 stakeholder responses: The Tyseley Energy Park, a major energy-from-waste facility that currently treats over two-thirds of the municipal solid waste of Birmingham in the United Kingdom.

The results of the questionnaire and Game Theory-hybrid tool are compared and contrasted with existing literature to reveal their commonalities and differences. The findings allowed conclusions to be drawn that circular economy awareness and cooperation readiness from stakeholders are high, but their practices do not sufficiently align with this. However, the study revealed a range of encouraging and optimistic thoughts from stakeholders surrounding the development of a circular economy, despite (as repeatedly mentioned) benefits and costs not always being evident to all participants. Finally, the supporting decision-making process suggests mechanisms to embed cooperation in circular economy adoption so that decisions are made optimally (as a collective) and are acceptable to all the stakeholders.

Keywords: circular economy; cooperation; decision-making; game theory; multi-criteria decision analysis; questionnaire; scenario analysis; solid waste; stakeholders; survey

to the memory of mis Abuelos Carmen y Chucho

and mi Abuela Socorro, who I always seek to make proud

to my always perseverant parents and to my siblings

to the memory of our beloved family dog Ginger

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Abbreviations

3Rs	Reduce, Reuse, Recycle
ABM	Agent-Based Modelling
AHP	Analytical Hierarchy Process
CE	Circular Economy
CGT	Cooperative Game Theory
CI	Consistency Index
DM	Decision-Making
EfW	Energy-from-Waste
EIP	Eco-Industrial Park
FW	Fortress World
GHG	Green House Gas
GT	Game Theory
GVA	Gross Value Added
IAM	Integrated Assessment Modelling
IR	Inconsistency Ratio
IS	Industrial Symbiosis
LCA	Life Cycle Assessment
MCDA	Multi-Criteria Decision Analysis
MF	Market Forces
MFA	Material Flows Analysis
MSW	Municipal Solid Waste
MSWM	Municipal Solid Waste Management
NCGT	Non-Cooperative Game Theory
NSP	New Sustainability Paradigm
PI	Preferability Index
PR	Policy Reform
RDM	Robust Decision Making
RI	Random Index
SA	Scenario Analysis
SMEs	Small and Medium Enterprises
TEP	Tyseley Energy Park
UM	Urban Metabolism
UPE	Urban Political Ecology

Glossary

Benefit: the increase of satisfaction levels, the gaining of an advantage or profit (not necessarily monetary) from performing an action.

Circular economy: a set of principles and tools which embrace waste as a primary resource, allowing its reintroduction into the consumption system at different stages of the consumption cycle, for example by minimising the extraction and degradation of materials, promoting resource and energy conservation (reduce, reuse, recover and recycle) and driving the regeneration of its input sources.

Cooperation: the division of labour between participants in which each one is responsible for solving a portion of the problem whilst achieving one's own goals.

Indicator: a signal that shows how a situation develops and measures its changes.

Linear economy: the currently predominant socio-economic system that extracts resources, refines them into materials, transforms them into parts and components ready to use, assembles them to a final product and when the good is no longer useful it is disposed of without recovering the remaining value in it.

Municipal solid waste: waste collected by municipal services, for example, from households and bulky waste and road sweepings, as well as other waste which, because of its nature or composition, is similar to waste from households (EU Landfill Directive, 2013).

Nash Equilibrium: a single-stage non-cooperative game theory equilibrium definition that finds the combination of stakeholder preferences to scenarios which gives the highest possible level of satisfaction to each stakeholder without changing preferences unilaterally.

Recycling: any recovery operation by which waste materials are reprocessed into products, materials or substances whether for their original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations (European Commission, 2010).

Resource: a stock of materials, energy, water, money, and human capital that organisations or individuals utilise in order to function appropriately.

Scenario: the description of possible future events.

Shapley Value: a cooperative game theory allocation method that assumes participants agree to behave cooperatively beforehand and assigns each stakeholder their marginal contribution to the coalition they join (Cano-Berlanga et al., 2017). Its main advantage is that it provides a fair solution that always exists and is unique (Karmperis et al., 2013).

Sharing economy: a socio-economic system in which assets, infrastructure, resources or services are shared between private individuals, either free or for a fee (Boyko et al., 2017).

Stakeholder group: a set of individuals or organisations who are influencing or being influenced (or both) by a set of decisions regarding a specific issue.

1 INTRODUCTION

1.1 General Overview

An increasingly growing global population, combined with an expanding middle-class able to demand more and more goods and services, is resulting in the slow depletion of energy and resources stocks around the globe. Since the 1980s, the demand of extracted materials from the Earth's crust has increased by over 60% (Circle Economy, 2020). From the estimated 62 billion metric tonnes *(Gt)* of raw resources extracted worldwide annually, half will not regenerate, they are lost forever, and a quarter of these materials are turning into 12 Gt of waste every year (OECD, 2015).

Humanity has taken a linear approach towards resource use; we take, make, use and dispose of (Ellen MacArthur Foundation, 2015a). The planet is becoming scarce in resources but rich in waste, and only about a third of the waste generated is recycled (OECD, 2015). There are several well-established hierarchies for approaching change in waste management. The most well-known is a Waste Hierarchy (Gharfalkar et al., 2015) used ubiquitously to rethink the entire use of materials in any aspect of our economy (Potting et al., 2017). Recycling rates vary widely between high-volume materials (e.g., paper, plastics, glass, steel), and rare and precious metals (e.g., platinum, palladium, lithium). In many cases, recycling cannot be done in perpetuity; for example, paper loses some of its quality each time it is recycled. Therefore new paper fibres need to be mixed with the recycled fibres (Clift et al., 2015). Also, recycling rates fluctuate extensively amongst developing and developed countries, the reasons for which are varied and include policy-making, available technology and culture towards sustainability, to only name a few (Leonard, 2008). In summary, recycling is a limited process in which materials are reintroduced into the consumption system to use them for their original or a different purpose. Recycling has been widely adopted as the most convenient solution to reintroduce materials in the consumption process, and even burning waste to recover some energy has also been encouraged, despite rarely (if ever) closing the loop (Leonard, 2008).

Thus, more profound solutions than recycling are needed to achieve resource security while improving all other sustainability dimensions. Here is where the *Circular Economy (CE)* comes into play: it provides for a more active approach to resource and waste management in which materials are fed back into the process through multiple actions (for example: *Reduce, Reuse and Recycle – the 3Rs concept*) rather than being 'lost'. As opposed to solely recycling, a CE is broader and aims to contribute towards sustainability through several simultaneous agendas, including economic growth, resource security, social development, and environmental responsibility (Haupt et al., 2017). A CE attempts to reintroduce resources back into the consumption process at many different stages; from rethink and regenerate, design and extraction, repair and remanufacture, to recovery and recycling (Korhonen et al., 2018b).

Regarding resource recovery and reintroduction in the consumption process, the design stage of a system must consider making it easier to collect and recycle waste (Su et al., 2013); in other words, dealing with waste even before generating it. However, in an ideal CE, there is no distinction between waste and resources; rather than the traditional *'waste management'* approach there would be *'resource value management'* (Lieder and Rashid, 2016). In order to achieve an optimal creation of value from waste, industry and non-industry stakeholders need to cooperate (Bocken et al., 2014).

In an attempt to evaluate the global economy circular state, the "*Circularity Gap Report*" by Circle Economy (2018) introduced the first indicator to measure how circular the current world economy is – '*Global Circularity Metric (%)*'. The metric is the proportion of cycled resources as part of the total input flows of fossil fuels, ores, minerals, and biomass. The value for 2018 was estimated to be 9.1% dropping to 8.6% in 2020 (Circle Economy, 2020), which casts doubt on the current worldwide approach to a closed-loop economy, and the measures to increase circularity are not sufficient. However, it is reasonable to expect substantial regional disparities when calculating this figure; these are not addressed in the report apart from the seven primary societal needs (i.e., housing, nutrition, mobility, consumables, services, health and communication).

Some of the most important considerations that support the potential of adopting a CE are the enormous beneficial impacts it could deliver. For example, Heshmati (2015) presents five main reasons to implement CE as a development strategy:

1) The world is facing significant environmental changes, due to the combination of inadequate regulation and oversight, and rapid urbanisation and industrialisation processes – CE can help with decoupling economic growth from environmental burdens.
2) The increasing demand for resources and energy has caused shortages, derived from the intense economic growth – CE can help with reducing resource requirements and supply shortages that are related to population and industry growth and structure.
3) Countries expect their competitiveness to be negatively affected by the increasing implementation of stricter production, environmental and labour standards combined with the changing regulations in international trade – CE can help with overcoming the green barriers to remain competitive.

4) CE contributes to material security, alternative energy sources and savings in resource use, and simultaneously the environmental benefits improve health and wellbeing.
5) CE will help in the improvement of technology and education standards due to the implementation of radical shifts in regulation.

On more tangible examples, Veolia and Imperial College London (2015)[1] estimated that a CE could generate £29 billion of the UK's GDP (1.8%), and could also create 175,000 additional jobs in the country. Furthermore, the estimated European Union (EU) macroeconomic benefits are even more considerable for 2030, with up to €0.6 trillion annually from primary resources savings and up to €1.2 trillion in non-resources and externalities, such as depreciation from circular investments and materials insecurity and price volatility (Ellen MacArthur Foundation et al., 2015). Environmental benefits were estimated to reduce waste generation by up to 40%, and emit 70% less *Green House Gases (GHG)* in 2050 when compared to 2012 EU levels (European Commission, 2015). Finally, the increase in circular jobs would be as high as 8.1% in the Netherlands (Circle Economy and EHERO, 2017), and a potential jobs creation of 3% in Sweden (Ellen MacArthur Foundation, 2013a).

Furthermore, some private companies that allow their customers' needs and indirectly other stakeholders (such as society) to influence their business models (in a limited way) have subsequently redesigned their products and services to become more sustainable (Witjes and Lozano, 2016). The private sector has gradually embraced the popularity of the CE. For instance, Cooling-as-a-Service (CaaS) entails businesses providing the 'service' of maintaining a room at a particular temperature (Climate Finance Lab, 2019; BASE and K-CEP, 2019). The advantages of servitisation as a sharing business model include customer savings on the initial investment in equipment and incentives for businesses such as efficient energy use, maintaining units for the longest possible use through maintenance and repair to reduce costs to the provider (K-CEP, 2019). On other examples, Veolia (2016) reports on 17 different case studies of cooperation with customers, partners and local authorities serving as examples of good practices towards a CE. These cases range from recycling materials (e.g., plastic bags, paint, waste detergent, and flat screens) to other alternatives lower in the waste hierarchy such as energy recovery (e.g., biogas from digesting food waste, by-products of the whisky sector, and wastewater sludges) including their resulting biomass being used in fertilisers.

Stakeholder cooperation is a vital feature to successfully achieve CE implementation and overcome the barriers that arise in the design and adoption stages. In many cases, such as when

[1] Veolia is a French trans-national company which provides activities within three main service and utility sectors traditionally managed by public authorities – these include water management, waste management and energy services.

understanding of objectives is unclear, a cooperative result is improbable unless a third party (an external authority) is involved (Grimes-Casey et al., 2007). However, enforcing cooperation is not the only way of improving sustainability performance; Robèrt and Broman (2017) heavily criticise this through the following misconceptions:

1) We rely entirely on authorities to force trust (cooperation) towards sustainability.
2) Policy-makers shape law based on this misunderstanding, which results in reinforcing the previous mindset.

On another note, although Witjes and Lozano (2016) developed a framework called "*ProBiz4CE*" which suggests that cooperation between procurers and suppliers leads to benefits such as decreasing waste generation and raw materials utilisation, they did not provide a contribution to enhance cooperation between them. Moreover, their analysis is limited to the public procurement process; this means that only government and private companies are involved. Pomponi and Moncaster (2017) analysed the dimensions of CE and proposed to complement the three "old" dimensions (economic, environmental, and societal) with the "new" dimensions (governmental, technological and behavioural). The role of individuals seems to be equally critical for CE, as stated by Pomponi and Moncaster (2017, p.716): *"it is apparent that it is people, rather than only technologies, who are also key to embracing circularity".* However, to transition to a fully CE a right balance of infrastructure, technology innovation, policy, consumer behaviour and business models is needed. For such process, it is helpful to introduce the concept of *Urban Metabolism (UM)*, which is an analogy from the biological sciences to understand the resource and waste flows in, within and outside of cities. UM indicators are important to evaluate CE scenarios at the meso or city scale in terms of waste generation and management.

In this research, cooperation and collaboration are not interpreted as synonyms and are not used interchangeably. There is a subtle difference between the two. Collaboration is when multiple stakeholders work together to achieve a single shared goal, as opposed to cooperation, which is the division of labour between participants in which each one is responsible for solving a portion of the problem whilst achieving one's own goals, a situation in which conflict is likely to arise (Castañer and Oliveira, 2020). Cooperation is defined in three main dimensions which participants share: attitudes, behaviour and outcomes (Castañer and Oliveira, 2020).

The CE concept has been progressively attracting attention from academics, industry, general public and governments. For a successful transition towards a CE, its principles need to be the guideline in the design of business models. To overcome the barriers faced to implement CE, cooperation among stakeholders is essential, and yet this is proving difficult to attain in practice. Besides, stakeholders from each perspective have their interests and priorities, which often result in conflict. Furthermore, decisions made in the interests of some individuals may result in terrible outcomes for a whole system.

Several concepts and techniques that improve cooperation between stakeholders were reviewed such as *Agent Based Modelling (ABM)*, *Multi-Criteria Decision-Analysis (MCDA)*, and *Scenario Analysis (SA)*. However, *Game Theory (GT)* is presented as the method that best suits this thesis' objectives and it consists of mathematically analysing the different stakeholders' interests, incentives, preferences, and strategies in the *Decision-Making (DM)* process (Myerson, 1991; Brams, 2004). GT is widely used to describe and predict how individuals interact and react according to their interests in the interactive DM process (Simon, 1999). The study can assist in strengthening the negotiation and bargaining strategies to cooperate, being a determinant factor for improving the circularity of the current resource or waste management policies and strategies of urban areas at the local scale. Therefore, it is worthy to complementarily utilise such an innovative, underexplored, and still not sufficiently mapped or investigated technique in this particular subject.

GT is useful for situations where conflict derives from different stakeholders' priorities. The process of adopting CE principles should expect many disputes and partnerships. For example, deciding whether recycling or incinerating waste in cities is, when all perspectives are taken into account, the best strategy for the environment, urban flora and fauna, citizens, local authorities or business owners. Indeed, many factors come into play into the DM process, such as land space, investments and infrastructure, which could represent barriers or opportunities for cooperation.

A necessary primary condition for CE implementation at a city scale is the joint support and continuous interest of all stakeholders (Lieder and Rashid, 2016). Cooperation was identified as a new and unintended practical use of the tool developed by Bocken et al. (2015), based on mapping value and systems-thinking, to facilitate innovation for sustainable business models. *Cooperative Game Theory (CGT)* can facilitate the joint support of stakeholders, *while Non-Cooperative Game Theory (NCGT)* can help in the stability and continuous interest of those involved.

In summary, as represented in Figure 1–1, in order to deliver CE in cities, the aim should be implementation at the local scale by adopting business models designed with circularity principles. However, implementation of a CE faces a variety of challenges ranging from societal attitudes, practices to governance and the attraction of investors. To overcome these barriers, capture multiple values and successfully transition towards a CE, cooperation among stakeholders is paramount.

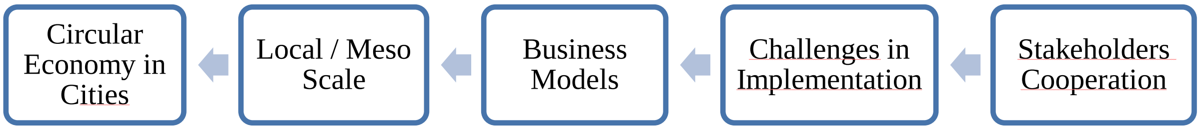

Figure 1–1: Problems addressed by this research.

There are some excellent collaboration examples across multiple different sectors at multiple different scales (ZeroWIN, 2014). However, in contrast although several studies aim to facilitate CE implementation (e.g., Bocken et al., 2016; Rizos et al., 2016; Witjes and Lozano, 2016) and others mention it as an essential enabler in the transition towards a CE (e.g., Circle Economy, 2018; Preston, 2012; Witjes and Lozano, 2016), cooperation has not yet been studied as a critical element for the successful adoption of circularity principles. An exceptional publication studied inter-organisational cooperation between three industries to advance their transition to a CE, and proposed areas of common interest to be key for successful cooperation (e.g., reuse of waste and organisational innovation; Ruggieri et al., 2016).

The purpose of this doctoral research is, therefore, to ultimately address this gap by combining a questionnaire to study cooperation features and a GT-hybrid tool to facilitate stakeholder cooperation in the transition towards a CE. Thus, it seeks to aid stakeholders through the delivery of better and informed decisions in the future scenario evaluation process, with a specific focus on *Municipal Solid Waste (MSW)* of cities. This focus is because the MSW is, as discussed above, an area which is likely to present conflicting viewpoints from a wide range of involved city stakeholders, and because of its applicability to a case study in the city of Birmingham, UK.

1.2 Aims and Objectives of the Study

The overall aims of this study are:

> *'To develop a methodological procedure to study the cooperative features amongst circular economy stakeholders'.*
>
> *'To assess their cooperative behaviour when selecting future scenarios of municipal solid waste'.*

The five objectives of this research that underpin this aim are shown below, while their particular methods to achieve and research outputs are indicated in Table 1–1:

O1. To identify instruments used to study CE awareness and stakeholder cooperation in survey-based research in both student and industry contexts.

O2. To identify and critically review options to then select the most appropriate method (or combination of methods) to study stakeholder cooperation in the CE transition.

O3. Based on the findings of O1 to develop a questionnaire which serves as an instrument to study CE awareness and other relevant stakeholder cooperation features.

O4. Based on the findings of O2 to develop a GT-hybrid tool that studies stakeholder cooperation when assessing future CE scenarios of *Municipal Solid Waste Management (MSWM)*.

O5. To test both the questionnaire and the GT-hybrid tool through their application in a case study, compare their outcomes, and contrast with existing literature.

Table 1–1: Objectives, Methods and Research Outputs of this thesis.

Objective No.	**Methodology No.**	**Methodology to achieve the objective (see Chapter 0 for more details)**	**Research output**
O1	M1	Review the current literature on survey studies that measure CE awareness and other cooperation features	Literature review and establish a taxonomy of CE stakeholder cooperation (Section 2.2)
O2	M2	Review the relevant engineering DM methods used in the CE and MSW contexts	Literature review and establish a research gap (Section 2.3)
O3	M3	Development of a questionnaire to measure the CE awareness and other cooperation aspects of stakeholders	A questionnaire instrument to study CE awareness and other cooperation features in two cohorts: students and companies (Chapter 4)
O4	M4	Development of a GT-hybrid methodological process that studies stakeholder CE cooperation in the assessment of MSW scenarios	A GT-hybrid based methodological procedure (Chapter 5)
O5	M5	Testing of both the questionnaire and the tool using statistical analysis in a case study, and compare both outcomes with the existing literature	Results from both applications, a case study and comparison with existing studies (Section 6.3)

2 LITERATURE REVIEW

This chapter presents a critical review of the relevant literature; it mainly consists of the sections:

- The presentation of the theoretical framework to this research (Section 2.1).
- The review of the literature on surveys of *Circular Economy (CE)* awareness and other aspects (Section 2.2).
- The review of *Decision-Making (DM)* methodologies in the CE context (Section 2.3).
- Finally, Section 2.4 presents a summary and the gap of knowledge in the literature addressed by this research.

2.1 Theoretical Framework

This section presents briefly highly relevant terms and areas, as well as the interpretations elaborated for this research. The concepts are in the sub-sections: *Urban Metabolism (UM* – Section 2.1.1), *Circular Economy (CE* – Section 2.1.2) and both concepts' relationships with and potential to help in the development of more sustainable urban areas (Section 2.1.3).

2.1.1 Urban Metabolism (UM)

2.1.1.1 Description

Urban Metabolism (UM) has been taken and adapted to cities from its origins within biological sciences (Holmes and Pincetl, 2012). In brief terms UM involves the following:

- Identifies, describes, and measures city flows,
- Considers urban areas as living organisms, and
- Utilises processes that require inputs (resources), transformations for energy and nutrients (materials and products) and produce outputs (waste).

Thus, UM presents a framework to study the relationships between inputs and outputs in cities and their surrounding physical environment (McDonald and Patterson, 2007). It was defined by Agudelo-Vera et al. (2012: 4) as "*a way of quantifying the overall flows – inputs, transformations, and outputs – of resources and energy in urban areas"*. It studies all different scales, including individual, household, neighbourhood, city, country, and global levels. These diverse flows and their connections occur in, within/around and outside of cities and include:

1) Flows In – resources (e.g., fuels, food, energy, water, metals, and plastics).
2) Flows Out – manufactured products, but also waste (e.g., municipal solid waste, wastewater, and atmospheric pollution).
3) Flows Within/Around – stocks (e.g., buildings, markets, reservoirs, and warehouses).

There are three periods of UM from an historical perspective (Wachsmuth, 2012).

Firstly, *Human Ecology*, introduced by Burgess (1967), considered the city as an ecosystem analogous to natural ecosystems. However, by focusing mainly on how humans adjust themselves to the surrounding environment, this approach lacks the inclusion of nature as a principal actor in the city's metabolism. Furthermore, the city is assumed to be a continuously growing and isolated system that is not interacting with the outside world (its hinterlands); this results in controversial and mutually exclusive properties.

The second appearance of UM is known as *Industrial Ecology* (Fischer-Kowalski, 1998; Fischer-Kowalski and Hüttler, 1999), which is also addressed as the UM in engineering. It acknowledges nature as the primary external source of materials and the destination of wastes. It is based on the consumption of resources and nature's limitations in terms of supply to help comprehend the development of cities (Wachsmuth, 2012). In this context, the city's dependence is on the external environment, which is the supplier of the resources and the place to deposit the waste during the city's growth. This research is more closely aligned to this period because of its engineering and scenarios perspective.

Finally, the third period of UM is known as *Urban Political Ecology (UPE)*; referred to as a new conceptualisation of the city as the result of socio-natural flows (Wachsmuth, 2012). This emerged after increasing concerns on the environment from the argument that nature not only restricts and is the foundation of society, but that the city is inherently social and natural, and urban nature and urban society are equally political (Swyngedouw, 1996). Unlike *Industrial Ecology*, UPE does not need (and in fact it is not feasible to have) precise methodologies to study the role of nature inside the city. UPE asserts that nature is omnipresent in all social fields and implies that every attribute of modern urbanisation is socio-natural. UPE embraces the basic principle of industrial ecology; natural resources flow into the city, and humanity transforms them for urban life. However, introducing other forms of value enhance the metabolic approach (Swyngedouw, 2006).

The primary empirical UM studies are divided into ecological and engineering approaches. The former approach is shaped by the conceptualisation of energy flows which were called *Emergy* by Odum (1983). Scholars define this concept as the solar energy available, which is used directly or indirectly with the purpose to produce goods and services. Hence, it is measured in terms of solar energy joules (seJ) and attempts to integrate energy and material analyses of cities by studying them if solar energy were the only energy input. This methodology aligns with two thermodynamics Laws (Holmes and Pincetl, 2012):

- First Law: Energy is not created nor destroyed; it is only transformed,
- Second Law: The quality of a proportion of energy in every process will decay by the conversion to waste heat.

Emergy studies fall beyond the scope of this research, and that is why this thesis does not explore them in any more detail than outlined above.

The *Mass-Energy* flows is another UM framework that has been widely developed by engineers in line with the second appearance of UM – *Industrial Ecology*. One of its most important principles is that materials flow into the production system, and using energy, they are transformed into goods and services to satisfy demand needs. The *Industrial Ecology* framework is the approach that rises as dominant for UM studies (Holmes and Pincetl, 2012). The following sub-section presents the most recognised and widely applied *Mass-Energy* flow methodologies because other stakeholders interpret the outcomes more easily. Therein their advantages and disadvantages are highlighted.

2.1.1.2 Methodologies – Mass-Energy flows

Many authors have provided detailed reviews of the various methodologies used to study UM for cities around the world. For example: Zhang (2013); Huang et al. (2012); Dinarès (2014); Holmes and Pincetl (2012); Loiseau et al. (2012) and more specifically in the UK context (Clift et al., 2015). UM methods have been developing for several decades, and it has evolved gradually over this time from analysing processes, accounting and assessing, simulating models, up to optimisation and regulation (Zhang, 2013).

The first methodology to study UM is *Life Cycle Assessment (LCA)* – an environmental management technique used to identify, quantify and compare all necessary inputs to perform an activity in all its process stages, and in so doing help assess all its potential impacts (Daniels and Moore, 2002). LCA consists mainly of four key steps, also used in standards, for example, ISO 14044 (International Organization for Standardization, 2006):

1) Definition of goal and scope.
2) Inventory analysis, data collection and validation.

3) Potential impact assessments.
4) Interpretations and elaboration of recommendations.

Karmperis et al. (2013) present a generally well-elaborated short review and introduction of the LCA method. Some of the main disadvantages of LCA are that it is very time and data demanding, databases usually are generic for industries rather than specific for case studies, and it still lacks considering the social dimension of impacts.

The second methodology to study UM is the *Ecological Footprint*. In simple terms, it attempts to measure the ecological assets to build a product and compares this with how fast the planet can regenerate those resources and absorb the waste produced in the process (Clift et al., 2015). Likewise, the variations known as *Carbon Footprint* and *Water Footprint,* attempt to measure the *Green House Gas (GHG)* emissions and water required to perform an activity, respectively. The Ecological Footprint rests on the principle that everything we consume must come from the finite resources on Earth. It has inspired the "Earth Overshoot Day"; this is a date in the year in which humanity depletes the resources that the planet can replenish. [In 1970 there was no overshoot – in other words the earth used less than its one planet worth of resources at the end of the year. However, from 2012 to present the overshoot has occurred in August – two thirds of the way during the year, meaning by the end of the year one and a half planet's worth of resources are used – see more at https://www.overshootday.org/.] The disadvantages of these methods include neglection of other impacts by only considering average productive land, carbon emissions and water; and the methods rely on an incomplete description of the inputs and outputs of activities (Zhang, 2013).

Finally, the third methodology is *Material Flow Analysis (MFA)* and its variations. Within the literature analysed these are the most used methods within engineering spheres to study UM. MFA is the systematic assessment of flows and stock of resources within a system with defined space and time boundaries (Allesch and Brunner, 2015). MFA fundamentally depends on the conservation principle, in other words, input equals output. The *Economy-wide MFA* developed by Eurostat (2001) has been the most well-known methodological framework. Some of the drawbacks of MFA include ignoring the quality differences of materials when aggregating them (Zhang, 2013), and the fact that it is challenging to identify and quantify indirect material flows (Loiseau et al., 2012).

To conclude this section, Kennedy et al. (2011) shed light on the relationship of the two schools of UM; the *Emergy* school describes the urban flows in solar energy equivalent terms; *Mass-Energy* describes these material and energy flows in terms of mass equivalent. They are not contradictory; however, the latter has been considered as the mainstream as it uses units which are easily recognisable, understandable and used by local governments (Kennedy et al., 2011). Indicators from the MFA methodologies were used in this research and will be introduced below.

2.1.2 Circular Economy (CE)[2]

2.1.2.1 Overview

To briefly describe the current state of the CE literature, a bibliometric search collected data from the *Web of Science* database in April 2021. The terms examined included "*circular economy*" and the combinations with the DM methodologies to compare in Section 2.3 (which helps to achieve O2); that is, "*game theory*", "*agent based model*", "*multi criteria analysis*", "*scenario analysis*", "*robust decision making*" and "*integrated assessment model*". The results are shown in Table 2–1 and include only publications that mention the CE or "zero waste" terms and are illustrated in Figure 2–5. The excluding criteria for the search were as follows:

1) Publications in the English language only.
2) Only publications after the year 1999, as the CE development is recent and to identify the latest research.
3) Both the grey and peer-reviewed literature.
4) The terms searched were included in any of the fields (title, abstract, keywords, and main text).
5) The subject area was limited to engineering, aligned with the aims of this research.

Table 2–1: Number of reviews and articles from each search term.

Search term	**Number of reviews and articles found in Web of Science**	
"circular economy" OR "zero waste"	12,239	Figure 2–1
("circular economy" OR "zero waste") AND Game Theory	19	Figure 2–5
("circular economy" OR "zero waste") AND Agent Based Model	14	
("circular economy" OR "zero waste") AND Multi Criteria Decision Analysis	24	
("circular economy" OR "zero waste") AND Scenario Analysis	24	
("circular economy" OR "zero waste") AND Robust Decision Making	2	
("circular economy" OR "zero waste") AND Integrated Assessment Model	3	

[2] It must be noted that the author published a Little Book based on a large portion of concepts interpretations as listed [1] in Appendix A.

However, since CE is a new research area, performing further analysis helps to identify trends in its development and progress. The *Web of Science* analysis tools helped to perform a quantitative description of the data from the available literature. Figure 2–1 depicts the annual number of publications; they show a clear and consistent trend of increasing publications for the CE from 2008 to (September) 2021. Even though the original search was until 2018, it was worth checking the latest three years.

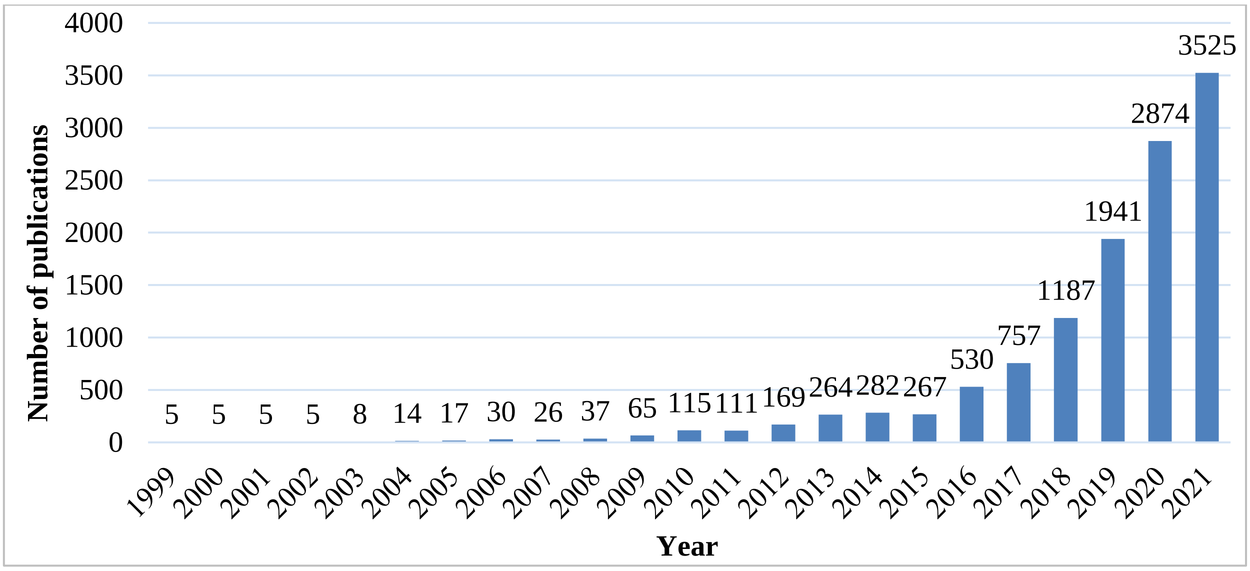

Figure 2–1: Annual number of publications with the terms “circular economy” or “zero waste”.

Figure 2–2 depicts the geographical locations of authors; these are a result of national and international government efforts to implement CE in practice and boost its research. The Chinese government formally adopted CE as a development strategy in 2002 (Geng and Doberstein, 2008), and ratified the first CE law shortly after (The Standing Committee of the National People’s Congress China, 2008). Likewise, the European Commission (2015) published an ambitious CE Action Plan and recently updated it (European Commission, 2020). Some countries that seem to have a better CE performance (based solely on their reintroduction of materials in the consumption system) such as Germany, Japan and the Netherlands (Circle Economy, 2020). However more research is needed to fully understand and compare the nationwide employment of CE.

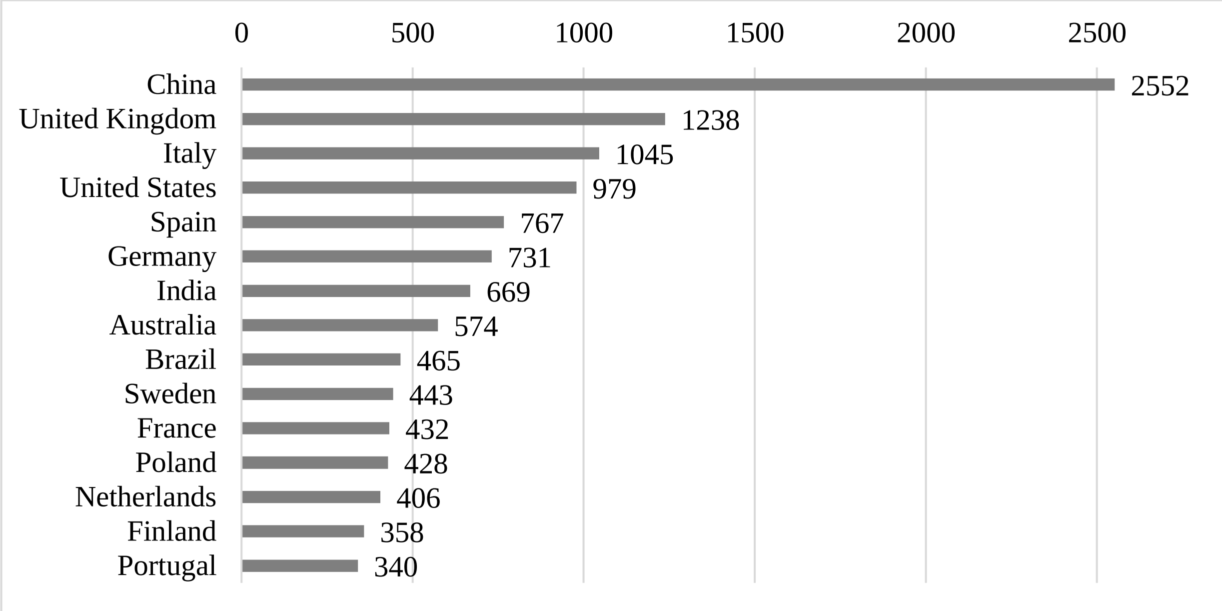

Figure 2–2: Geographical locations of authors of publications with the terms "circular economy" or “zero waste”.

2.1.2.2 Origins

Some authors (e.g., Greyson 2007; Heshmati 2015; Rizos et al. 2016) attribute the most significant influence of the development of the CE to Boulding’s (1966) essay titled *“The Economics of the Coming Spaceship Earth”*, which introduced the idea of a “spaceship” economy. That work described the future Earth as a closed system with no inputs from the outside (apart from the energy provided by the sun) and no outputs going outside, without infinite stocks for extraction nor disposal/pollution. Thus, humanity must adapt to the circular ecological system with perpetual reutilisation of materials and embrace the external inputs of energy.

Meadows et al. (1972) explored important planetary boundaries for the first time. Their work analysed the consequences of global consumption and production patterns with a computer model. Five key variables are the base of the model: agricultural production, population growth, non-renewable resources consumption, industrialisation, and pollution. An update of the work (Meadows et al., 2004) reinforced the alarming message based on the statement that the resources on Earth are finite. Thus, if humanity does not take measures soon, before the start of the XXII century, the exponential growth in population and consumption would lead to the planet experiencing an uncontrollable decline.

Stahel and Reday (1976) set the first basic characteristics of the CE. With an industrial economics focus, they introduced resource efficiency, dematerialisation, waste prevention and regional job creation in the industrial economy as key concepts for a closed-loop economy. Stahel (1982) added the foundations for selling utilisation rather than ownership as a sustainable business strategy to a closed-loop economy, permitting companies to continue profiting without generating costs and risks to the consumers associated with waste. The previous idea is behind servitisation business models, and further expanded in the "performance/sharing economy" (Stahel, 2010).

Pearce & Turner (1990) were also pioneers mentioning the CE term formally. In their work, they stated that:

1) Every resource used will return to the environment as waste or emissions.
2) It is not possible, based on the first and second laws of thermodynamics respectively, to recycle and transform back to resources all the waste due to physical constraints.

Furthermore, they state that "everything is an input of everything else", and more importantly elaborate on the relationship between economics and the environment, highlighting the latter's economic functions as a resource provider, waste receiver and source of utility. Pearce & Turner (1990) argued that traditional economics regularly does not consider the environment, so they proposed to elaborate and expand the current economic horizons by emphasising the need to consider development more comprehensively including social and environmental aspects.

In the city context, Girardet (1996) introduced the seminal distinction between linear and circular UM. The author described linear UM as a city that just uses what resources it needs and disposes of the waste; there exists no relationship between outputs and inputs. Conversely to this linear consumption paradigm, a CE provides for a more active approach to resource and waste management in which materials are fed back into the system rather than being 'lost'.

In support of CE thinking, there are several *Schools of Thought,* three of the most well-known are:

1) *Cradle-to-Cradle (C2C)* is a design philosophy first introduced by McDonough & Braungart (2002) that aims to build products to be perpetually recovered and reutilised. C2C considers all resources used in human activity as nutrients and classifies them into technical and biological. The former are designed to be reintroduced into the technical cycles of industrial processes; whereas the latter, are to be recovered by nature's cycles.

2) *Product-Service Systems (PSS)* are determinant in the sharing economy and aim to understand better that the approach from products fulfilling necessities, must turn into the final consumer need, demand or function needed to be satisfied (Tukker, 2015). That is,

instead of focusing on the final product sold to clients, the result or service required should be the primary target. Tukker & Tischner (2006: 1552) provided one of the most cited definitions for PSS: "*consists of a mix of tangible products and intangible services designed and combined so that they jointly are capable of fulfilling final consumer needs*".

3) Industrial Networks build on the work of *Industrial Symbiosis (IS)*, where a minimum of three industries collaborate by exchanging resources (Den Boer et al., 2014). Practitioners perceive IS as the CE in practice, as several case study examples are found in the grey literature (e.g., ZeroWIN, 2014). Further explanation can be found in Section 2.1.3.1.

2.1.2.3 Definitions and interpretation

CE provides an alternative economic proposal which emerged as a change in paradigm for the current production process. Its name derives from and contrasts with the traditionally linear approach adopted towards resource use, where; *we take, make, use and dispose of* (Ellen MacArthur Foundation, 2016). Briefly explaining the linear economy further helps to better understand the concept of what makes a CE. Figure 2–3 illustrates both the linear and circular approaches to resource and waste management. The linear economy involves mainly the following stages:

1) Extraction of resources from the Earth's crust.
2) Refinement of these resources to transform them into materials ready to utilise.
3) Materials are processed to create parts and pieces.
4) Parts and pieces are assembled and joined together to form a product / good.
5) Consumers utilise the good for a specific time.
6) Ultimately the product's lifetime ends. In turn it becomes waste and is disposed of.

Notwithstanding its final demise to a waste product, waste (in all its forms) can be produced at any stage of the lifecycle. All steps of the process have costs and consume resources, likewise they cause pollution and generate GHG emissions. To summarise the linear economy in one simple phrase would be: (we) extract, to use and dispose of. Conversely, to summarise a CE, it is an attempt to reintroduce resources at different stages of the consumption process as shown in Figure 2–3, which was created by the author of this thesis. However, it is helpful to take into consideration that the production and retail processes are highly globalised. This results in resources being extracted from a specific geographical area, moved across the globe and disposed of in a completely different place.

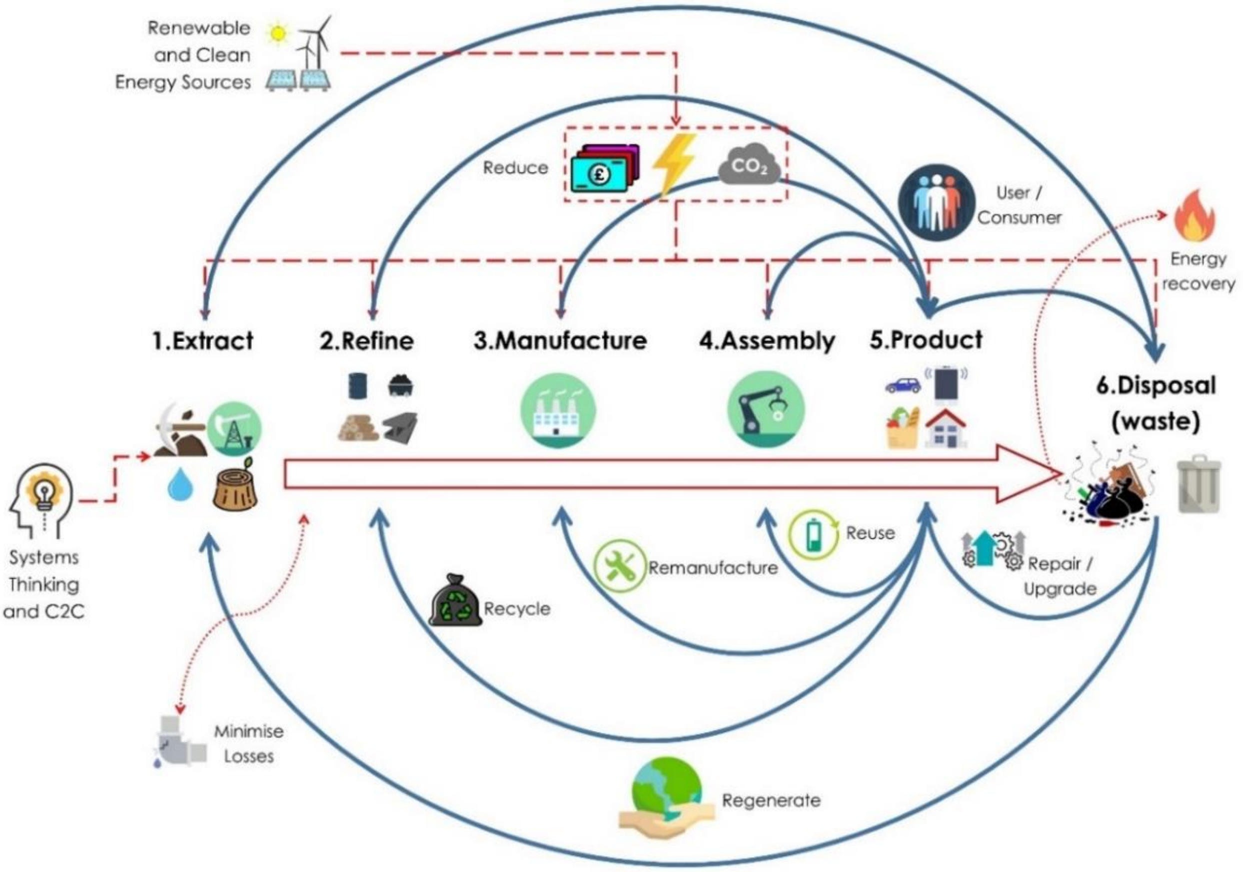

Figure 2–3: A Circular Economy (CE) diagram *(Source: self-elaboration)*.

Interest on the CE, from academics, businesses and governments, has been growing steadily over the last decade (Geissdoerfer et al., 2017) and several recent articles have analysed the concept and the evolution of its interpretations in this time. For example: Hill (2011) pioneered the discussions on accounting the inventories of materials leading to overconsumption; Heshmati (2015) investigated the implementation and current circular practices; Lewandowski (2016) classified circular business models into eight categories; Sauvé et al. (2016) compared the CE with sustainable development and environmental sciences; Lieder and Rashid (2016) developed a comprehensive CE framework in the manufacturing industry; Ghisellini et al. (2016) provided an extensive review of research on CE; Benton et al. (2017) provided a sophisticated understanding of material risk and the means to embed it into corporate practice; Blomsma and Brennan (2017) investigated the origins of the CE concept; Murray et al. (2017) discussed differences and similarities between sustainable business models and CE; Rizos et al. (2017) reviewed definitions, processes and impacts of a CE; Geissdoerfer et al. (2017) compared the sustainability and CE concepts.

In order to define what CE means for this research it is worth looking at stock definitions that exist. Table 2–2 presents some of the most recognised found within the general literature reviewed.

Table 2–2: Circular Economy (CE) interpretations and definitions.

Source	Interpretation/definition
Geng and Doberstein (2008)	Closing the loops of material flows in an economic system is understood as the accomplishment of a CE.
Bocken et al. (2016)	CE is a set of business models and design strategies that aim to slow, close and narrow resource loops.
Sauvé et al. (2016)	CE is the incorporation of environmental externalities in the consumption process of products. Through a closed-loop of material flows, the environmental costs are internalised, including waste generation, pollution and extraction of raw materials.
Geissdoerfer et al. (2017: p.3)	CE is "a regenerative system in which resource input and waste, emissions and energy leakage are minimised by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling".
Circle Economy and EHERO (2017)	In a CE, value is conserved and added through reuse, repair, remanufacture and recycle. In this way, materials are recovered instead of being spent. The system aims for a long-term function, and its main goal is to continue adding value in all its stages.
Bastein et al. (2013)	In a CE, emissions and waste are used in the value creation process; this increases resource security and reduces the load on the environment. This presents new economic opportunities, creates competitive industries, and generates jobs.
Su et al. (2013: p.215)	The CE focus "has gradually shifted from narrow waste recycling to broad efficiency-oriented control. Moreover, more areas have been covered, such as energy efficiency and conservation, land management, soil protection and water resource management".
Ghisellini et al. (2016: p.11)	"By promoting the adoption, CE aims to increase the efficiency of resource use, with special focus on urban and industrial waste, to achieve a better balance and harmony between economy, environment and society".
EEA (2016)	CE mainly focuses on reducing resource consumption by recycling, reusing inputs, and considering waste as a resource. However, it also boosts the improvement of social well-being, economic growth and jobs creation while attempting to minimise environmental damage.
Ellen MacArthur Foundation (2013a: p.26, 2013b: p.7, 2015: p.2)	"A CE is restorative and regenerative by design and aims to keep products, components and materials at their highest utility and value at all times". "It replaces the 'end-of-life' concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals (…), and aims for the elimination of waste (…)". "It aims to enable effective flows of materials, energy, labour and information so that natural and social capital can be rebuilt".
European Commission (2015: p.2)	To transform our economy into a CE, waste generation should decrease, and the value of products, materials and resources needs to be conserved. A CE "is an essential contribution to the EU's efforts to develop a sustainable, low carbon, resource-efficient and competitive economy".
van Buren et al. (2016)	A CE aim is more than recycling; it implies reducing raw materials consumption, the design of products easily reused, maintenance and repair allow extending their life. It also creates social-economic value and promotes the conservation of natural resources.

As observed from the table, the CE definition has been developing over the last fifteen years, and more sustainability dimensions have been gradually considered (Geissdoerfer et al., 2017). However, some interpretations are limited to recycling only, and any link to sustainable development (social equity particularly) are at best quite weak (Kirchherr et al., 2017b) and at worst non-existent. Furthermore, research on the topic is fragmented, and interpretation amongst disciplines and practitioners is varied (Rizos et al., 2017); thus a lack of consensus and shared understanding between stakeholders could lead to a deadlock for the concept (Kirchherr et al., 2017b). Similarly for the inclusion of stakeholders, this work deemed it important to consider a wider range of participants in the CE transition, and finally the more comprehensive actions to capture the remaining value in waste (including the waste hierarchy). Due to these shortfalls within this research a CE is interpreted as follows:

> *A CE is a set of principles and tools which aim to contribute to the planet's sustainability by minimising the extraction and degradation of materials, promoting resource and energy conservation, embracing the waste hierarchy as a guiding principle (reduce, reuse, recover and recycle) and driving the regeneration of its input sources. As such, it fosters the willingness to, and facilitates in, the repair and upgrade of products through innovative and systems-thinking that embraces waste as a primary resource, allowing its reintroduction into the consumption system. A CE is inclusive with the environment, society, governments, companies, and academia, and boosts the development of resilient business models which capture various forms of value through stakeholder cooperation.*

2.1.2.4 Criticism and limitations

The CE concept has detonated criticism and debate on multiple aspects:

1) Firstly, there is no agreed consensus for its definition, which results in stakeholders interpreting it to include their own vested interests (Rizos et al., 2017). Also, if the vague definitions dominate, the concept could end in another sustainability deadlock, and there is the risk that its implementation will become only another buzzword in the sustainability narrative (Kirchherr et al., 2017).

2) Secondly, impacts on the social dimension have been underestimated just as in many sustainability studies for decades (Murray et al., 2017).

3) Lastly, there are many physical limitations of recycling added to an ever-growing economic model such as some materials being recyclable only for a certain amount of time, there are inefficiencies in energy generation, and rare-earths and critical materials are found in only finite amounts (Ghisellini et al., 2016).

Additionally, Korhonen et al. (2018) present the limitations of the concept in terms of six classifications:

- Thermodynamics – resources are consumed, and waste and emissions are generated.
- System boundaries – spatial: issues are postponed along the life cycle; and temporal: short-term solutions can build long-term problems.
- Physical scale of economy – rebound and boomerang effect, causing larger issues than originally intended.
- Path-dependency and lock-in – first technologies retain their market position in spite of their inefficiency.
- Management and governance – inter-organisational management of inter-sectoral flows of resources.
- Cultural and social definition – the concept of waste is socially and culturally constructed, and this construction is highly dependent on temporal context, so it is dynamic.

Recycling processes typically require some sort of treatment for the material, and these usually require considerably high amounts of energy. Moreover the impact of this energy could represent a greater hazard for the environment than obtaining new virgin materials conventionally; this is due to lack of technology or design of products (Geissdoerfer et al., 2017).

Most of the ongoing actions towards the transition to a CE are related to closing loops in the current linear system (Prendeville et al., 2018). The application of recycling is undoubtedly not recent (Reijnders, 2000), and to contribute effectively to the sustainability agenda, recycling should be based on designing products and processes to conserve and delay losses in quality. In addition, it is about avoiding toxic materials used in products, predicting the needs for future materials, and assuring the use of recycling outputs as needed inputs of the economy. Even though recycling is helpful, it is not of its own enough. Leonard (2008) suggested the concept of '*true recycling*'. Whereby products are designed to be durable and are supported by local collection, cleaning and recycling infrastructure, thus creating local jobs and boosting the local economy, and most importantly reduces the demand to harvest new raw resources. However, many limitations are related to recycling. For example, the number of times a product (e.g., glass, paper, wood, metal, concrete) can be recycled is limited. Therefore, there is a need for more interventional solutions, and this is where the more progressive CE thinking comes into play, for example, by rethinking the designs to replace non- or semi-recyclable materials.

2.1.2.5 *Barriers and enablers*

Many authors have explored the challenges to adopting CE principles, for example, Heshmati (2015) identifies problems to the CE implementation from multiple perspectives:

1) General – an absence of reliable data and information, unadvanced technology, low levels of leadership and public awareness.
2) Entrepreneurial – low level of proactivity, difficult access to funding, and inexperience of green entrepreneurs.
3) Innovation – research is needed to provide benefits of sustainable ventures, describe the transition process, and to simultaneously help improve social conditions, reach environmental targets and generate economic growth.

Rizos et al. (2016) explore both the barriers and enablers for *Small and Medium-Sized Enterprises (SMEs)* in the implementation of CE business models, including lack of: supply-demand network support, capital, government support, technical know-how, information, administrative burden and company environmental culture.

Barriers to a CE were divided into four types by Kirchherr et al. (2017):

- Regulatory
- Technological
- Cultural
- Market barriers

The suggestion was that the last two were most pressing to overcome because of the lack of awareness and interest from consumers, and the market largely being dominated by low virgin material prices and high initial investments. The role of civil society in CE implementation is widely underestimated (Naustdalslid, 2014) and there is a critical need to change the economic principles from one that often does not consider the environment sufficiently (and the consumption behaviour of consumers and producers) to one which complies more readily with CE principles (Lieder and Rashid, 2016).

Rizos et al. (2016) used a database of case studies provided by *GreenEcoNet* to both identify and explore the importance of barriers and enablers for SMEs in the implementation of CE business models in the EU. The key findings suggest that even though there are efforts in policy to encourage CE implementation, SMEs experience several barriers in the transition. These include, but are not limited to:

- Lack of the supply-demand network support
- Capital
- Government support
- Technical know-how
- Information
- Administrative burden
- Company environmental culture

Contrary to common belief in the literature of CE, cultural barriers seem to be more pressing than technological in the EU (Kirchherr et al., 2017), as a large number of surveyed businesses and policy-makers claim that a *"lack of consumer awareness and interest"* and *"hesitant company culture"* are the most prominent reasons hindering the CE implementation (Kirchherr et al., 2018). Outside the EU, this might not be the case as developing countries could find it more urgent to acquire the technology that will bring them closer to a CE. However, this would need to be further researched in order to understand better the barrier differences across geographical areas.

As such, one of the objectives of this research is to help overcome some of the barriers categorised by Kirchherr et al. (2018) depicted in Figure 2–4. The order from bottom-up as suggested by Kirchherr et al. (2018) aims to create a "cascading" effect that will help the barrier below to overcome the one above. For example, the most important to this research are the cultural barriers, "*hesitant company culture*" and "*limited willingness to cooperate in the value chain*" which could then lead to obtaining funding for circular business models. This then enables to overcome obstructing laws and regulations and improve the circular procurement processes in government. In consequence, it would help to address the technological barrier "*too few large-scale demonstration projects*" with an applied case study as participants hoped that the case study site researched in this thesis would "*become a national exemplar*".

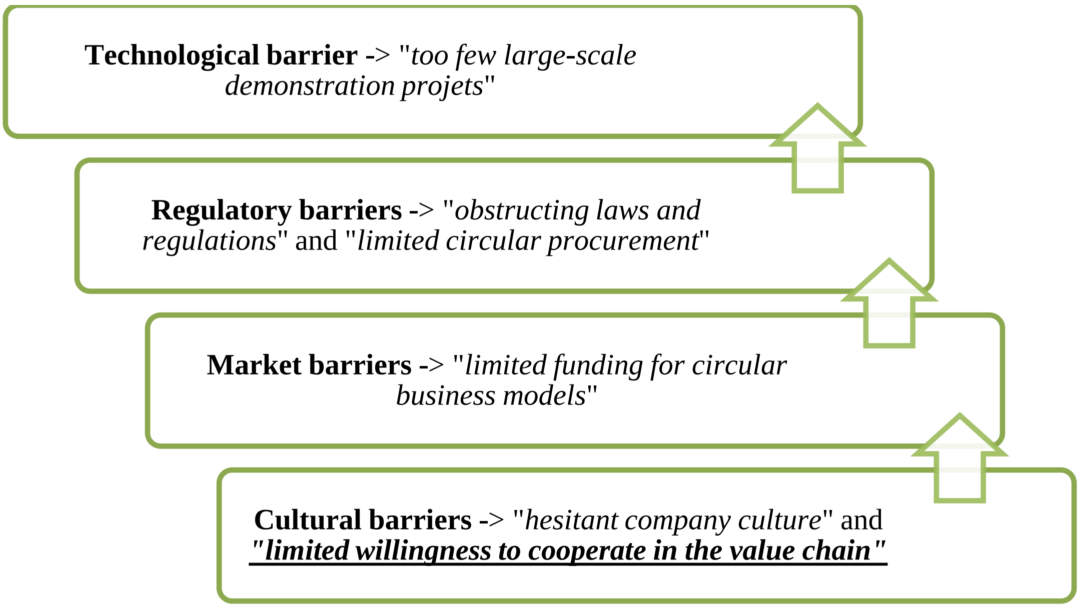

Figure 2–4: Barriers to CE adoption – all addressed in this research (*Kirchherr et al., 2018).*

On the contrary, factors that can enable the transition to a CE have also been widely researched, for example, de Jesus and Mendonça (2018) studied and categorised the drivers of a CE and the barriers to these opportunities in the following, and some examples are in the paragraphs below:

- Technical
- Economic
- Financial
- Market
- Institutional
- Regulatory
- Social
- Cultural

Improvement opportunities for preventing waste generation and waste management towards a CE, are most present in developing countries (Ilić and Nikolić, 2016). Castán Broto et al. (2011) identified urban infrastructures as a key enabler of circular practices; stating they are the conductors of circular urban flows, thus their importance features most significantly in the creation and maintenance of circular loops.

Digital technology is an essential potential enabler of achieving circular cities. Whereby the combination of the digital revolution and the transition towards a CE helps tackle the issues presented by the high urbanisation rate (Sukhdev et al., 2017). Moreover, digital technologies have a developing and supportive role in the CE implementation and assessment – by enabling material reintroduction and optimisation of resource flows at the appropriate place and time

(Pagoropoulos et al., 2017). *Artificial intelligence* is another potential key enabler to achieving the transition towards a CE (Ellen MacArthur Foundation, 2017; Sukhdev et al., 2017). Smart cities can advance the circularity of urban areas through the collection and analysis of large amounts of data on materials, people and external conditions, identification of the challenges of material flows, outlining the key areas of structural waste, and informing more effective DM on how to address these challenges and provide systemic solutions (Andrade and Yoo, 2019).

However, people seem to have an equally significant role as technologies in the transition towards a CE; thus, *education* is a crucial enabler to enhance a participatory, well-informed and circular demanding society (Webster, 2013; Pomponi and Moncaster, 2017). Thus, adopting new techniques to embrace CE education in new generations (Whalen et al., 2018) and action learning for industry practitioners (Cother, 2020) is vital. Customers are an essential part of CE, and their awareness is key for implementation; only if improving this with public campaigns, seminars and educational programs (Lieder and Rashid, 2016). Furthermore, there might be a need for government intervention and circular start-ups as barrier breakers (Kirchherr et al., 2017).

2.1.3 UM as a framework for circular cities design

2.1.3.1 Industrial Symbiosis (IS)

Engineering scholars acknowledge *Industrial Symbiosis (IS)* as the most important application of UM to the CE in cities. IS emerged from the engineering perspective of UM known as *Industrial Ecology* (see Sub-section 2.1.1.1). Chertow (2000) introduced the most accepted definition, which emphasises the geographic proximity of multiple industries as a determinant factor for separate firms to collaborate and share the synergistic possibilities. This offers taking advantage of the mutual benefit exchange of energy, water, materials, by-products, and most importantly, waste streams as secondary resources. However, geographic proximity is arguably not the essential nor sufficient characteristic for IS; and even less the simple agglomeration or industrial clusters should not be confused with IS practices. Innovation and sharing networks of information result in the improved efficiency in resources usage by sharing and exchanging (Lombardi & Laybourn, 2012).

Industries create value-added products, decrease costs and improve environmental quality through the concurrent sharing of utilities, services and by-product resources (Chang and Pires, 2015). *Eco-Industrial Parks (EIP)* are considered the tangible realisation of the IS concept

(Chertow 2000), as industries embrace the synergies in their production processes to yield a more substantial result than if they worked individually. EIP simultaneously increase resource efficiency, reduce costs of regulation and waste streams and provide access to better partnerships (Chang and Pires, 2015).

The first EIP documented case study and also the most well-known is in Kalundborg, Denmark, where the seminal example of sharing water, steam and other resources. Also, the achievements included avoiding disposal fees and reduced prices by substituting resources; reducing intake of surface water; economic savings due to energy-cascading designs; reducing carbon emissions from electricity generation from steam and heat from the power plant; and exchanging wastewater between companies (Jacobsen, 2006). In summary, both academics and practitioners, often refer to IS as the CE in action/practice and recognise it as a CE practical enabler and critical research area.

2.1.3.2 UM applications to CE

Girardet (1992) was the first to bring to discussion the links between UM and sustainability. The sustainability of cities is jeopardised by the linear production of waste in the UM process; transforming linear into circular flows improves urban resilience. Waste management and reutilisation approaches help to achieve the previous (Castán Broto et al., 2011). Kennedy et al. (2011) developed one of the pioneering applications of UM towards designing circular cities. In the study, postgraduate students in Civil Engineering at the University of Toronto have used UM as a guideline to sustainable design. By redesigning the flows of energy and materials (e.g., greywater reuse, sludge from wastewater, energy from waste and fly-ash), they attained to close these loops partially and reduced the inflows of materials, water, and energy.

Back to the engineering perspective of UM, increases in the efficiency of resource management, waste recycling and energy conservation are some of the potential benefits of the powerful tools for analysis delivered by UM (Kennedy et al., 2007). CE design in cities can be supported by the UM framework in several ways (Kalmykova and Rosado, 2015), for example, by:

1) Quantifying flows of resources – basic units for CE.
2) Analysing the distribution of flows to different industries.
3) Identifying possible links amongst stakeholders with suitable infrastructures and materials, as well as drivers for resource flows.
4) Assessing the effects of CE using indicators such as resource consumption, productivity, and reutilisation.

Likewise, Kennedy et al. (2011) classified the UM applications in four categories which could serve as potential areas in the contribution towards a CE in cities:

1) UM research has produced additional sustainability indicators.
2) UM research has also contributed to improved accounting for GHG emissions.
3) Mathematical UM models have been developed to assess the impact on UM of policy and technological changes.
4) UM has the potential to be used as an urban design tool, although developments are very much in their infancy. For example, the UM tool has been used to study the resource flows of different neighbourhoods in Toronto, Canada (Codoban and Kennedy, 2008; Kennedy et al., 2011).

The Ellen MacArthur Foundation (2017) suggests encouraging innovation in the urban economy. *'Circular-by-design'* products must replace one-way or linear products. This could create opportunities for local business models and vibrant communities in addition to the environmental benefits from circular design. Thus, the Ellen MacArthur Foundation (2017) identifies the following enablers for CE in urban areas:

1) Cities concentrate people and materials; density allows access to important services and this proximity enables reuse and sharing models.
2) Efficient markets have enough demand derived from the large variety of material supply.
3) Municipal governments being able to shape urban policy and planning. Besides, if there is a lack of entrepreneurship, local governments can interfere.
4) The extensive collection of data derived from the digital revolution, such as the Internet-of-Things and smart cities, represents the potential to identify and systematically solve issues regarding material flows and waste management.

A research framework to bring CE to a meso-level in the built environment (buildings), was proposed by Pomponi and Moncaster (2017). The main highlight is the inclusion of Political, Technological, and Behavioural (i.e., Social) dimensions to CE. Additionally, they argue that the transition to circular construction should consider both top-down and bottom-up initiatives. Therein CE contractors would design and construct buildings to 'generate' rather than 'consume'; and will provide a sharing, automated and electric-powered transportation (Sukhdev et al., 2017). Kennedy et al. (2011) explored the applications of UM in urban planning and design; the findings suggest that future studies should integrate more economic, social and health (wellbeing) indicators in the UM framework, and should work on the challenge to design and rebuild urban areas sustainably.

The aim of a CE within cities is to improve resource security, social equity, and environmental responsibility conditions in future urban areas. To support this thinking, Agudelo-Vera et al. (2012) identified the most paramount objective towards more resilient cities by focusing on the unclosed links amongst the demand and resources available in cities. Likewise, Agudelo-Vera et al. (2012) showed that the implementation of separating the flows of waste and exploiting the remaining qualities of resources, and the effective (re)-use of local resources makes urban resilience reachable. Barbosa et al. (2014) suggested that increased sustainability would be achieved if urban areas became more self-sufficient in terms of water, food, materials, and energy. In other words, a city needs to be more autonomous, providing improved resilience to external factors – satisfying its own basic needs without importing resources to operate.

2.2 Review of Surveys Studying CE Features

This section of the thesis addresses the first objective (O1) in Table 1–1, which identifies cooperation features by reviewing CE survey-based studies, has been published[3]. Usually, the most common reason to investigate the awareness (and understanding) of a particular topic or theme is to engender increased use or changes in practice (Liu et al., 2009). To apply this thinking to CE practices, sustainable consumption and behaviours must be investigated (Veleva and Bodkin, 2018). Studies that try to evaluate CE awareness and stakeholder perceptions and practices related to CE, and hence seek to make the transition towards a CE, remain scarce in the peer-reviewed literature. Thus, the search of CE survey studies was expanded to include the ‘grey literature’.

This is because the grey literature, despite its great variation in quality, usually contains relevant conference proceedings, working papers and business, consultant and government reports on CE surveys (Adams et al., 2016). The Google Scholar tool was used to track this down as it is sometimes hard to find. The search strategy used the Boolean operators (“circular economy” OR “zero waste”) AND (survey OR questionnaire*). Table 2–3 provides the created taxonomy of CE features to achieve stakeholder cooperation for this study; it is based on the most relevant literature from the search – one of the underlying objectives (O1) behind this research. This section reviews both the grey and the limited academic literatures found that have adopted surveys and questionnaires to measure the relevant features to achieve stakeholder cooperation in a CE.

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[3] Palafox-Alcantar, P.G.; Hunt, D.V.L.; and Rogers, C.D.F. 2021. Current and Future Professional Insights on Cooperation towards Circular Economy Adoption. Sustainability. 13, 10436, Available at MDPI: https://doi.org/10.3390/su131810436.

Table 2–3: Taxonomy of stakeholder cooperation aspects in the CE transition.

	CE features to achieve cooperation							
Authors	Awareness	Waste behaviours	Activities/ practices	Barriers/ drivers	Attitudes	Indicator preferences	Benefit/costs expectations	Perceptions of others
Liu et al. (2009)	✓				✓			
Xue et al. (2010)	✓	✓		✓	✓			
De Feo and Williams (2013)	✓	✓	✓		✓			✓
Liu and Bai (2014)	✓	✓			✓			✓
Lakatos et al. (2016)	✓	✓			✓			
Ferronato et al. (2017)	✓	✓	✓	✓	✓			✓
Guo et al. (2017)	✓							
Pheifer (2017)				✓				
Adams et al. (2017)				✓	✓			
UKGBC (2017)			✓	✓				
Borrello et al. (2017)		✓	✓		✓	✓		
Veleva et al. (2017)	✓		✓		✓			
Buil et al., (2017)	✓	✓			✓			
Smol et al. (2018)	✓	✓			✓			✓
Greentech Brussels (2018)	✓		✓	✓	✓		✓	
Masi et al. (2018)			✓	✓	✓		✓	
Marios et al. (2018)	✓							✓

Table 2–3 (cont.): Taxonomy of stakeholder cooperation aspects in the CE transition.

	CE features to achieve cooperation							
Authors	Awareness	Waste behaviours	Activities/ practices	Barriers/ drivers	Attitudes	Indicator preferences	Benefit/costs expectations	Perceptions of others
Mahpour (2018)				✓				
Rodriguez-Andara et al. (2018)	✓			✓	✓			
Fonseca and Domingues (2018)	✓	✓			✓			✓
Kirchherr et al. (2018)	✓		✓	✓				
Liakos et al. (2019)	✓		✓				✓	
Cother (2020)				✓				
Borrello et al. (2020)		✓	✓	✓	✓			✓
Rodríguez-Chueca et al. (2020)	✓		✓		✓	✓		
Ferronato et al. (2020)	✓	✓	✓	✓				
Gazzola et al. (2020)	✓		✓		✓		✓	
Loste et al. (2020)	✓		✓					
González-Domínguez et al. (2020)	✓				✓			✓
Revinova et al. (2020)	✓			✓				✓

2.2.1 Studies on student cohorts

To begin the review, a search of literature using Google Scholar was performed. Publications that had the key terms were filtered using the tools of the search databases, thus, the search strategy for these studies was the following: TS=("circular economy" AND student* AND (survey OR questionnaire*)). Few results (24) were obtained and after scanning through them, only nine of them were found relevant for the review because most mentioned CE or zero-waste once but were not fully related to the topic. Most include university students, which align well with the purpose of this paper. The first study found focused on primary school children (aged 8-12) in Spain and analysed how future generations are involved in the recycling of aluminium cans. It was shown that workshops with recycled cans could increase the awareness and intention to recycle of future generations (Buil et al., 2017).

The rest of the studies focused on university students, although from different geographies globally. For example:

- Engineering students have been surveyed about: the effectiveness of active learning procedures when considering environmental and social issues (Rodriguez-Andara et al., 2018) and the importance of CE topics to their courses and future careers (Rodríguez-Chueca et al., 2020).
- University students have been surveyed about fashion industry trends and their own behaviours towards more circular companies (Gazzola et al., 2020).
- University students have been surveyed with respect to their attitudes and practices with respect to recyclable waste segregation and collection activities in university campuses (Ferronato et al., 2020).
- Students on Massive Open Online Courses (MOOCS) have been studied with respect to the use of environmental assessment tools (including CE as enablers for improving sustainability; Loste et al., 2020).
- Industrial engineering students have been studied with regard to the applications of CE techniques to design and develop products (González-Domínguez et al., 2020).
- University students have been studied with respect to their current awareness of barriers to and future prospects of the sharing economy and related business models (Revinova et al., 2020).

De Feo and Williams (2013) surveyed the perceptions of university students (i.e., next generation users) on aspects relating to the siting process for new incinerator and landfill facilities within Campania, Southern Italy. It is focused on a region where authorities have historically failed to deliver *Municipal Solid Waste Management (MSWM)* robust solutions. The study first aimed to measure the knowledge of *Municipal Solid Waste (MSW)* (their awareness) and then measured its relation to their opinion (behaviour/attitudes) towards more sustainable MSW treatments. The findings suggested that there is a high correlation between being more aware and having more positive attitudes towards MSW problems. This study also enquired about the opinions of respondents towards a range of stakeholders (e.g., technicians, politicians, citizens) participating in the siting (DM) process of MSW facilities. The results showed that respondents generally accepted that all stakeholders should participate in the DM process. Even though it was not the purpose of the study, it did not consider the vast array of CE related alternatives for incineration and landfill – other than recycling. Furthermore, the authors only studied differences amongst faculties and course years but did not consider differences between other potential DM stakeholder groups.

Ferronato et al. (2017) explored awareness and opinion differences between the general public in a developed society (i.e., in Varese and Salerno, Italy) and higher education students in a developing country (i.e., in La Paz, Bolivia). The authors found that while recycling rates remain low in emerging society, nearly two-thirds of the students recycle more than half the waste produced at home. Furthermore, more than half of the students are unaware of the informal sector practices (e.g., scavengers) in terms of recycling. The study did not ask any demographic questions since it was focused on university students, and thus correlations between age and household income were impossible to perform. Besides, further relevant CE aspects were not addressed in the study apart from understanding the recycling practices of the respondents at home.

Only one conference proceedings article performed a study with cohorts of both Students and Companies. Fonseca and Domingues (2018) surveyed attitudes and agreement of the local government to adopting CE principles and found that there is high positivity of participants towards *'businesses based on product-service systems to reuse and recycle parts'*. They concluded that more work is needed in the students' syllabi to reinforce this perspective not least because students will become change agents in their future work – moving us towards (or away from) circularity.

2.2.2 Studies on practitioners and businesses

Despite its variation in quality, the grey literature contains a number of relevant conference proceedings, working papers and business, consultant and government reports on CE surveys (Adams et al., 2016). The Google Scholar tool was once again used to track down this type of literature as it is sometimes hard to find through traditional search tools (e.g., Scopus, Engineering Village). The search strategy used the Boolean operators: TS=((“circular economy” OR “zero waste”) AND (survey OR questionnaire*)). The filtered results showed a large amount of studies involving companies (n=87), thus the most relevant for this research were reviewed. The findings for CE awareness are as follows:

Liu et al. (2009) performed the first recorded study attempting to measure CE awareness. The research aimed to provide a starting point for understanding CE behaviours and awareness of the general public in Tianjin, China. Their findings demonstrate that the older the population, the more sustainable consumption behaviours they have, but the younger population is generally more aware of the new CE paradigm. However, the study was limited to the *3Rs (Reduce, Reuse and Recycle)* framework while CE implies a broader scope. In addition, the data collection procedures were dubious since a single investigator returned far too large samples of data. Moreover, the design of the survey did not allow for identifying factors that influence pro-environmental behaviours – this can be considered a shortfall in that research.

Guo et al. (2017) performed another study that investigated the CE awareness of the public in the West of China. The survey was carried out in two different periods, 2008 and 2013, to allow comparison of the CE development in the region. The outcomes showed that on average, the awareness and practices of CE in households from 2008 had nearly a six-fold increase in five years. The study performed well in gaining more in-depth insight into the public attitudes and behaviours towards CE, even by providing multiple types of waste generated in households. Also, this was the first study to ask about attitudes towards the future development of CE in the region. However, the analysis could have benefited more from a Likert scale type of response because the questions were limited to only agree and disagree statements. Besides, the phrasing of some questions might have confused respondents, for example, asking respondents if they would be willing to purchase energy conservation appliances, only if the government partly subsidises the extra cost.

Xue et al. (2010) performed another early study measuring the awareness of CE of six city authorities in China. The survey’s aim was to investigate the relationship between CE awareness and its relationship with the enforcement efficiency at city level. The findings indicated that the awareness levels are higher in cities where CE schemes and campaigns have been implemented (with up to 79% of respondents being aware of CE). Also, the most pressing barriers to implementing a CE were identified as weak public awareness and the absence of financial support. Despite attempting to gain insights on the performance of promoting CE, the questions were limited to more individual CE actions, for example, home activities or daily routines.

Furthermore, the questions about barriers to a CE were designed with an overview about diverse and general areas rather than providing a detailed focus of specific aspects relating to CE development.

Marios et al. (2018) studied public awareness and attitudes towards CE in Greece. The survey asked participants to (1) rank areas of CE that affect consumers positively and (2) identify which business activities would benefit most from CE adoption. The outcomes showed that CE knowledge was not the highest amongst the population, but their attitudes and expectations were very positive. However, the study did not provide insights into the respondents' behaviours or current or potential future CE practices that could be adopted.

Smol et al. (2018) studied CE public awareness in the southern region of Poland. The study focused on daily routine(s) and household CE related activities, as well as the future expectations on how CE will develop in the region. The results generally showed that over three-quarters of the respondents were familiar with the CE concept; however, when asked about their daily routine activities, about two-thirds dealt with their household waste in isolation. However, fewer than half were willing to adopt sharing or collaborative economy principles as opposed to a sense of ownership. The main drawback from this study is that the questionnaire was designed specifically for the case study region; thus, it would need to be adapted, taking into local context and conditions for use elsewhere. Additionally, and in order to effectively evaluate the progress on the CE adoption, the awareness and behaviours would need to be measured and correlated – these aspects were not considered.

Lakatos et al. (2016) investigated the consumer behaviour and attitudes of responsible consumption to promote the CE in Romania. The study found high awareness of CE and willingness to adopt CE principles. The focus was only on consumers' attitudes and their sustainable daily behaviour and practices. The study did not address expectations nor perceptions of other stakeholders in the CE transition.

Borrello et al. (2017) studied the viewpoints from consumers towards CE strategies that attempt to reduce food waste. The survey investigated the willingness of participants to be actively involved in the food saving strategies. The results showed that consumers are mainly driven by monetary incentives. However, the scope of the study presented respondents with two scenarios from which to choose from and did not emphasise cooperation opportunities between households and local governments to reduce the municipal food waste. This last issue is further studied by Borrello et al. (2020), where consumers were asked for their opinions about participating in CE business models for food waste reduction. The results showed that the participant most likely to engage with a food-as-a-service business model is one who has already been involved in CE practices and has developed a long-lasting relationship with the retailers.

Liu and Bai (2014) explored a different scope of the awareness and behaviour of firms to CE development in China. In their study, they attempted to establish the relationships between awareness and actual practice of firms to operate under CE principles. The findings suggest that indeed there is a ‘striking gap’ where high levels of awareness are not enough in isolation for transitioning successfully to a CE. However, these authors did not explore further the barriers to why this occurred. Also, one of their questions asked if the interviewees work with other firms to adopt IS; however, the analysis was only limited to a yes or no response, limiting greatly the information that could have been gained.

Masi et al. (2018) focused on the main actors in a supply chain (focal firms) to study their awareness, practices and barriers. The authors also studied how well the focal firms have implemented or considered implementing CE practices soon. The outcomes establish the relationship between CE practices with short-term economic enablers. The authors developed taxonomies on barriers and enablers for these focal firms – the output of which was a framework for use in similar case studies. Some of the drawbacks of the study are the small but sufficient for statistical significance sample size (77 respondents), which leads to an exploratory rather than definitive study. That said it could be used to help firms in better accomplishing their sustainability goals. A more in-depth study on barriers to specific industries rather than a generic approach could have been considered – leading to the identification of the triggering factors of adopting CE.

On a similar example, Liakos et al. (2019) evaluated the awareness and actual CE practices of manufacturing companies. The authors performed an extensive review of CE empirical models and concluded that there is limited empirical research on practices and awareness of CE. The study aimed to test the CE model by Lieder and Rashid (2016) and validated that the three sustainability pillars are deeply embedded in the CE interpretations of firms. However, most of the responses received came from the UK and Ireland. As most of the manufacturing firms are located in developing countries, a more globalized study would have provided a more valuable insight into the state of play.

Veleva et al. (2017) surveyed employees from US companies in the biotech and pharmaceutical sectors about their awareness and attitudes towards the firms’ zero-waste-to-landfill strategies. The sample consisted of only 102 respondents; however, it was found to be statistically significant. The main limitation was that the study focused on the non-hazardous waste, but both industries are known for producing highly hazardous waste that needs careful management. The study found that companies focus circular efforts on recycling and waste-to-energy. They also report inconsistent data on waste and lack good indicators on reduction and reuse, and employees are not engaged in the “zero waste” transition and their awareness is underdeveloped.

Regarding more specific industry studies, Adams et al. (2017) analysed the levels of awareness, challenges and enablers to CE practices in the UK construction industry. The results show that despite the extensive awareness, the industry as a whole is not clear on what CE could represent for the built environment. A significant barrier is that customers, designers, and subcontractors view themselves as the least informed about this transition. The authors identified cooperation in the supply chain as one of the organisational barriers; however, the study did not provide a more in-depth analysis of the factors affecting this. Despite providing a detailed review of the barriers and enablers in the specific construction sector, further questions regarding opinions on other stakeholders in the supply chain could have been asked. Mahpour (2018) analysed the barriers to the adoption of CE in the construction and demolition waste management sector. They categorised 22 barriers into sets: behavioural, legal and technical. Even though the study provided insightful results for the sector, it did not ask about any other of the features to achieve cooperation towards CE.

Even though the main aim of the publication from Cother (2020) was not to measure CE awareness or practices, a short survey was performed on barriers and drivers to achieve CE projects. The findings showed that individual motivation is the prime enabler, while internal resistance, lack of funding, and time limitations are the main barriers.

An in-depth review of the literature showed that none of the reviewed questionnaire-based studies investigated the role of stakeholder cooperation directly as an effective enabler of the CE adoption. The critical analysis of these studies helped in the design of a taxonomy and development of a comprehensive questionnaire survey on stakeholder cooperation to fill this research gap. This research focuses only on the first (i.e., awareness), third (i.e., activities/practices), fourth (i.e., barriers/drivers), fifth (i.e., attitudes) and last (i.e., perception of others) CE factors of the taxonomy presented in Table 2–3. This is because self-claimed CE awareness and actual CE practices are not always correlated to each other, a phenomenon also known as the ‘striking gap’ (Liu and Bai, 2014). Critically, awareness, barriers, attitudes and practices are assumed to be initial conditions for stakeholders to perceive others beneficially and thus be willing to cooperate, the primary focus of this research. The relationships with the other factors are out of scope for this thesis.

2.3 Review of Decision Making (DM) Methods in the CE and Waste Management Contexts[4]

Cooperation between stakeholders is the main characteristic in the proposed CE definition for this research in Sub-section 2.1.2.3. Concerning that, the "Circularity Gap Report" by Circle Economy (2018), identified seven key elements of a CE, amongst them cooperation to create and capture joint value. In other words, to create shared value and transparency, private and public stakeholders across supply chains must work together. Kirchherr et al. (2018) coded barriers for the CE implementation in the EU and highlighted the lack of enthusiasm of stakeholders to cooperate across the supply chain as a prominent obstacle to overcome. ZeroWIN (2014) is a project in which a business model was developed and collaboration across sectors and via Industrial networks was achieved. Veleva and Bodkin (2018) found that many entrepreneurs and corporations in the USA are collaborating in waste reduction and reutilisation business models, despite the lack of regulations and awareness of the CE paradigm.

The transition towards a CE requires integrated and comprehensive decisions; thus, interdisciplinary thinking is imperative, and cooperation amongst diverse areas is essential. There are multiple and varied methodologies which address the DM process; however, in engineering, these techniques are usually limited to optimising resources, time or costs. The DM methodologies compared in this research were: *Agent-Based Modelling (ABM), Multi-Criteria Decision Analysis (MCDA), Scenario Analysis (SA), Robust Decision Making (RDM)* and *Integrated Assessment Modelling (IAM)*, all to be compared against *Game Theory (GT)* to find their advantages when studying cooperation. Based on the results from Table 2–1, Figure 2–5 shows the annual number of publications of these methods in the CE context that are relevant for this thesis.

[4] Palafox-Alcantar, P.G.; Hunt, D.V.L.; and Rogers, C.D.F. 2020. The complementary use of game theory for the circular economy: A review of waste management decision-making methods in civil engineering. Waste Management. 102, 598-612, Available at Elsevier: https://doi.org/10.1016/j.wasman.2019.11.014.

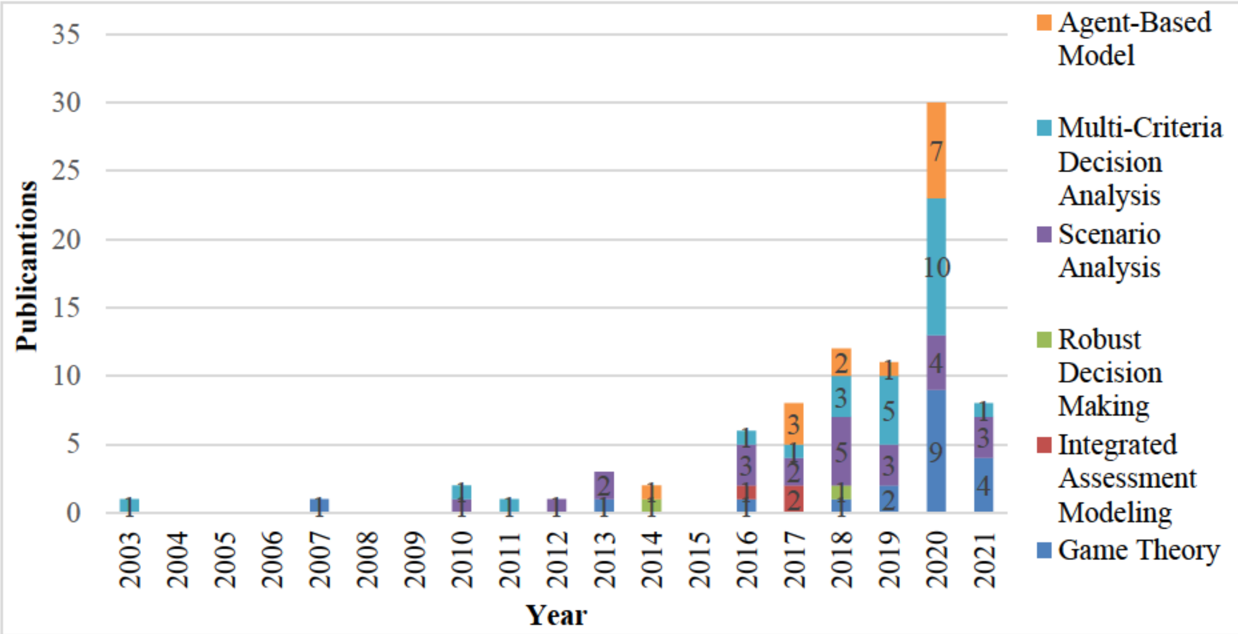


Figure 2–5: Annual number of publications with the methodologies compared in the CE context.

The following Sections (2.3.1 – 2.3.6) explain the properties of the methodologies that study the DM process, trade-offs, objectives and uncertainty, as well as the discussion of some applications. Section 2.3.7 then discusses their similarities and differences and provides arguments for why this research innovatively uses GT as a complementary method.

2.3.1 Agent-Based Modelling (ABM)

Agent-Based Modelling (ABM) simulates the interactions between independent agents and assesses the impacts of their actions on a system (Zechman, 2011). ABM is used to observe the system impacts of the interactions between agents and their behaviours (Macal and North, 2010). Academics use this technique to provide simulations of group dynamics derived from the interactions of individual agents in communities (Kandiah et al., 2017). The main properties of an agent in ABM are:

1) It attempts to accomplish a set of goals.
2) Interactions with the environment and other agents are driven by a specified group of social rules (Fraccascia et al., 2017).
3) They can influence other agents behaviour through pre-determined communication systems (Kandiah et al., 2017).

Moreover, rather than the modeller defining them, the interactions between agents and the interplay between environment and agents, create the system's complex behaviour (Macal and

North, 2010). Agents can also learn from the environment and are capable of adapting to varying circumstances and new data (Silvia and Krause, 2016).

When studying an economic system, ABM is capable of modelling an evolving macro space derived from the interactions among numerous agents ruled by determined simple actions (Wang et al., 2017). Rather than attempting to predict the future, ABM explores the different futures resulting from alternative conditions (Lange et al., 2017). The technique is capable of understanding the relationship between diffusion processes and customers' purchase decisions derived from them (Lieder et al., 2017). ABM has also been used to study cooperation in industrial districts and inside supply chains (Fraccascia et al., 2017). In ABM, the definition of rules is critical, and a simple change can have a radical impact on the agents' behaviour and the model outcomes (Bonabeau, 2002).

Examples of literature reviews in the waste management context include modelling the optimisation of collection services of MSW (Nguyen-Trong et al., 2017); investigating private operators selfish behaviour leading to MSW treatment market competition (He et al., 2017); and identifying the causes of concern in single-stream recycling programs (Shi et al., 2014). Whereas, in CE literature, examples of ABM applications comprise of studying customers behaviours to accepting new CE strategies in their business models (Lieder et al., 2017); measuring the impacts of economic fluctuations on coal IS networks (Wang et al., 2017); evaluating the behavioural changes of residents when launching a local recycling program (Tong et al., 2018); analysing behavioural trends of the waste household appliance recovering (Luo et al., 2019); and simulating mechanisms of economic benefits distribution from adopting IS (Yazan and Fraccascia, 2019).

2.3.2 Multi-Criteria Decision Analysis (MCDA)

Multi-Criteria Decision Analysis (MCDA) aims to organise the alternatives in a hierarchical way (Hadian and Madani, 2015) and thus, prioritise the criteria effectively (Zhao et al., 2017) and thus useful for finding preferences. It is an operational assessment useful to study issues with high uncertainty, multiple interests and conflicting objectives (Wang et al., 2009). MCDA can rank policy alternatives using stakeholder perspectives and cost/benefit information (Ali et al., 2017). MCDA may be used to resolve complicated problems which are ambiguous and highly uncertain, to rank alternatives, it is useful to use a complimentary weighting determination method (Zhao et al., 2017). MCDA is also used when several parameters influence the performance of a task (Sabaghi et al., 2016). The most popular application of MCDA is addressing DM problems under conflicting criteria (Santos et al., 2017). An important advantage of MCDA is that it allows transparency in the analysis and the DM process (Lokesh et al., 2018).

There are a large number of examples that apply MCDA in the WM context, for example: to select the best landfill site (Xi et al., 2010; Demesouka et al., 2016; Kapilan and Elangovan, 2018), or the site for incineration power plants (Feyzi et al., 2019); and to optimise waste flows costs (Cheng et al., 2003); to reduce the reasonable food waste treatment alternatives by combining it with LCA (Angelo et al., 2017). Soltani et al. (2015) reviewed the MSW studies focusing on the stakeholder viewpoints. CE applications of MCDA include considering the parameters in the disassembly process at the end-of-life of an aircraft (Sabaghi et al., 2016); evaluating the performance of thermal power plants and take into account the preferences of the DM participants (Li and Zhao, 2016); and assessing the potential new uses to mining waste (Kaźmierczak et al., 2019). Scholars also used MCDA in comprehensive DM models, for example, Zhao et al. (2017) developed a framework to evaluate the benefits of EIP in a comprehensive CE point of view; and Strantzali et al. (2019) proposed a DM model to optimise the logistics of importing liquified natural gas.

2.3.3 Scenario Analysis (SA)

Scenario Analysis (SA) studies identify how to achieve a set goal in the future (normative) or what will happen in an undetermined (exploratory) manner (Madani et al., 2015) or how to move from an explored to an aspirational (normative) scenario, also referred to as transitive scenarios (Hunt et al., 2013). Academics use scenarios to explore what needs to be done now by looking into what the future holds (Boyko et al., 2012), to test development strategies and select the best plan by using optimisation methods in parallel (Madani et al., 2015). SA aims to identify the preferred scenarios considering criteria within a range of technical, social, economic and environmental drivers of change (Santos et al., 2017). Uncertainty in SA is a set of plausible future outcomes; in other words, the SA models problems where uncertain futures are the base for resilient DM (Pallottino et al., 2005).

SA should not be confused with predictions; on the contrary, they are plausible ways in which the future might develop (Hunt et al., 2012a). Valuable insights are provided for policy-makers when evaluating future implications of current and planned practices (Islam, 2017). To reduce the risk of making the wrong decision, SA considers the temporal evolution of statistically independent scenarios to secure a ‘robust’ choice (Pallottino et al., 2005). This analysis aims to establish the best options by taking into account the short and long-term costs and benefits of different expected results (Geng et al., 2010).

Hunt et al. (2012a) provided an extensive review of methods that derive scenarios, mainly applied to the case of urban regeneration sites. Hunt et al. (2012b) built on the previous work by identifying four scenario archetypes (i.e., *Policy Reform (PR), Market Forces (MF), New Sustainability Paradigm (NSP)* and *Fortress World (FW)*) that emerge within an abundance of scenarios literature. Consistent narratives for them exist in the literature, which helps in the comprehension of fundamental drivers to accomplish a significant and feasible world change. Hunt et al. (2011) used an urban futures toolkit to define and better measure the current and future performance of UK underground space. This extreme-yet-plausible analysis, which has particular utility in determining the resilience of a proposed policy or action, can be supplemented by aspirational futures approaches to increase alignment with a city's, or its citizens', needs and wants (Rogers, 2018; Hunt and Rogers, 2015a, 2015b). A complete SA can be used to investigate cases of extremes; this allows the user to understand how an intervention might be vulnerable when attempting to deliver the intended solution (Lombardi et al., 2012; Boyko et al., 2012). In CE, an example of a positive extreme is looking at a scenario which leads to absolutely zero waste, yet what needs to be in place for such a scenario to happen is of considerable concern; the literature also regards these as the "necessary conditions" to exist in the future (Rogers et al., 2012).

SA is often used to complement future predictions: Luo et al. (2019) further complemented their study with SA to provide recommendations for different optimal scenarios in the household-appliance waste recovery industry. LCA is widely combined with SA: Deviatkin et al. (2016) compared the environmental impact of multiple approaches for utilising sludge from recycling paper mills; De Figueirêdo et al. (2013) seek to improve the transport and reduce the carbon footprint of the export melon industry; Friedrich and Trois (2016) calculated the total GHG emissions of three scenarios for an MSW management system; likewise Ripa et al. (2017) identified many uncertainties and opportunities to improve (and driving factors for) MSW management scenarios; Cong et al. (2019) determined the viability of recyclable end-of-use products since the design stage; Fei et al. (2018) contrasted the energy efficiency and economic and environmental impact of traditional technologies with mechanical-biological MSW treatment. Also, SA was integrated into economic and mathematical models to assess the profitability of natural gas power plants (Cucchiella et al., 2018). Moreover, MCDA has been complemented with SA to study the best combination of MSW management strategies for future

2030 scenarios (Estay-Ossandon et al., 2018). Both techniques are easier to combine and take advantage of their strengths.

2.3.4 Robust Decision Making (RDM)

Robust Decision Making (RDM) addresses uncertainty based on various future representations instead of solely seeking an optimal outcome as the main criterion for DM (Lempert and Collins, 2007). Characterisation is not the main aim of RDM, rather it is to aid decision-makers in managing deep uncertainty by the identification of robust alternatives (Lempert et al., 2004). RDM is iterative and analytical, it considers stakeholder engagement and is helpful in “deeply uncertain” situations, i.e. when the parties ignore or disagree on the consequences of their actions in the model (Hall et al., 2012). Put slightly differently, RDM may be used to assess adaptation alternatives for highly vulnerable habitats (Darch, 2014) and maintain an expected performance under regular as well as worst-case scenarios (Sawik, 2014). RDM facilitates reaching consensus when parties in a DM problem have significant differences in value appreciation and beliefs (Hall et al., 2012).

This method is analytical rather than intuitive; to eliminate uncertainty it is systematic and it attempts to make effective and safe decisions (Croskerry, 2009). RDM is a ‘bottom-up’ approach that aims to identify the vulnerabilities and assess the trade-offs among robust strategies, whilst performing satisfactorily to the decision-maker (Hadka et al., 2015) and; it aims to perform adequately for the decision-maker under both favourable and unfavourable conditions (Sawik, 2014). Eschewing attempts at optimisation, RDM attempts to identify robust decisions that would maintain a “convincing performance” in a wide range of plausible scenarios, while highlighting vulnerabilities in a system by exploring combinations of uncertain scenarios (Matrosov et al., 2013), and provide solutions which are adaptable and insensitive to the presence of uncertainty (Daron, 2015).

2.3.5 Integrated Assessment Modelling (IAM)

Integrated Assessment Modelling (IAM) is used to combine several disciplinary areas to understand systems linkages and interactions, and thereby meet many objectives such as sustainability, economic costs and others (Madani et al., 2015). IAM reports on interactions between endogenous variables (Lee, 2017) and, for example, has been used to exploit knowledge from multiple disciplines to assess climate change policy alternatives (Weyant et al., 1996). An important advantage of IAM in the air pollution context is that it provides “quick” simulations without having to repeatedly run dispersion models (Oxley et al., 2013). In spite of its advantages, IAM is categorised as a complex, and time and large data consuming, method. IAM can integrate stakeholders in the DM process towards avoiding conflict in search for more sustainable SW management alternatives (Hornsby et al., 2017).

Instead of assessing the effects of suggested policies, IAM aids policy makers in describing optimal outcomes and as a result decisions (Tol, 1997). Lee (2017) compared it with eight other econometric methodologies and ranked it last due to its high operating cost and complicated implementation. In the literature, this method has been mainly applied to climate change policy studies (e.g. Tol, 1997; Zhu and Ghosh, 2014) and air pollution (e.g. Carnevale et al., 2014; Oxley et al., 2013; Zhu et al., 2015). IAM can model effects at both regional and local scales and integrate multiple sub-models, such as energy-economy and climate sub-models, into a single integrated system to assess policies in several different ways (Zhu and Ghosh, 2014). IAM considers both impacts and costs of implementing abatement measures to decide on the best option (Carnevale et al., 2014).

2.3.6 Game Theory (GT)

GT is the utilised and well-liked name given to the more accurate “conflict analysis” or “interactive decision theory”. “*The set of mathematical tools for formally studying conflict fall within a field called GT*” (Madani and Hipel, 2011: 1951). GT studies cooperation and conflict derived from the interactive DM process between intelligent and rational stakeholders (Chew et al., 2009). However, in practice most players have limited rationality (Li and Fan, 2013), meaning that their decisions are bounded to incomplete information about the problem, their limited cognitive capacity or the restricted time to make such decisions (Lee, 2011).

GT is of great interest to practical DM as it presents insights on circumstances where the decisions made by two or more participants will affect one another’s satisfaction. Through the analysis of hypothetical examples and quantitative models, it attempts to comprehend cooperation and conflict. These models/examples may seem very simplistic, but the analysis can provide valuable information for real-life situations where very abstract detail is ignored (Myerson, 1991). In a system where uncertainty is complex, and interactions are heavily existent, GT is a suitable DM technique (Lou et al., 2004), as it assigns probabilities to utility functions which can quantitatively measure the likelihood of an event (Myerson, 1991). Furthermore, GT can predict the most likely results in games where participants are concerned with their priorities and strategically decide based on selfish behaviour (Asgari et al., 2014).

GT can be used to improve the understanding of stakeholders' relationships (Howard, 2006). GT can model several interactions between players and predict the different outcomes of the negotiations (Soltani et al., 2016). In problems where:

1) A small number of agents are involved in strategic interaction, and there are hidden information and incentives.
2) There is awareness between stakeholders that their decisions affect each other's outcomes and their potential benefits depend upon other actors' choices; GT is particularly useful (Grimes-Casey et al., 2007).

GT derives into two main branches.

First, *Cooperative Game Theory (CGT)* is concerned with analysing the DM process when the stakeholders have agreed to cooperate beforehand. Cooperation results in more optimal outcomes for the participants, but the fair distribution of benefits and costs is of great importance to maintain stable cooperation. For this, there are many methods, often referred to as allocation methods.

Second, *Non-Cooperative Game Theory (NCGT)* analyses conflict when stakeholders are not in a predetermined arrangement to cooperate. Thus, there is an assumption that players are willing to maximise their benefits regardless of what the other participants' decisions may be, resulting in stable or equilibrium combinations of strategies which are often optimal for individuals but not for the model as a whole (Cano-Berlanga et al., 2017).

This research reviewed several GT applications which are relevant for the CE agenda; the description of some examples (and where appropriate their limitations) are reported by the following authors.

Example 1: To select the optimal option from a set of energy from waste alternatives (Soltani et al. 2016), the purpose of the study was only to examine energy recovery and landfill strategies, however further work could consider other CE alternatives.

Example 2: To analyse individual and collective water savings in different inter-plant water integration schemes, and then to find the most stable and fair allocation of the benefits to the involved companies in the schemes (Chew et al., 2009). The previous study further expanded by analysing indirect integration, in other words, introducing a local authority in the scheme to induce cooperation through a ‘green incentive’ (Chew et al., 2011).

Example 3: To find that the DM of the bottler to choose between refillable and disposable is related directly to the expected behaviour of the customer, rather than replacement costs, the product itself, or other characteristics (Grimes-Casey et al., 2007).

Example 4: To enhance the stability of cooperation in an EIP by introducing a sharing of savings where all the parties were equally important, thus the partners had no incentives to abandon the coalition (Hiete et al., 2012).

Example 5: To apply the *Nash Equilibrium* concept by considering an industrial ecosystem as a game in an ‘emergy’ analysis of two plants exchanging materials; Lou et al. (2004) demonstrated that differences in environmental and economic targets influence the decisions of manufacturers in their production strategies.

Example 6: To demonstrate through cooperative and non-cooperative DM models in a green supply chain that when participants cooperate, they achieve the highest selling price and profits to the channel and involved members (Zhang and Liu, 2013).

Finally, GT can find the best allocation of benefits and costs in a system, rather than optimising for each stakeholder separately and identify the most stable, balanced, and favourable combination of strategies. Once obtained the results for fair allocation, it is imperative to prevent the participants from abandoning the coalition through the application of multiple stability definitions in a non-cooperative game (Asgari et al., 2014). An example of where this has been achieved in practice in highly competitive business environments is in achieving a fair allocation between countries’ fishing quotas in the North Sea (Gallastegui et al., 2015). MSW separation mechanisms help to successfully achieve cooperation by introducing government constraints and cooperative costs (Chen et al., 2018). Additionally, GT has been used to study the effects of uncertainty from remanufacturing technology and recycled products quality in order to set recommendations on varying regulatory situations (Tan and Guo, 2019). By mapping their stakeholders, resource flows and technology routes, cooperation has been identified as a critical characteristic to achieve bio-based value chains (Lokesh et al., 2018).

2.3.7 Comparison of DM methodologies and GT

This section of the thesis addresses the second objective (O2) in Table 1–1, which is to review and select the most appropriate methods to study stakeholder cooperation. In comparing the methods, it is useful to know the steps involved in each and to highlight the commonalities and differences between them. Figure 2–6 provides a set of flowcharts of the methodological stages of the approaches previously discussed. In support of the flowcharts, Table 2–4 compares the issues addressed by each method; they are the characteristics observed in the reviewed literature that the different techniques focus on. There is no explicit comparison in the literature between all the proposed methodological approaches. It was decided then to combine GT, MCDA and SA because a questionnaire would align well with Objective 2 (O2) about a survey and the MCDA collection data from respondents.

Table 2–4: Characteristics comparison of Decision-Making (DM) methodologies.

Characteristic	**Methodology**					
	GT	ABM	MCDA	SA	RDM	IAM
Conflictive objectives	✓		✓		✓	
Cooperation	✓	✓			✓	
Decision making	✓	✓	✓	✓	✓	✓
Foresight	✓			✓	✓	
Optimisation	✓	✓	✓			✓
Rank alternatives			✓			
Stakeholders' interactions	✓	✓				✓
Strategic behaviour	✓					
Uncertainty	✓	✓	✓	✓	✓	✓

Table 2–4 shows that all the methods address uncertainty and DM, although Figure 2–6 shows that in different ways. All of the techniques can deliver optimal outcomes. The ranking of alternatives is specifically addressed only by MCDA. However, while such ranking does not provide an intended starting point for GT analysis, CGT can allocate stable results through different methods. Every allocation has a higher stability capacity; they can be ordered according to a fairer distribution of payoffs. The final superficial observation is that ABM most closely approximates to GT. The researcher must not overlook that there are important differences, as discussed below. Even though the properties addressed by GT and ABM are broadly similar, the flowcharts in Figure 2–6 demonstrate that the procedures are different, and the outcomes vary significantly.

While the concepts of GT can be embedded in the action rules in ABM to program the agents to behave accordingly, contrary to GT, the aim of ABM is not to analyse the agents' interactions but to evaluate the effect of their actions in the system simulation. It is, therefore, of critical importance to make the distinction between GT and ABM.

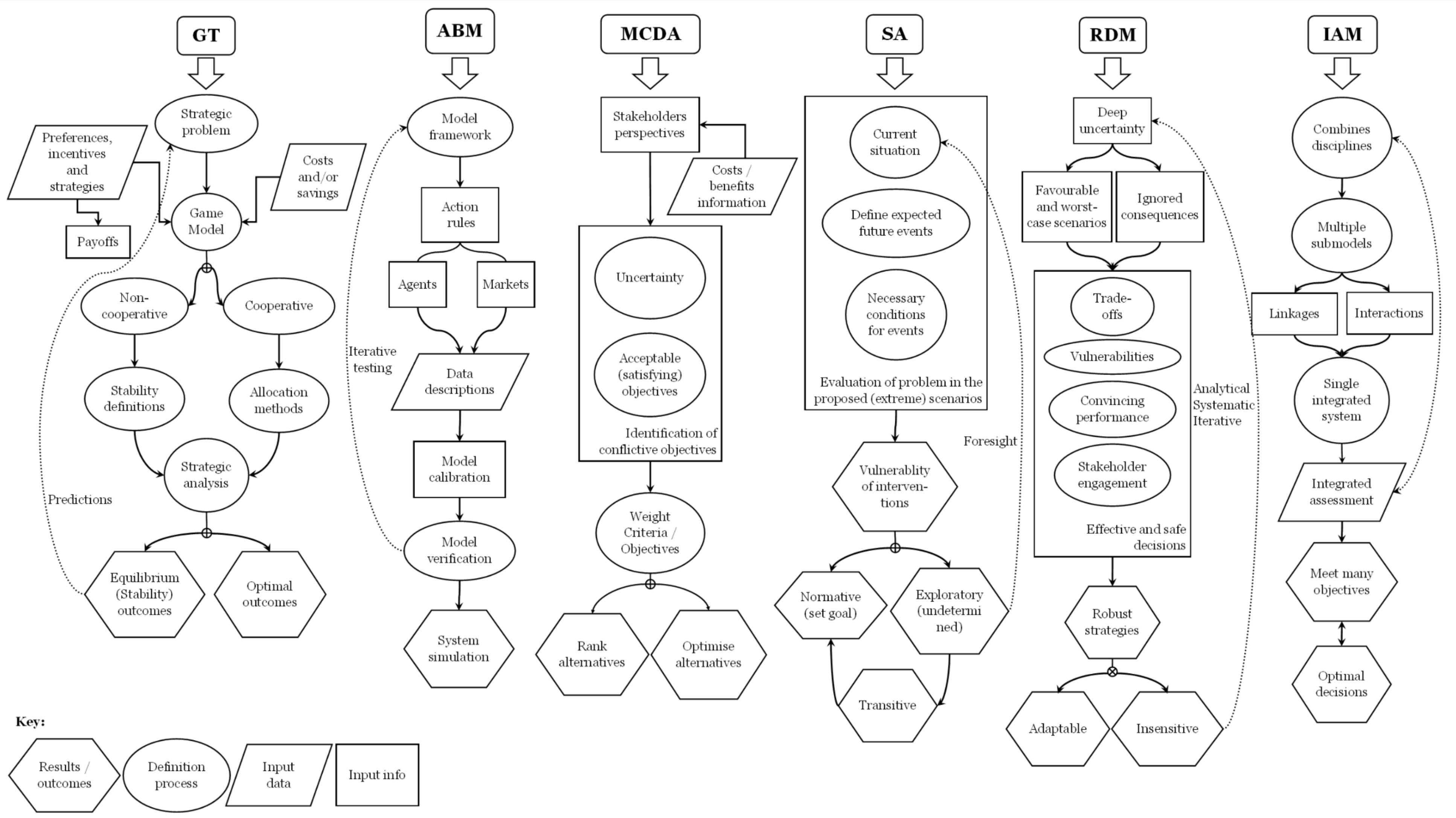


Figure 2–6: Process flowcharts of the different methodologies.

ABM is useful when modelling complex systems with large amounts of autonomous and heterogeneous agents to investigate how their behaviour impacts the entire system's outcomes. While GT analyses the strategic interactions among stakeholders, usually between two players, but upgraded models can analyse more participants (Myerson, 1991). A significant drawback of ABM is that it models human behaviour, therefore factors difficult to measure and include in the rules are often not considered, such as emotions, complex psychology, and subjective choices. Also, the scope of ABM is not the total system but at the individual-units level, and thus ABM usually requires large amounts of data which then leads to computation and time issues (Bonabeau, 2002). However, having a large amount of individual-scale data does not imply that the entire system can be modelled.

Similar to GT, MCDA considers the viewpoints of actors and requires information on costs/benefits or payoffs. Soltani et al. (2016) acknowledge that MCDA is useful in accounting for multiple criteria when ranking or optimising alternatives. MCDA selects the optimal alternatives by ranking them using weighting criteria established subjectively by a single stakeholder. In contrast, GT provides the optimal combination of strategies by analysing the preferred alternatives between multiple stakeholders when the data gathered is quantified. One particular advantage is the ability of GT to complement MCDA when considering conflict and its impact on stakeholders reaching an agreement.

Regarding SA, the main difference is that GT provides predictions for strategic interaction between participants. At the same time, scenarios aim to foresight the development of a current problem – exploring how to move to an extreme or the desired context or attempt to predict the future state from a set of plausible conditions. Uncertainty is interpreted differently in both methods: for SA it represents a set of likely future results, while in GT, it is based on the bounded rationality of participants which derive from limited-informed decisions. SA fails to analyse cooperation between stakeholders, their interactions, and their strategic behaviours to achieve (frequently) conflicting objectives, and this is closely associated with the process of the scenarios creation.

In spite of addressing uncertainty as multiple future expectations to provide robust alternatives and considering stakeholders' interactions, RDM differs from GT in considering their strategic behaviour, in other words. their ability to predict their counterparts' actions in response of their own decisions. Both methods facilitate cooperation between participants to reach preferred outcomes, particularly when there are differences in value perception and objectives. RDM aims to deliver robust rather than optimal alternatives, which are adaptable and not fragile (or vulnerable to unexpected external impacts), while GT provides optimal and stable results if cooperative and non-cooperative analyses are combined.

IAM meets multiple objectives through the integration of several disciplines in its assessment and it considers the interactions and linkages between participants or sub-models, but not their strategic behaviour as with GT. IAM delivers optimal decisions by considering implementation costs, whereas GT considers preferences, payoffs and incentives of stakeholders.

Several studies have reviewed and compared different DM methodologies, or against GT, for example, Lee (2017) has already made a strong case in comparing econometric techniques in the bio-energy development and CE research agendas, such as IAM, linear and non-linear programming, and *Data Envelopment Analysis (DEA)*, among others. The comparison aimed to help select the best technique available given their performance on 11 aspects. On the other hand, Soltani et al. (2015) reviewed MCDA studies in the MSWM context; they found that the stakeholders with the highest participation are experts, local authorities and local residents, as might have been anticipated. Kastner et al. (2015) reviewed and compared literature related to the use of ABM or GT as tools in enhancing the use of IS. Soltani et al. (2016) provided a limited literature review of MSW management studies using GT methods to find solutions to this particular problem. Sinha (2016) investigated how static and dynamic systems modelling support the understanding and monitoring of environmental management.

One final observation is that strategies of individual actors are commonly unknown to others, which results in conflict (Lou et al., 2004). In spite of the multiple benefits from cooperation, one of the most prominent barriers to cooperation are the stakeholders' conflicting interests (Chew et al., 2011). The study and practice of CE could benefit from the use of techniques incorporating GT elements. GT advocates the study of cooperation and conflict of participants/stakeholders. Since cooperation is a feature too often missing in CE and waste management DM, the successful implementation of CE could be facilitated if GT is adopted as another methodological approach.

Overall, cooperation is a feature too often missing in CE waste management DM, and it has not yet been addressed sufficiently. From the characteristics in Table 2–4, the most important for this research is the ability of GT to study the strategic behaviour of actors. GT is useful for situations where conflict derives from different stakeholders' priorities and value perception. The implementation of CE should expect many disputes and partnerships. For example, when deciding whether recycling or incinerating waste is the most optimal strategy for the environment, citizens, local authorities or business owners. Indeed, many factors come into play in the DM process (such as land space, investments, and infrastructure), which could represent barriers or opportunities for cooperation. Thus, GT can provide valuable insights in understanding the design and implementation stages when adopting CE.

2.4 Summary

The gap in knowledge addressed by this research is as follows:

Even though several researchers have studied CE implementation (e.g., Bocken et al. (2016); Rizos et al. (2016) and Witjes and Lozano (2016)) and despite the fact that others recognise its relevance to the successful adoption of CE principles (e.g., Circle Economy (2018); Kirchherr et al. (2018) and Veleva and Bodkin (2018)), cooperation between stakeholders (and its satisfactory achievement) has not yet been researched in terms of it being a key element for CE transitioning.

Several features can facilitate cooperation between stakeholders, for example,

1) A common understanding and interpretations of what a CE is; and
2) A clear recognition of what benefits and costs to expect in the transition and higher levels of trust between participants.

In light of these findings, GT presents potential to facilitate such stakeholder cooperation, for example, by optimising EIP (i.e. *Industrial Symbiosis (IS)*), a principal research area and a critical enabler for a CE – Sub-section 2.1.3.1 (Boix et al., 2015). Furthermore, optimisation methods have been reviewed in the context of EIP design by Boix et al. (2015) and highlighted the need to consider social aspects and multi-objective studies. The importance of GT for a CE emerges from the need to overcome conflicting objectives through cooperation between participants that capture multiple (sometimes conflicting) value judgements within a negotiation process.

Another point to raise is that, even though helpful in the DM process, the compared methodologies do not consider the strategic behaviour of the actors involved in a negotiation (Madani et al., 2015). In contrast, GT provides a valuable perspective on how the preferences and decisions of actors have an impact on further counter-decisions and outcomes of strategic interaction. An advantage of GT is that it considers the individuals' practical interests; thus, seeking to reach the system's optimal results from the individual self-optimising behaviours (Madani et al., 2015).

NCGT is widely used to describe and predict how individuals interact and react according to their interests in the interactive DM process. CGT is handy to identify and find solutions in a situation of sharing resources management where stakeholders are willing to cooperate, according to their potential gains and interests. Thus, by using an innovative, unexplored, and still not a sufficiently documented technique in this area, GT; it is hoped that this research will provide a helpful tool of negotiation and analyse the optimal and sustainability solutions best suited towards the implementation of CE.

The aim of this doctoral research is to address this significant shortfall by creating a decision support tool that combines the procedural steps of SA, MCDA and GT in order to embrace their strengths and minimise their drawbacks. Furthermore, this research proposes utilising a questionnaire to gain insights into participants' cooperation readiness and other CE features. The tool presented herein is applicable to different cases which aim to evaluate CE development scenarios. However, this research tests the methodology with the specific case of the MSW of Birmingham, UK's second-largest city. Birmingham was chosen because of the fact that even though the West Midlands has one of the lowest UK landfill rates for 2019 (6.3%), most of its MSW is incinerated at the Tyseley facilities and this is arguably a linear economy approach – it has the third highest incineration rate and third lowest recycling/composting rate in the UK (52.7% and 39.4% respectively) (ONS, 2021).

3 METHODOLOGY

[Please note that a large portion of this chapter is the basis of original and already published work by the author[5,6]*.]* The review of literature has shown that there is no methodological framework that has single-handedly studied cooperation of stakeholders in the *Decision Making (DM)* process regarding *Circular Economy (CE) Municipal Solid Waste Management (MSWM)* scenarios. This chapter presents the methodological steps to address this shortfall. This research proposes the complementary utilisation of *Game Theory (GT)* to address the multiple stakeholder DM processes in hypothetically built scenarios of MSWM. This section introduces a methodology that fully integrates *Scenario Analysis (SA), Multi-Criteria Decision Analysis (MCDA)* and GT in order to facilitate a fairer and more stable DM process. Its main contribution to DM is that it addresses the issue of stakeholders' conflicting perspectives towards more cooperative CE waste management at the city scale. The chapter consists of three main parts:

- General overview (Section 3.1), which introduces the suggested framework developed in order to study cooperation.
- The questionnaire used in the study (Section 3.2):
    - The framework for design (Section 3.2.1).
    - The pilot work aiming to refine it (Section 3.2.2).
    - The introduction of the questions (Section 3.3).
- Methodological steps of the GT-hybrid tool (Section 3.4), which present the detailed description of the steps proposed to conduct this research.

Chapter 4 and 5 respectively outline the application of the questionnaire and the GT-hybrid tool.

3.1 General Overview

This five-stage methodology seeks to combine the strengths of a questionnaire, SA, MCDA and GT, and a survey to study cooperation in the CE implementation, an aspect that has yet not been widely researched, more specifically in MSWM scenarios. Other available methodologies were discussed and discarded in the literature review chapter (Section 2.3), and these were also

[5] Palafox-Alcantar, P.G.; Hunt, D.V.L.; and Rogers, C.D.F. 2021. Current and Future Professional Insights on Cooperation towards Circular Economy Adoption. Sustainability. 13, 10436, Available at MDPI: https://doi.org/10.3390/su131810436.

[6] Palafox-Alcantar, P.G.; Hunt, D.V.L.; and Rogers, C.D.F. 2020. A Hybrid Methodology to Study Stakeholder Cooperation in Circular Economy Waste Management of Cities. Energies. 13(7), 1845, Available at MDPI: https://doi.org/10.3390/en13071845.

published[7]. This research developed such practical and hybrid process to improve cooperation opportunities between stakeholders. This research treats the development of several scenarios for CE or MSWM as alternatives, which are options from which the stakeholders have preferences. MCDA is used to model the preferences of stakeholder groups in DM by introducing "compensation", meaning to agree on a set of trade-offs which settle for less of the most preferable alternative and more of the less preferable ones but without decreasing the general satisfaction of the stakeholders (Soltani et al., 2015). GT can analyse trade-offs by considering potential cooperation and conflict between stakeholders. In contrast, MCDA techniques fail to take into account stakeholders' preferences and their influence when attempting to negotiate and reach consensus (Soltani et al., 2016).

Soltani et al. (2016) performed a critical study, which analysed optimal *Energy-from-*Waste *(EfW)* alternatives using a GT approach. However, the study was limited to considering only energy recovery and landfill as MSWM options. The methodology presented here helps to expand such scope and considers alternatives more closely aligned to CE principles, such as recycle, reduce, incineration and the eventual eradication of landfill; in addition to considering a wider cohort of stakeholder groups such as consultants, general public and academics.

The five-stage methodology (M1 to M5) presented here maps directly onto the five objectives (O1 to O5) presented previously in Table 1–1, in other words M1 maps to O1 and so on. They are briefly described as follows:

M1. *Stage 1* – Consists of a critical review of the existing survey-based grey and academic literatures on measuring CE awareness and other relevant features to cooperation (e.g., attitudes, behaviours, and expectations). This helped establish a workable taxonomy for stakeholder cooperation in CE, and thus helped to develop the different questionnaires used on which the third stage (M3) of this methodological process is based. Section 2.2 fully described this review.

M2. *Stage 2* – Consists of a critical review of the literature on the methodologies that study the DM process in the CE and *Municipal Solid Waste (MSW)* contexts. This, and the aforementioned, literature reviews enabled identifying the research gap; in other words, there is no preliminary framework that studies cooperation of stakeholders as a critical enabler to the transition to a CE. Furthermore, this also helped in identifying the

[7] Palafox-Alcantar, P.G.; Hunt, D.V.L.; and Rogers, C.D.F. 2020. The complementary use of game theory for the circular economy: A review of waste management decision-making methods in civil engineering. Waste Management. 102, 598-612, Available at Elsevier: https://doi.org/10.1016/j.wasman.2019.11.014.

strengths and shortcoming of the methods to develop a combined tool in the fourth stage. Section 2.3 fully described this review.

M3. *Stage 3* – As a result of the first stage (M1), the development of a questionnaire that measures the CE stakeholder cooperation was undertaken. This included features previously presented in Table 2–3 (i.e., awareness, behaviours, activities, barriers, attitudes, indicators preferences, benefits and costs allocation expectations, and perceptions on other stakeholder groups). Chapter 4 further applies this questionnaire to two different cohorts, MSc students and industry practitioners, which is linked to the GT-hybrid tool as part of M5. This is presented in Sections 3.2 and 3.3.

M4. *Stage 4* – As a result of Stage 2 (M2), the development of a GT-hybrid tool (with GT elements embedded) was undertaken to help study stakeholder group(s) cooperation when evaluating and selecting CE future scenarios on MSWM. Chapter 5 applies this tool to stakeholders in the MSW at the Tyseley case study site. Figure 3–1 shows in more detail the methodology for both the questionnaire (M3) and the GT-hybrid tool (M4) and how they both interact in terms of information flow. In addition, Figure 3–2 shows the generalised 6-step procedure for applying the GT-hybrid tool; Sections 3.4.1 – 3.4.6 will further explain each of the required steps in more detail.

M5. *Stage 5* – Both the questionnaire and the developed GT-hybrid tool are applied in parallel to a live case study in this stage (see Chapters 4 and 5). This involved collecting data from stakeholders through combination of an online questionnaire and semi-structured questionnaire. Chapter 0 presents the subsequent comparison of the results with existing literature. Section 6.2.1 presents a sensitivity analysis of the MCDA results in order to verify the validity and robustness of the results. Therein Section 6.3 contrasts in detail outcomes from the GT-hybrid tool and questionnaire / survey.

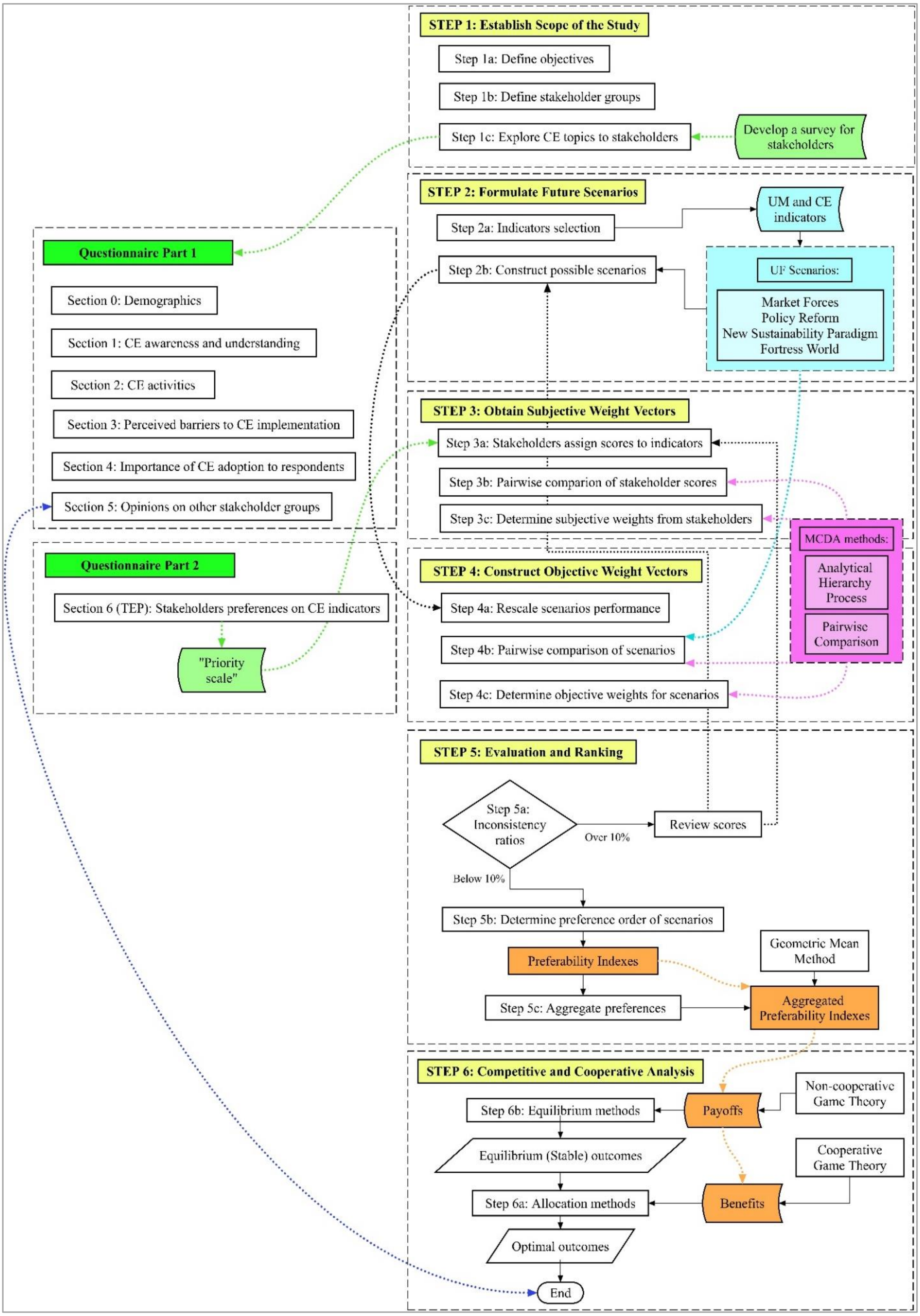


Figure 3–1: Detailed questionnaire combined with GT-hybrid tool flowchart.

3.2 Survey to Evaluate Circular Economy Aspects to Participants

A questionnaire is the set of questions that are asked to an individual. A survey is the process of collecting (through a questionnaire in this research), analysing and interpreting data from many individuals (Creswell, 2013). As shown in Figure 3–1 the questionnaire consists of one basal section (Section 0 – Demographics) and six sections (Section 1 to 6) divided into two parts (see Figure 3–1). Part 1 (Sections 1 to 5) attempts to understand several aspects regarding CE awareness of respondents; these are subsequently used in Step 1 of the methodology flowchart. Part 2 (Section 6) allows for application of the GT-hybrid tool.

3.2.1 Survey Framework

The survey adopted within this thesis research aims to gain insight into the respondents' thoughts on the difficulty (or ease) with which to introduce circularity into their organisations. As previously mentioned in the literature review of CE and waste management surveys (Section 2.2), there are many studies that have measured a range of aspects that resonate with this research, for example:

- '*General public awareness (of CE)*': in Tianjin, China (Liu et al., 2009), western China (Guo et al., 2017), and in southern Poland (Smol et al., 2018).
- *'Awareness and opinions of consumers (to CE)*': in Thessaloniki, Greece (Marios et al., 2018).
- '*Officials' awareness (of CE)*': in six cities in north-western China (Xue et al., 2010) and firms in manufacturing clusters in China (Liu and Bai, 2014).

Research that more also directly aligns with this research, although without the CE element, is

- *'Waste management knowledge and the opinions on new landfill and incinerator facilities'* from university students were studied in Salerno, Italy (De Feo and Williams, 2013). This study was then further expanded to compare the results between the local society of a developed country (Varese and Salerno in Italy) and highly educated citizens in a developing country (La Paz, Bolivia; Ferronato et al., 2017).

Finally, there are a few studies that attempted to measure the *CE awareness, practices and barriers of focal firms in the UK* (Masi et al., 2018), *manufacturing firms in the UK and Ireland* (Liakos et al., 2019), and the *CE awareness, challenges and enablers in the UK construction sector organisations* (Adams et al., 2017). Many of the questions in the survey were based on this relevant literature; Sub-section 3.3 presents respective features adopted in the questionnaire.

Most of these previous studies have used a large sample (~ 200-500 respondents); however, the present study aims to survey a more discreet set of respondents – in other words those who already are reasonably well-informed of CE and its relevant aspects. To ensure this, the first section of the questionnaire measured their awareness and knowledge of a CE.

For the survey, there were two cohorts of respondents selected to distribute the questionnaire. They are classified into two categories:

- Companies involved with the ARLI project[8] at the University of Birmingham (n=27 out of approximately 125). They represent an equal number of people surveyed who hold important posts in the organisations related to sustainability or Corporate Social Responsibility.
- Postgraduate Masters level students from:
    - University of Birmingham (Sustainable Construction in Engineering School, n=88 out of 89).
    - University of Oxford (Business School, n=13 out of 37).

Students at both the Universities of Birmingham and Oxford are, as part of their Master's studies, well-versed in CE practices. Students were chosen for the survey because they will become change agents in their future work – moving society towards (or away from) circularity.

For the GT-hybrid tool, stakeholders are classified into five categories (following the instructions in Step 1b – Section 3.4.1.2); namely:

- Companies.
- Academic Institutions.
- Local Government.
- General Public.
- Consultants/Externals.

The 'priority scale' questionnaire (regarding application of Part 2 of the questionnaire – the GT-hybrid tool – Section 3.4.3.1) was sent by email to a total of 36 potential respondents who had good knowledge of CE practices and who were key stakeholders concerning the development of

[8] ARLI project is an ERDF funded project whereby a team of experienced academics and engineers support businesses in developing cost-effective products and processes, which provide energy-efficiency gains in the use of raw and waste materials. The CE based project, delivered through the School of Engineering, aims to identify waste streams, or other materials that could be transformed into higher value goods for construction and other manufacturing industry applications – https://www.birmingham.ac.uk/partners/sme-support/business-support-programmes/arli.aspx

the *Tyseley Energy Park (TEP)*[9]. To those who responded, an in-person meeting was organised. Responses were collected in person from n=14 of them in order to minimise the risk of misinterpretation of the question and ensure the table was filled in as required (see more details in Section 3.4.3.1). It took respondents around 10 minutes to complete this section of the questionnaire. More details on the process of stakeholder selection can be found in Section 5.2.

Due to the exploratory nature of the study and the small but high-quality sample (n=27 out of approximately 125 companies, n=101 students, and n=14 TEP stakeholders respectively), the analysis involved mainly descriptive statistics. The study was valid and reliable because the intention was to precisely study a very specific group, and it was meant to analyse their preferences and decisions. It was made clear to participants from the beginning that the answers *"I don't know"* and *"I'd rather not say"* were available to select without providing any justification or reasoning in all the questions posed.

To incentivise the voluntary participation of businesses respondents in the survey, a small gift (a printed copy of the "*Little Book of Circular Economy in Cities*" published by the author of this thesis, even though free to download) was offered as a gesture of appreciation. For the Birmingham students, 5% of their final module mark was allocated to the full completion of the survey, in which students were given the opportunity to and demonstrate their understanding of the CE concept. This was reviewed by the University of Birmingham Ethics Committee, and they asked that this be stated clearly in the module marking information so that students would be aware. The students were also reminded of this at the start of the lectures and just before the completion of the online questionnaire. The survey took place over a two-month period (between the beginning of March and end of May 2021). The GT-hybrid tool face-to-face questionnaire took place over a two-month period (i.e., between the end of May 2019 and beginning of August 2019), according to each participant's availability.

The questionnaire was distributed via email; alternatively, a link to the electronic version in the "Jisc online surveys" platform was provided. Two reminders, each a month after the previous invitation, were sent to selected potential participants to encourage them to take part in the study. They were also asked to share the survey with colleagues who could benefit the study; thus, a "snowballing" technique helped to increase the participant pool. The aims of each section are outlined as follows:

Section 1: To explore the respondents' awareness of a CE.

[9] TEP is the energy-waste nexus for the City of Birmingham and will complement the adjoining waste to power plant (350,000 tonnes of municipal waste 25MW electricity) with a range of innovative technologies which can transform other more complex waste streams into energy https://www.energycapital.org.uk/tyseley-energy-park/

Section 2: To find out about CE related activities within the organisations.

Section 3: To investigate the perceived barriers to implementing a CE.

Section 4: To analyse the importance of a CE to the respondents.

Section 5: To gain insights on the respondents' perceptions of other stakeholder groups.

The GT-hybrid data collection (as presented in Section 3.4.3.1) was conducted as a face-to-face semi-structured survey. This was to decrease the risk of misinterpretation or confusion related to the questions posed, not least where the use of a *'priority scale'* was adopted. The aim is to measure respondents' preferences of the indicators to evaluate CE scenarios (this section generates the data for Step 3a onwards – Section 5.4.1).

Ethical approval was obtained from the University of Birmingham Ethical Committee to ensure the participants' confidentiality (ERN_19-0203A). The first pages of the survey included:

1) A participant information sheet, which included the study and confidentiality information.
2) A consent form, to be signed by the respondents.
3) A participant identification sheet, containing the demographics questions.

Appendix ***B*** presents all of these.

3.2.2 Pilot Work

Before sending out the questionnaire to the potential participants, there was the need to perform pilot work to help improve its quality (Crowther and Lancaster, 2008; Robson, 2011). The *Liveable Cities* team helped to perform the pilot work during three monthly meetings at the University of Birmingham. The group consisted of six members including senior academics and other PhD students from (civil and systems) engineering and architecture backgrounds; importantly, they had previous experience in research using the design of questionnaires and carrying out surveys (e.g., collecting data for analysing the *Urban Metabolism (UM)* of Birmingham). The team was asked to bear in mind the following questions to provide critical feedback on and experience of undertaking the questionnaire:

- Were any questions unclear?
- Could any be misinterpreted?
- Do the response options make sense?
- How long did it take you to complete the questionnaire?

- Were there any questions missing and/or that were unnecessary?
- Were any questions demanding too much information?
- Were there any formatting or functionality issues with the version of the questionnaire that you completed?

The feedback from the team members helped shape and refine further the design of the questionnaire. This iterative testing made the questionnaire more understandable, easier to respond to and provided assurance that the survey could capture a significant amount of data; for example, providing more response options to some questions.

3.3 Questionnaire Sections

3.3.1 Section 0 questions: Demographic details

The basal section (referred to as Section 0) consists of eight questions to garner the demographic information of participants to allow for further statistical analysis. The demographic questions for students were based on Ferronato et al. (2020), Loste et al. (2020) and Revinova et al. (2020), as their studies are on the future of CE development – next generation of practitioners – who are, in essence going to be university students. The full questionnaire is presented in Appendix C.

For the companies and stakeholders, they were based on those from the survey by Greentech Brussels (2018) as this also surveyed SMEs that had a notion of CE practices. It is worth mentioning that the question phrasing differed slightly between companies and students. For example, companies were asked about their current practices and students about the importance of CE to their future career and discipline.

The demographic questions aimed to gain background information on the participants. These questions provide context for the corrected survey data, allowing a better description of the participants and analysis of their data (Creswell, 2013). For students, questions were asked to better understand their countries of origin as some may have heard more about CE, younger generations might be more aware of CE related topics; the gender distribution of the participants as the module was in an engineering course which traditionally is predominantly attended by males; and the degrees or programmes they are currently reading for. For companies and stakeholders, it was important to categorise them correctly, understand their sector and the time the respondent had been in the position in the organisation. These characteristics enable a better description of their backgrounds and understanding of their responses to be formulated.

Table 3–1: Questionnaire on demographic composition.

Cohort	No.	Question (Q)	Choices for Question (Ai)	References
University Students	Q0.1	Nationality	Open-ended	(Loste et al., 2020; Ferronato et al., 2020; Revinova et al., 2020)
	Q0.2	Age	Open-ended	
	Q0.3	Gender	Open-ended	
	Q0.4	Degree / programme of study	Open-ended	
	Q0.5	University	Open-ended	
Companies and Stakeholders	Q0.1	Stakeholder group	Company; Academic Institution; Local Government; General Public; Consultants/Externals	Greentech Brussels (p. 2018)
	Q0.2	Corporate Social Responsibility / Sustainability Department?	Yes; No	
	Q0.3	Name of organisation	Open-ended	
	Q0.4	Location of organisation	Open-ended	
	Q0.5	Industry sector	Open-ended	
	Q0.6	Main position	Open-ended	
	Q0.7	Time in the position and organisation	Open-ended	
	Q0.8	Size of organisation	1 - independent; less than 10; from 10 to 49; from 50 to 249; 250 and above	

3.3.2 Section 1 questions: CE understanding

The first section aims to explore CE awareness from the respondents. Table 3–2 presents the questions, choices and references. The first question was from Greentech Brussels (2018, p.11) by improving the scale responses. The second question from UKGBC (2017) included "reducing" to study how deep the 3Rs are linked to the interpretation of CE. The last question from Liakos et al. (2019) to assess the respondents CE awareness. All answers in every section included the *"I don't know"* and *"I'd rather not say"* options, and "*Other (please specify)"*.

Table 3–2: Questionnaire on awareness and understanding of a CE.

No.	Question (Q)	Choices for Question (Ai)	References
Q1.1	How well do you understand the concept 'circular economy'?	(Very well) 5; 4; 3; 2; 1 (Not well at all); Never heard of it	(Greentech Brussels, 2018, p. 11)
Q1.2	Do you agree with the following statement…? *The 'circular economy' is just another word for reducing, reusing and recycling materials.*	(Strongly agree) 5; 4; 3; 2; 1 (Strongly disagree)	(UKGBC, 2017)
Q1.3	In your opinion, which of the following concepts are important to the 'circular economy'?	Close material loops; Reduce; Reuse; Recycle; Systems thinking; Renewable energy use; Build resilience; Design out waste; Share resources; Increase exchange	(Liakos et al., 2019) – 2-Q3

3.3.3 Section 2 questions: CE practices

The second section attempts to find out about CE related practices within organisations. Table 3–3 presents the questions for this section, their responses and the references they were based on. This entire section of the questionnaire was based on the work from Masi et al. (2018), since their survey aimed to evaluate the CE practices of SMEs in the UK and Ireland.

Table 3–3: Questionnaire on CE practices and future importance.

No.	Question (Q)	Choices for Question (Ai)	References
Q2.1	The organisation I represent is implementing / not yet considering implementing… My discipline/ future career will consider the following as important/ unimportant		
Q2.1.1	Reducing energy	(Implementing successfully/ Important) 5; 4; 3; 2; 1 (Not considering it yet/ Unimportant)	(Masi et al., 2018)
Q2.1.2	Reducing material consumption		
Q2.1.3	Reducing pollutant emissions		
Q2.1.4	Reducing wastes		
Q2.1.5	Taking back products from consumers after the end of their functional life		
Q2.1.6	Taking back products from consumers after the end of their usage		
Q2.1.7	Remanufacturing products		
Q2.1.8	Recycling materials		
Q2.1.9	Refurbishing products		
Q2.1.10	Reusing energy and/or water across the value chain		
Q2.1.11	Cascading use of components and materials		
Q2.1.12	Designing products for reduced consumption of material/energy		
Q2.1.13	Designing products for reuse, recycle and/or recovery of material/component		
Q2.1.14	Designing process for minimisation of waste		
Q2.1.15	Selecting suppliers using environmental criteria		
Q2.1.16	Using renewable energy/material in the production process		
Q2.1.17	Cooperating with other firms to establish eco-industrial chains		
Q2.1.18	Adopting a leasing or service-based marketing strategy		
Q2.1.19	Targeting “green” segments of the market		
Q2.1.20	Green packaging		
Q2.1.21	Including environmental factors in the internal performance evaluation system		
Q2.1.22	Environmental auditing programs such as ISO 14000 certification		
Q2.1.23	Cross-functional cooperation for environmental improvements		
Q2.1.24	Eco-labelling of products		
Q2.1.25	Special training for workers on environmental issues		

3.3.4 Section 3 questions: Perceived barriers to implementing CE

The third section investigates the perceived barriers to implementing CE. Table 3–4 presents the questions for this fourth section. The questions are based mainly on those barriers identified and classified by Kirchherr et al. (2018), Adams et al. (2017) and Masi et al. (2018), because they categorised respondents into more comprehensive cohorts such as business, academia and government. Usually, the literature focuses on firms' only to adopting a CE. If instead of rating each question participants had been asked to rank the options, responses may have looked slightly different. However, it was decided to design them as a rating to make them easily comparable with the referenced literature.

Table 3–4: Questionnaire on barriers to implementing CE.

No.	Question (Q)	Choices for Question (A_i)[1]	References
Q3	Please rank the appropriate barriers according to their level of importance to overcome to your organisation/ discipline – future career		
Q3.1	Cultural barriers Hesitant entrepreneurship due to high uncertainty Insufficient cooperation in the value chain Lacking consumer awareness and interest Operating in a linear system	(Most) 5; 4; 3; 2; 1 (Least)	(Kirchherr et al., 2018; Ferronato et al., 2017; Masi et al., 2018; Adams et al., 2017)
Q3.2	Regulatory barriers Limited regulation of circular economy procurement practices Hindering laws and regulations Lack of global consensus	(Most) 5; 4; 3; 2; 1 (Least)	(Kirchherr et al., 2018; Masi et al., 2018)
Q3.3	Market barriers Low virgin material prices Lack of circular products/services standardisation High upfront investment costs Limited financial support	(Most) 5; 4; 3; 2; 1 (Least)	(Kirchherr et al., 2018; Masi et al., 2018; Adams et al., 2017)
Q3.4	Technological barriers Limited ability to deliver high quality remanufactured products Limited circular designs Too few large-scale demonstration projects Lack of data	(Most) 5; 4; 3; 2; 1 (Least)	(Kirchherr et al., 2018; Masi et al., 2018; Adams et al., 2017)

3.3.5 Section 4 questions: Importance of CE adoption

The fourth section of questions analyses how the participants identify the importance of a CE to their organisations. The questions designed are presented in Table 3–5. For the first question, Liu et al. (2009) investigated the public's attitude towards the future of CE and its development; and

Smol et al. (2018) asked the local inhabitants in Malopolska, Poland about their opinion on the development of CE in the region. This study focused on the importance of CE for the organisations. The second question was adapted from De Feo and Williams (2013) including the last three answer options to respondents. The last question was based on CE enablers and opportunities (Pheifer, 2017), the enablers/drivers of CE in the construction sector (Adams et al., 2017), and the perceived best methods to push CE development (Xue et al., 2010).

Table 3–5: Questionnaire on the importance of a CE.

No.	Question (Q)	Choices for Question (Ai)	References
Q4.1	How important is adopting circular economy principles in your organisation/ discipline?	(Very important) 5; 4; 3; 2; 1 (Not important at all)	(Smol et al., 2018; Liu et al., 2009; Liu and Bai, 2014)
Q4.2	What do the components from the waste generated in your organisation/ discipline represent to you?	Discards to dispose of in landfill; Materials to recycle; Waste to incinerate; By-products valuable to others; Hazardous materials to manage carefully	(Ferronato et al., 2017; De Feo and Williams, 2013)
Q4.3	Which of the following do you think would enable your organisation/ discipline to transition to a more circular economy approach?	Limited resource supply; Increasing of future profits; Sustainable business strategy; Entering new markets; Public opinion; Energy savings; Fluctuating resource prices; Enforcements by law; Keeping up with competitors; Reduce waste; Avoid landfill; Decrease costs	(Adams et al., 2017; Xue et al., 2010; Pheifer, 2017)

3.3.6 Section 5 questions: Perceptions on other stakeholders

The fifth and last section of the survey attempted to gain insights on the organisations' perceptions of other stakeholders. Table 3–6 presents the survey questions of the section. There is no similar question in the literature to the first question, which was designed to measure the levels of willingness to cooperate by respondents. Smol et al. (2018) asked their respondents the reasons for sharing journeys or renting properties directly from owners, and the most selected response was due to the lack of trust between participants. The second question was improved from De Feo and Williams (2013) by introducing several more options and expanding the question to *"new waste management facilities"* rather than only the *"landfill and incinerator"* options given in the original article. As for the last three questions, there were none similar identified within the literature base searched. The aim for each one was: Q5.3 aims to compare the results with those of the *Shapley Value* from Step 6b at the end of the GT hybrid tool. The *Shapley Value* method assigns each stakeholder their marginal contribution to the coalition they join (Cano-Berlanga et al., 2017). Its main advantage is that it provides a fair solution that always exists and is unique (Karmperis et al., 2013) (for more details see Section 3.4.6.2). Q5.4 aims to reveal new barriers specifically for successfully achieving stakeholder cooperation in the CE transition; and Q5.5 to reveal any new enablers.

Table 3–6: Questionnaire on stakeholders' perceptions of other groups.

No.	Question (Q)	Choices for Question (Ai)	References
Q5.1	Do you agree with… *It is essential to trust other stakeholders when cooperating in the implementation of the CE principles*	Strongly agree; Agree; Somewhat agree; Neither; Somewhat disagree; Disagree; Strongly disagree	(Smol et al., 2018)
Q5.2	Who among the following actors have to take part in the siting of a new waste management facility in the city?	Researchers; Private investors; Entrepreneurs; Local politicians; Local policymakers; Local authorities; Land planners; Transport planners; Regulatory bodies (emit permits/licenses); Waste management operators; Technology suppliers; Local inhabitants/citizens; External consultants	(Ferronato et al., 2017)
Q5.3a	Which stakeholder(s) are most/least powerful in the circular implementation process?	(Most) 5; 4; 3; 2; 1 (Least)	The aim of this question is to compare the results with the Shapley Value results (Section 3.4.6.2) – study published as listed [4] and was only asked to ARLI companies
Q5.3b	Is their power increasing, decreasing or staying the same?	(Increasing) 5; 4; 3; 2; 1 (Decreasing)	
Q5.4	What barriers to cooperation between stakeholder groups (i.e., to reach agreements would you expect in the CE transition?	Open-ended	No similar questions in the literature. They aimed to reveal new barriers/enablers for successfully achieving stakeholder cooperation in the CE transition
Q5.5	Likewise, what would facilitate achieving cooperation between stakeholders (i.e., to reach agreements) in the circular economy transition?	Open-ended	

Coding techniques were used to analyse there last two questions: it was helpful to make use of algorithms that detect the main words used in the responses, thus providing a glimpse at topics and making it easier to understand additional barriers and enablers to achieve stakeholder cooperation. Algorithm use is helpful as it allows to manipulate, summarise and visualise characteristics of large text datasets. In this process, the aim was to reveal the most common bigrams and correlations between commonly used words and model topics in the responses. The R package used is *tidytext* (Silge and Robinson, 2016) because of its practicality with text data mining and visualisation. A word network plot is built to show the correlations of words and the frequency that they are used.

3.4 Game Theory (GT)-Hybrid Tool Steps

The second part of the questionnaire (Section 6 is used in the Step 3 of Figure 3–1 flowchart). This step includes cooperative and non-cooperative GT to further complement the analysis. A detailed consideration of all six steps of the GT tool follows in Sections 3.4.1 to 3.4.6 (see Figure 3–2). This is further applied in Chapter 5.

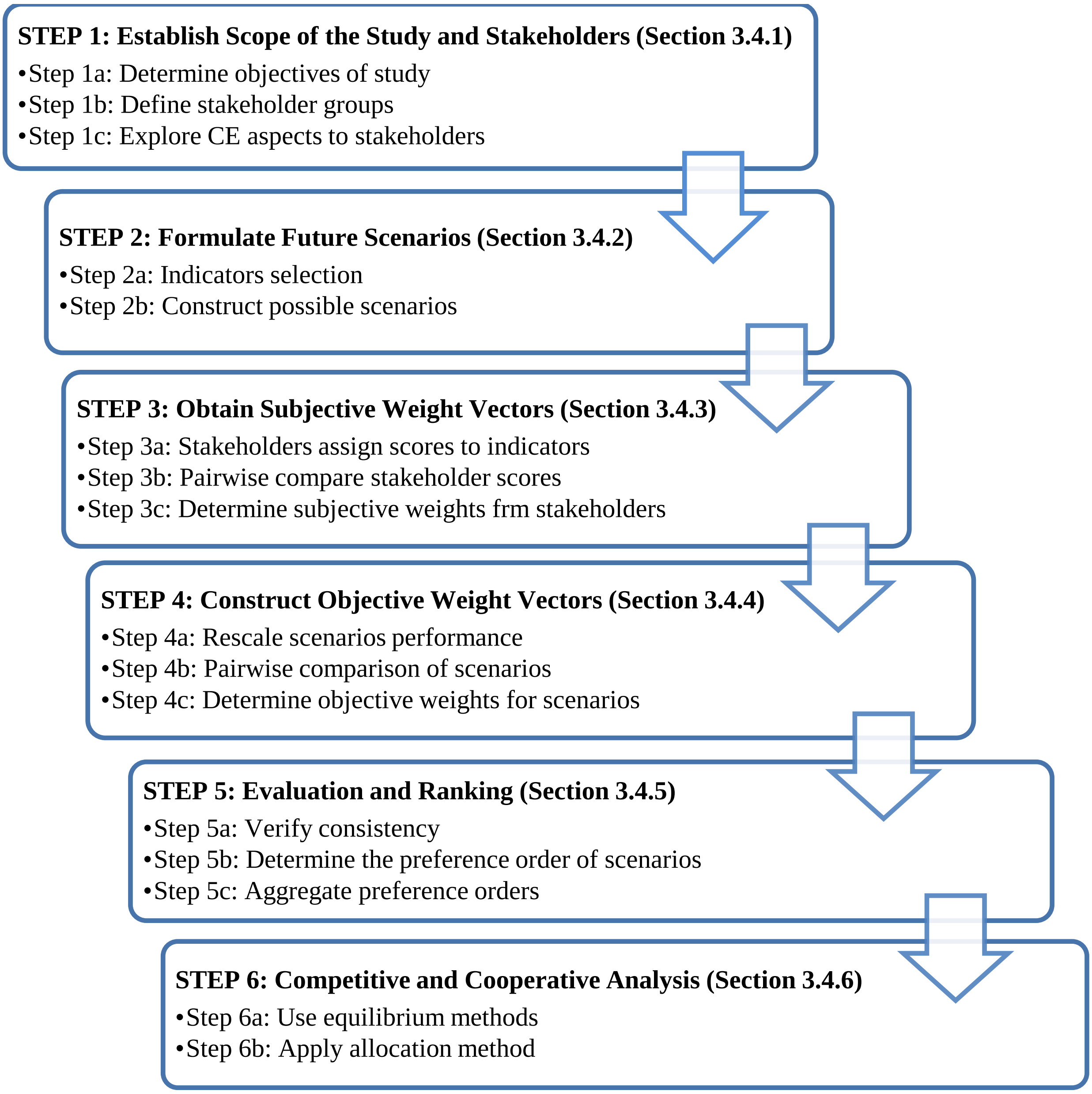


Figure 3–2: Summarised GT-hybrid tool flowchart.

3.4.1 STEP 1: Establish Scope of Study

This method adopted four sub-steps from the "*Stakeholder Analysis Module*" tool (Weiner and Brown, 1986) to define and classify the stakeholder groups on in the DM process of MSWM:

1) Define the problem to study (Step 1a).
2) State the crucial elements that caused the problem (Step 1a).
3) List all stakeholders with interest in the elements of the issue (Step 1b).
4) Remove any duplicated stakeholder groups (Step 1b).

3.4.1.1 Step 1a: Define the objectives of the study

The first step in this method is to define the scope of the study (i.e., problem to be solved). This step needs to clearly state the problem and consider any influencing factors. Defining the objectives refer to specifying what the study intends to draw out, for example, compare MSWM or EfW alternatives or evaluate projects for new waste management facilities (Soltani et al., 2016). Section 5.2 shows the case study application of this step.

3.4.1.2 Step 1b: Determine stakeholder groups

The second step in this method is to determine and classify the stakeholder groups, which the DM process will consider. Banville et al. (1998) were the first to include the stakeholder concept into MCDA. They based such incorporation on solidly arguing that socio-political characteristics must be considered in the DM process. A stakeholder is defined as a group or an individual who is influencing or being influenced by (or both influencing and being influenced by) a set of decisions regarding a specific issue (Soltani et al., 2015).

If the stakeholders are highly unlikely to cooperate, others might think that the possibilities of their inclusion in the DM process, or the effectiveness of the DM process itself, would be significantly reduced (Macharis et al., 2012). However, the proposed framework aims to encourage cooperation – it makes transparent to all actors the benefits of cooperation and the adverse consequences of failing to cooperate – and as such advocates the inclusion of the opposing actors in order to shed light on their contradictory or contentious views. The methodology is devised to increase the overall levels of satisfaction of all involved. It, therefore, has the potential to change the views of stakeholders (or actors in the DM process) who might initially adopt a contradictory stance concerning the proposed (CE) intervention. This would be a rational response; irrational actors, who would disrupt any DM process, would be exposed as such as the methodology progresses. They would find themselves isolated, and their views potentially excluded, as a result of the openness and transparency brought to the DM. This might then result in them deciding to withdraw or being asked by the collective to withdraw.

Several scholars attempted to review the stakeholders who play a key role in MSW alternatives DM and the CE agenda transition. For example, Murray et al. (2017) identified that firms and governments are two of the main actors in the transformation of their products and processes to be aligned with CE principles; however, the study did not consider the role played by academics and local inhabitants in the process. De Feo and De Gisi (2010) included in the ranking of alternatives for MSW facilities politicians, technicians and citizens, and further categorised them into technical and non-technical respondents. Soltani et al. (2015) reviewed in detail MSW studies focusing on many stakeholders. They found that the stakeholders with the highest participation are experts and local authorities, followed by the local residents. The validity and reliability of the data collected is determined by the intention of the study being to analyse the respondents' (highly aware stakeholders in the CE transition of the project) preferences and decisions, with a small but high-quality cohort of respondents from the stakeholders surveyed.

3.4.1.3 Step 1c: Explore CE aspects to stakeholders (Questionnaire Sections 1 to 5)

Even though CE has been gaining momentum over the last decade (Geissdoerfer et al., 2017), an important drawback arises, as it is likely that many participants are not very knowledgeable of the CE concept. The survey collects primary source data on the awareness of multiple aspects of CE. Many of the questions designed for the questionnaire were based on the critically reviewed literature (Section 2.2). Chapter 4 presents the application and the results of the questionnaire.

3.4.2 STEP 2: Formulate Future Scenarios

It is now necessary to build scenarios in order to be evaluated by the researcher, ultimately. Researchers commonly construct scenarios from the participant stakeholders, the available MSWM alternatives and the indicators to assess them (Soltani et al., 2016). Section 5.3 shows the case study application of this step.

3.4.2.1 Step 2a: Indicator selection

In order to implement CE successfully, the method needs a set of indicators to evaluate the process; they must assess the development and provide a guideline to make appropriate decisions by policy-makers during the implementation process (Su et al., 2013). The researcher must choose a set of relevant and representative indicators in order to create future scenarios. To select the indicators to use in the evaluation process of CE scenarios, an extensive and thorough literature review on indicators and methods for assessing CE is needed. This review must also include *Industrial Symbiosis (IS)* indicators which, as discussed previously in Sub-section 2.1.3.1, are an important related research area and a driver towards CE; primarily at the industry and city scales.

There is an extensive literature compiling sustainability indicators; primarily on IS but also in the CE agenda. In general, the classification of indicators falls into contextual and performance, and quantitative and qualitative indicators (Leach et al., 2016). Contextual indicators provide a baseline for interpretation. Performance indicators address specific issues. Useful performance indicators must also have targets to achieve and a defined temporal aspect (Leach et al., 2016). The authors developed the *City Analysis Methodology (CAM)* to measure the direct impacts of intervention in cities (Leach et al., 2016). This new city sustainability-and-liveability performance assessment tool was used in a case study to evaluate Birmingham, UK (Leach et al., 2017).

Haupt et al. (2017) reviewed the CE indicators used in the waste management system in Switzerland and concluded that recycling rates are not sufficient indicators to evaluate CE performance. This step uses two tools to select the appropriate indicators for CE assessment as a guideline: Valenzuela-Venegas et al. (2016) reviewed sustainability indicators to evaluate *Eco-Industrial Parks (EIPs)* and identified 249 indicators to assess their performance. They then classified them into the three sustainability dimensions and suggested that for selecting suitable indicators the five criteria mentioned below must be considered. Saidani et al. (2019) reviewed in detail the literature attempting to build CE indicators. The authors have classified 55 sets of Circularity-indicators and have provided an associated selection tool (an Excel-spreadsheet) for selecting the Circularity-indicators for specific case studies.

Indicators must have characteristics considered to be appropriate for measuring the performance of CE scenarios. A good indicator should identify where the researcher is and provide a pathway to where they want to be (Hunt et al., 2008); therefore, a unit of measure is required. The process of correctly identifying indicators relevant to CE assessment is based on the work of:

- Valenzuela-Venegas et al. (2016) which describes the process of selecting a range of sustainability indicators relevant to evaluating the sustainability performance of EIPs.
- Saidani et al. (2019) which reviewed literature relevant to CE indicators.
- Valenzuela-Venegas et al. (2016) and Leach et al. (2016) in which the desirable properties for accurately selecting indicators are:

1) *Understanding*: be understood easily.

2) *Pragmatism*: be easily measurable and data easily obtained.

3) *Relevance*: be aligned with the goals and future of the EIPs and businesses.

4) *Representative*: enable the comparison of EIPs and allow for progress to be identified

5) *Multi-dimensional*: evaluate one or more sustainability dimensions.

3.4.2.2 Step 2b: Construct possible scenarios

The objective of utilising MCDA is to evaluate – according to stakeholders' preferences – which is the best from a set of hypothetically built, by the researcher, future CE scenarios of MSWM in cities. While there are many ways to develop scenarios, this research uses the four Urban Futures scenario archetypes, which are themselves based on four of the six scenarios developed by the Global Scenario Group. The remaining two scenarios involving societal breakdown were considered irrelevant to this exercise. This research selected them because of their ability to provide diverse stakeholder engagement in futures; for more details, refer to (Lombardi et al., 2012; Hunt et al., 2012a, 2011). They have been re-interpreted to show the thinking for MSWM and more details are shown in Appendix D to provide a fuller picture:

Scenario 1. *Market Forces (MF)*. An extreme extension of the business-as-usual scenario, yet one which ignores social and environmental concerns completely. In terms of MSWM, this would likely mean that sustainability does not feature high up the agenda and waste is considered as a burden and typically something that costs rather than makes money and hence CE receives little investment or attention.

Scenario 2. *Policy Reform (PR)*. This scenario is based on strict enforcement of the policy to achieve sustainability goals. In terms of MSWM, sustainability is likely to feature high on the agenda, and strict policies for ever-increasing charges for landfill and fines for waste production are likely to ensue. Individuals and society would be expected to take up and adhere to the policy reform principles by strong enforcement.

Scenario 3. *New Sustainability Paradigm (NSP)*. This scenario is shaped by widely accepted sustainable citizen values and behaviour. For MSWM, it is likely that citizens readily embrace CE principles, and the governance systems support such implementation.

Scenario 4. *Fortress World (FW)*. This scenario is characterised by highly polarised wealth distribution and wellbeing. In terms of MSWM, there are likely to be significant disparities in the way this issue is considered. The wealthy inside the fortress take care of their waste by pushing it out of the fortress, causing negative consequences for those who lie outside – a *Not-In-My-Back-Yard-ism (NIMBYISM)* mentality ensues.

3.4.3 STEP 3: Obtain Subjective Weight Vectors

In this step stakeholders are asked, through the use of a questionnaire (Part 2 – Table 3–7), to rank the selected indicators (Step 3a). The researcher then pairwise compares their scores (Step 3b) in order that a subjective weighting can be found (Step 3c). Section 5.4 shows the case study application of this step. It is worth noting that prior to applying GT methods, stakeholder group preferences should be revealed. For such a procedure to take place, *Analytical Hierarchy Process (AHP)* is used, which is a MCDA technique that uses pairwise comparisons to rank indicators and reveal the most preferred or optimal from a set of alternatives (Step 3 onwards).

3.4.3.1 Step 3a: Stakeholders assign scores to indicators (Questionnaire Section 6)

As mentioned above, the Part 2 of the questionnaire attempts to continue analysing the CE aspects of the surveyed stakeholders. The sixth section of the questionnaire is used for the analysis in this step, with the application presented in Chapter 5. Before applying GT, the method needs to reveal the preferences of the stakeholder groups in order to use them in the GT models. For such a procedure, this research uses the well-known MCDA method called AHP.

The first part of the ranking process is to utilise a 'priority scale' (De Feo and De Gisi, 2010), where stakeholders assign 'priority scores' to the indicators. This is based on how important the indicators were based on a well-recognised 9-point 'Saaty scale' (9 being most relevant and 1 being least relevant).

The sixth section of the questionnaire measures stakeholder groups' preferences of the benefits/costs to evaluate CE scenarios; Chapter 5 uses it for the GT analysis. [Table 5–1 in the next chapter, was provided in the survey with the necessary descriptions of the selected criteria to rank (see Section 5.3.1 for the case study application and a full description of the selected indicators).] Table 3–7 presents the questions asked in this section. The survey uses the "*priority scale*" introduced by De Feo and De Gisi (2010) to obtain the preferred criteria from all stakeholders. This technique was selected due to its visual appeal, but most importantly for its ease in understanding to respondents, it facilitates pairwise comparisons and overall capability of minimising the risk of obtaining inconsistent rankings.

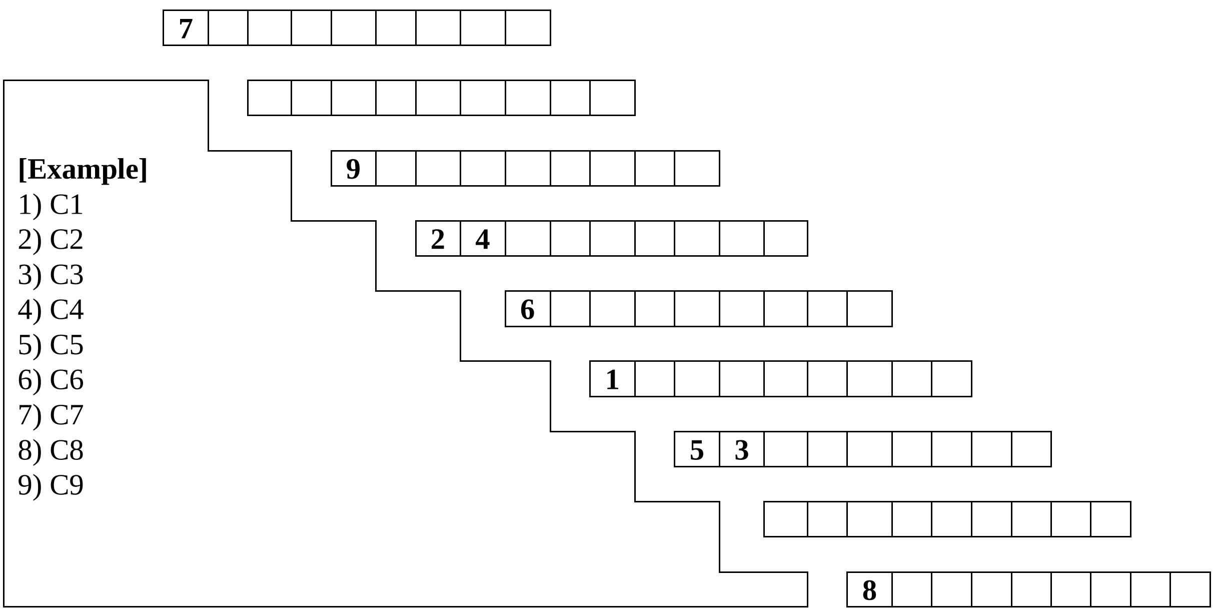
Table 3–7: Questionnaire on the indicators preferences of stakeholders

No.	Question (Q)	Choices for Question (A_i)	References
Q6.1	Would you rule out any of the indicators proposed to evaluate CE scenarios in the city?	Open-ended	(De Feo and De Gisi, 2010)
Q6.2	Are there any other relevant indicators that you would consider including to evaluate CE scenarios in the city?	Open-ended	
Q6.3	Please fill in the priority scale table following instructions: (see Table 3–8 and related text below)	(Indispensable) 9; 8; 7; 6; 5; 4; 3; 2; 1 (Irrelevant)	

After participants read through the selected indicators, Q6.1 asked respondents if they would not consider any of the indicators; and Q6.2 asked if any indicators were missing. Most of the respondents agreed that these indicators were easily measurable and relevant to the case study site. However, a few included concerns over *Gross Value Added (GVA)* impact as companies might be more interested in the profit they would expect; and also, about including skilled jobs creation. Overall, the responses validated that the indicators selected were appropriate. Table 3–8 provides an example of a filled-in priority scale. Q6.3 required respondents to fill in the priority scale, the following instructions were provided:

- Distribute the 9 indicators among 9 levels of relevancy, in order of decreasing relevance.
- The items on the same level have the same relevance.
- Please bear in mind to pairwise compare the items, i.e., avoid any inconsistencies, judge which item is preferred, or whether or not the items compared are identical.
- Warning: do NOT repeat the same number more than once.
- A worked example is provided below.

Table 3–8: “Priority scale” example



In the example scale provided, Indicator 7 is considered indispensable, and there is no other indicator which comes right after it. In contrast, Indicator 8 is regarded as a completely irrelevant indicator, and there is no other right above it. Indicators 2 and 4, and 5 and 3, were considered to have the same level of importance to the respondent. The analysis of this section continues in Step 3b of the methodology and the application to the case study site (Section 5.4).

3.4.3.2 Step 3b: Pairwise comparison of stakeholder scores

Using the output of Step 3a, the pairwise comparison of stakeholder scores is performed. Using Equations (3-1) and (3-2), the matrix of pairwise comparisons consists of one plus the differences in the ranking values ($DV_{i,j}$) of each indicator assigned by each stakeholder, and they are calculated as follows. However, if the comparison results in a negative number, the value of $DV_{i,j}$ will be given by the reciprocal of one plus the absolute value of the differences The matrix should resemble the following:

$$DV_{i,j} = 1 + (R_i - C_j), \tag{3-1}$$

$$DV_{i,j} = {}^{1}\!/_{(1 + |R_i - C_j|)}, \tag{3-2}$$

		Difference Values ($DV_{i,j}$)			
		C_j			
		1	**2**	**…**	**j**
R_i	**1**	$DV_{1,1}$	$DV_{1,2}$	…	$DV_{1,j}$
	2	$DV_{2,1}$	$DV_{2,2}$	…	$DV_{2,j}$
	…	…	…	…	…
	i	$DV_{i,1}$	$DV_{i,2}$	…	$DV_{i,j}$
	Σ	**ΣC_1**	**ΣC_2**	**…**	**ΣC_j**

Where, $DV_{i,j}$ is the difference between the values of the indicator in a row (R_i) minus the indicator in a column (C_j). The i and j subscripts are the row and column indicators, respectively. The following step will use the sum of the columns in the bottom row (ΣC_j).

3.4.3.3 Step 3c: Determine subjective weights from stakeholders

The well-known AHP technique performs the calculations of the subjective indicator weights. The method aims to produce weightings for criteria, based on qualitative ranking data from decision-makers (Saaty, 1980). The following formula uses the output of Step 3b to calculate the values of the *Normalised Values (NV)* matrix:

$$NV_{i,j} = \frac{DV_{i,j}}{\Sigma\, C_j}, \tag{3-3}$$

The indicator weighting calculation uses the arithmetic mean of the normalised values for each row ($\overline{NV_i}$):

$$I_i = \overline{NV_i} = \frac{1}{n} \sum_{i=1}^{n} NV_i, \tag{3-4}$$

To obtain the exact weights, it is necessary to perform iterations until the new weights obtained do not change significantly from the value previously calculated. To do so, the set of weights must multiply the original matrix of pairwise comparisons:

$$RV_i = \begin{bmatrix} I_1 \\ I_2 \\ \vdots \\ I_i \end{bmatrix} \begin{bmatrix} DV_{1,1} & DV_{1,2} & \cdots & DV_{1,j} \\ DV_{2,1} & DV_{2,2} & \cdots & DV_{2,j} \\ \vdots & \vdots & \cdots & \vdots \\ DV_{i,1} & DV_{i,2} & \cdots & DV_{i,j} \end{bmatrix}, \tag{3-5}$$

$$\check{I}_i = \frac{RV_i}{\Sigma\, RV_i}, \tag{3-6}$$

The normalised matrix of pairwise comparisons should look like the following:

		Normalised Values ($NV_{i,j}$)				**1st weights**	**Iterations**	**Final weights**
		$\widehat{C}_j$						
		1	**2**	**…**	**j**	**$I_i = \overline{NV_i}$**	**RV_i**	**$\check{I}_i$**
$\widehat{R}_i$	**1**	$NV_{1,1}$	$NV_{1,2}$	…	$NV_{1,j}$	I_1	RV_1	$\check{I}_1$
	2	$NV_{2,1}$	$NV_{2,2}$	…	$NV_{2,j}$	I_2	RV_2	$\check{I}_2$
	…	…	…	…	…	…	…	…
	i	$NV_{i,1}$	$NV_{i,2}$	…	$NV_{i,j}$	I_i	RV_i	$\check{I}_i$
	Σ	**$\Sigma\,\widehat{C}_1$**	**$\Sigma\,\widehat{C}_2$**	**…**	**$\Sigma\,\widehat{C}_j$**	**$\Sigma\, I_i = 1$**	**$\Sigma\, RV_i$**	**$\Sigma\, \check{I}_i = 1$**

Where, $NV_{i,j}$ calculated using Equation (3-3) is the normalised value of the indicator in the row ($\widehat{R}_i$) and the column ($\widehat{C}_j$). The sum of the normalised columns ($\widehat{C}_j$) must be equal to one. I_i is the (subjective) weighting for Indicator *i*, obtained through Equation (3-4). RV_i is the revised (weighting) value for Indicator *i*, calculated using Equation (3-5). $\check{I}_i$ is the final weighting for Indicator *i*, calculated using Equation (3-6). The reasons for pairwise comparing the ranking of indicators by stakeholders, range from avoiding any inconsistencies in the preferences, comparing the items in pairs to judge which item is preferred, or whether or not the items compared are identical (Doloi, 2008).

3.4.4 STEP 4: Construct Objective Weight Vectors

As opposed to the subjective weights which refer to the stakeholders' ranking of indicators, the objective weight vectors refer to the CE scenarios weightings, the rankings performed by the researcher, because they are obtained by mathematical methods based on initial data from the scenarios (Wang et al., 2009). Other consensus methods were considered, such as the *Delphi method*; however, they were deemed inappropriate to apply in this tool because other experts would have been needed and these were the same participants who ranked the indicators for the subjective weights. Section 5.5 shows the case study application of this step.

3.4.4.1 Step 4a: Rescale scenarios performance

This step rescales the data in order to prevent significant differences in the pairwise comparisons resulting in disproportional weightings and the ranking of CE scenarios. To do this, the 'priority scale' is considered again. However, the ranking of the CE scenarios is based on their expected performance for each CE indicator. The number of levels to use needs to be determined by setting a maximum allowed weight for a single scenario and by using Equation (3-7) (De Feo and De Gisi, 2010, p.2376):

$$1 = y + (y / c) \times (x - 1),$$
$$c = (x - 1) / \big((1 / y) - 1\big), \tag{3-7}$$

where y is the maximum allowed weighting (i.e., the worst case where all scenarios rank in the lowest level except one, which ranks as the topmost), x is the number of scenarios to compare, and c is the number of levels in the new scale. The following equations rescale the data from the CE built scenarios, depending on whether the indicator's aim is to be maximised or minimised respectively:

$$m' = \frac{m - a_{min}}{a_{max} - a_{min}} \times (d_{max} - d_{min}) + d_{min}, \tag{3-8}$$

$$m' = \frac{a_{min} - m}{a_{min} - a_{max}} \times (d_{min} - d_{max}) + d_{max}, \tag{3-9}$$

where a_{min} and a_{max} are the minimum and maximum range of the measurements; d_{min} and d_{max} are the minimum and maximum range of the intended target rescaling; $m \in [a_{min}, a_{max}]$ is the measurement to be rescaled; and m' is the rescaled measurement to the desired $[d_{min}, d_{max}]$ range.

3.4.4.2 Step 4b: Pairwise comparison of scenarios

To continue using the AHP technique, it is now necessary to pairwise compare the CE scenarios in terms of their importance to each indicator (Feyzi et al., 2019). For this, this step uses Equations (3-1) and (3-2), and the explanations in Section 3.4.3.2. However, the only difference is that this step must calculate a matrix of pairwise comparisons for all scenarios for each indicator.

3.4.4.3 Step 4c: Determine objective weights for scenarios

Similar to calculating the subjective weights of stakeholders, the objective weights for scenarios are calculated using the AHP technique (see Section 3.4.3.3). Using again the pairwise comparisons from the previous steps – rescaling and pairwise comparing scenarios based on their performance for each indicator – the utilisation of the ‘priority scale’ should facilitate its ranking and avoid inconsistencies. The main difference is that since multiple matrices of pairwise comparisons were elaborated (one for each indicator) in the previous step, the result will be a matrix of objective weights for scenarios, rather than a vector.

3.4.5 STEP 5: Evaluation and Ranking

After calculating both the subjective and objective weights, it is necessary to verify that they are consistent (Step 5a). After that, it is possible to determine the preferred order of the CE scenarios (Step 5b) and aggregate the stakeholder group preferences (Step 5c). Section 5.6 shows the case study application of this step.

3.4.5.1 Step 5a: Verify consistency

There must be consistency in the preference judgements of both indicators and CE scenarios. Using the ‘priority scale’ (De Feo and De Gisi, 2010) should avoid any inconsistency; however, calculating the *Inconsistency Ratio (IR)* helps to verify this. Its maximum value must be below 10%, for the judgements to be considered acceptable; otherwise, they are purely random and unreliable. The following formulas obtain the IR (Saaty, 1980; De Feo and De Gisi, 2010; Doloi, 2008):

$$\mathrm{CI} = \frac{\sum \mathrm{RV_i} - \mathrm{k}}{\mathrm{k} - 1}, \tag{3-10}$$

$$\mathrm{IR} = \frac{\mathrm{CI}}{\mathrm{RI}}, \tag{3-11}$$

where CI is the *Consistency Index*; ΣRV_i is the sum of the revised (weighting) values for the Indicator *i* (also known as the maximum eigenvalue of the matrix) calculated using Equation (3-5); k is the matrix dimension; RI is the *Random Index (RI)*. The RI is based on a mean CI value for purely random matrices; their values are given in Saaty and Tran (2007, p.966). If the IR values are above the maximum acceptable value, the researcher will have to return to ask respondents to reassign scores to the indicators (Step 3a – Section 3.4.3.1) or to reconstruct the performance of the scenarios (Step 2b – Section 3.4.2.2) and repeat the process until the IR values are within the adequate limits.

3.4.5.2 Step 5b: Determine the preference order of scenarios

The *Preferability Index (PI)* determines the preference order of CE scenarios by using the previously obtained weighting vectors for stakeholders and CE scenarios. Multiplying the (stakeholders) subjective vector weights (Step 3c) and the (scenarios) objective matrix weights (Step 4c), produces the PI vectors:

$$\mathrm{PI_x}=\begin{bmatrix} I_{x,1} \\ I_{x,2} \\ \vdots \\ I_{x,i} \end{bmatrix}\begin{bmatrix} S_{1,1} & S_{1,2} & \cdots & S_{1,i} \\ S_{2,1} & S_{2,2} & \cdots & S_{2,i} \\ \vdots & \vdots & \cdots & \vdots \\ S_{m,1} & S_{m,2} & \cdots & S_{m,i} \end{bmatrix}=\begin{bmatrix} S_{1,1}I_{x,1}+S_{1,2}I_{x,2} & +\ldots+ & S_{1,n}I_{x,i} \\ S_{2,1}I_{x,1}+S_{2,2}I_{x,2} & +\ldots+ & S_{1,n}I_{x,i} \\ \vdots + \vdots & +\ldots+ & \vdots \\ S_{m,1}I_{x,1}+S_{m,2}I_{x,2} & +\ldots+ & S_{m,i}I_{x,i} \end{bmatrix}, \tag{3-12}$$

where PI_x is the PI of Stakeholder *x*, $I_{x,i} \in (0 \leq I_{x,i} \leq 1)$ is the Stakeholder *x* subjective weight for Indicator *i*, and $S_{m,i} \in (0 \leq S_{m,i} \leq 1)$ is the objective weight for CE Scenario *m* and Indicator *i*. These indexes show, on a scale from 0 to 1, how preferable the CE scenarios are to each stakeholder; their total when summed must be equal to 1.

3.4.5.3 Step 5c: Aggregate stakeholders groups preferences

The individual preferences need to be added-aggregated, so the group preference is now considered as an individual. Contreras et al. (2008) and De Feo and De Gisi (2010) use the *Geometric Mean Method (GMM)* to aggregate group preferences, . The formula for GMM is:

$$\left(\prod_{i=1}^{n} x_i\right)^{\frac{1}{n}} = \sqrt[n]{x_1 \cdot x_2 \cdot x_3 \cdots x_n}, \tag{3-13}$$

where $x_1 \cdot x_2 \cdot x_3 \cdots x_n$, are the PIs of all stakeholders, n is the number of stakeholders for that group, and $\prod_{i=1}^{n} x_i$ is the aggregated PI of the stakeholder group.

3.4.6 STEP 6: Competitive and Cooperative Analysis

MCDA is used to model the preferences of stakeholder groups in DM by introducing "compensation", meaning to agree on a set of trade-offs which settle for less of the most preferable alternative and more of the less preferable ones but without decreasing the general satisfaction of the stakeholders (Soltani et al., 2015). While GT can analyse trade-offs by considering potential cooperation and conflict between stakeholders, MCDA techniques fail to consider stakeholders' preferences and their influence when attempting to negotiate and reach consensus (Soltani et al., 2016).

After the method determines the preferred order of scenarios and aggregates the preferences, the competitive and cooperative analysis aims to enhance the possibilities of stakeholders cooperating (and continue cooperating) towards achieving their combined most preferred CE scenario. Cooperation and competitiveness can certainly vary throughout a DM process. For example, a participant can start by exhibiting a certain order of the indicators, then switch to a different order, and then back to another order. However, this research focused only on a single stage of the interactive DM process. Further research could improve this by looking at more than one stage. Section 5.7 shows the case study application of this step.

Incorporating GT elements in the last step is the novel backbone of the method – this is a particularly useful mathematical technique to study the interactions between stakeholders with multiple viewpoints and objectives, which often result in conflict.

3.4.6.1 Step 6a: Use equilibrium methods

Non-Cooperative Game Theory (NCGT) uses equilibrium methods to facilitate the most probable outcomes in interactive DM. These methods can predict the behaviour of stakeholders since they prioritise their objectives. The PI obtained from the last step now construct the payoffs of each stakeholder; these payoffs represent the levels of satisfaction obtained from the combined preference selection of all stakeholders. First, the following equation calculates the combined preferences:

$$\varphi_s = \sum_{x=1}^{s}\left(PI_{x,m}\right), \tag{3-14}$$

where φ_s is the combined preference of the CE scenarios [s], for Stakeholders *x*, respectively, and $PI_{x,m}$ is the PI of Stakeholder *x* for CE Scenario *m*. In other words, φ_s is the sum of one PI on any CE scenario for each of the five stakeholders. The objective of calculating the preferences of stakeholders is to analyse them using GT techniques. In order to do so, the following equation constructs the payoffs for the NCGT analysis:

$$\Pi_s^{x,m} = \varphi_s \times PI_{x,m}, \tag{3-15}$$

where $\Pi_s^{x,m}$ is the payoff for Stakeholder *x* if Scenario *m* is their chosen alternative and given the combined preferences φ_s as calculated from Equation (3-14). Thus, *m* must coincide with the scenario in the combined preference for Stakeholder x.

The open-access software Gambit (v15.1.1) helped to perform the NCGT equilibrium analysis of payoffs for the stakeholders. A *Nash Equilibrium* (Nash, 1951) finds the combination of stakeholder preferences to scenarios which gives the highest possible level of satisfaction to each stakeholder. It also helps understand how stakeholders would not be motivated to change their scenario selection; such action would result in decreasing the satisfaction that they (and other stakeholders) obtain.

If and only if (iff) a state *s* presents no unilateral improvements to player *A*, then state *s* is *Nash* stable for player *A*. If moving from state *s* does not result in a better payoff for A, given the decisions of their opponents, there are no incentives to change their decisions, thus *s* is stable for A. Therefore, a *Nash Equilibrium* occurs if *s* is *Nash* stable for all players (Nash, 1951). If a state is stable under several equilibrium methods, it is highly likely to be the final resolution of a game (Madani and Hipel, 2011). Four different methods are used in the software to compute the *Nash Equilibrium*. For the specific methods, refer to the literature as follows:

1. Pure strategy equilibria (Porter et al., 2008; McKelvey and McLennan, 1996).
2. Minimising Lyapunov function (McKelvey, 1998).
3. Global Newton tracing (Govindan and Wilson, 2003).
4. Solving systems of polynomial equations (Govindan and Wilson, 2004).

3.4.6.2 Step 6b: Apply allocation method

Once the equilibriums are obtained, applying allocation methods can help in preventing the potentially formed coalitions from being abandoned by the stakeholders in the future. Thus, the benefits of the participants must be assigned adequately. In this framework, the benefits obtained are the proportional gains of payoffs from the combined selection of preferences of CE scenarios above. The following equation calculates these benefits:

$$\beta_s^{x,m} = \overline{\Pi}_s \times \Pi_s^{x,m}, \tag{3-16}$$

where the arithmetic mean of the payoffs for all stakeholders in the selected coalition ($\overline{\Pi}_s$) multiplied by the respective payoff of Stakeholder *x* ($\Pi_s^{x,m}$) is the benefit for Stakeholder *x* ($\beta_s^{x,m}$).

Cooperative Game Theory (CGT) can efficiently and equitably assign benefits and costs to a group of stakeholders (called coalitions), instead of optimising each of them separately (Asgari et al., 2014). The CGT allocation method used is the commonly used *Shapley Value* (Shapley, 1953), which assumes participants agree to behave cooperatively and assigns each stakeholder their marginal contribution to the coalition they join. The cooperation of players yields an overall gain; some players might have more substantial contributions to the coalition; thus, this method allocates a reasonable expectation of profits to each player depending on their share in the value creation (Shapley, 1953).

For the benefit allocation method, the data to use as input is the sum of benefits for each possible coalition ($\sum_{x=1}^{s} \beta_s^{x,m}$). The R programming package '*GameTheory*' to solve cooperative games (Cano-Berlanga et al., 2017) helped with the application of this method. The results are obtained with R version 3.5.1 on Windows 10 version 1903. For a detailed description of the *Shapley Value* method used in this study refer to Cano-Berlanga et al. (2017). The *Shapley Value* results are then compared with the original coalition total worth to reach the fairest distribution of the computed benefits. This final step yields the best allocation of "levels of satisfaction", and by tracing back the indicators which resulted as the highest weighted, focusing on increasing their performance would increase further the respondents' satisfaction. This provides the necessary evidence to increase the participants' satisfaction and encourage cooperation.

3.5 Summary

As can be observed in Figure 3–1, the final output of the GT analysis will be contrasted and discussed with the stakeholder responses to the questionnaire. As such, the design of Section 5 enquires the respondents' opinions on other stakeholder groups. For example, the results of benefit allocation shade light on the stakeholders bargaining power; Chapter 0 will further discuss this.

An objective of this research is to complement the stability results of the negotiation process with optimal outcomes in order to successfully adopt CE principles in an MSWM system in a city. NCGT presents stable combinations of decisions, while CGT delivers fair (optimal) allocation of benefits. Combined, both methodologies could potentially promote cooperation and suggest equilibriums in the negotiations which are fair to the participants involved, and most importantly prevent them from abandoning the coalition.

The proposed framework aims to deliver recommendations on how to reach a 'most optimal' scenario. That is, each stakeholder might have an 'optimal scenario', but for the stakeholders as a whole there will be a 'combined optimal', which will (at least for some) be 'sub-optimal', yet acceptable, to individual stakeholders. Thus, the scope is oriented to stakeholder groups and aims to help decision-makers particularly in conflicting CE situations, where participants have clashing objectives; an aspect that has not been yet addressed previously in the CE literature.

4 APPLICATION OF CIRCULAR ECONOMY TOPICS SURVEY

[Please note a large portion of this chapter is the basis of original and already published work by the author[10].] This chapter addresses the third objective (O3) in Table 1–1 which based on findings from O1 presents the testing of the proposed questionnaire to measure the awareness and attitudes of stakeholders towards multiple aspects related to the *Circular Economy (CE)*. The key target of the survey is to explore the levels of CE awareness, attitudes, behaviours, and practices of the organisations' respondents. Also, their challenges, enablers, and beliefs towards cooperation, to improve CE implementation by the representative stakeholders. The chapter consists of the following sections:

- A general description of the research sample (Section 4.1).
- The results of the CE topics survey:
    - CE awareness of respondents (Section 4.2.1).
    - CE activities in organisations/disciplines (Section 4.2.2).
    - Perceived barriers to implement CE (Section 4.2.3).
    - Importance of adopting CE principles (Section 4.2.4).
    - Perceptions of other stakeholder groups (Section 4.2.5).

4.1 Section 0 – Description of the Sample

The aim of this research was to investigate whether stakeholder cooperation acts as an enabler for CE adoption. The sample consisted of two quite distinct sets of participants: current professional practitioners of CE, and the potential future leaders of industry, academia and government (i.e., future professionals; see Table 4–1). The basal section (referred to as Section 0) consists of six questions, which asked about the demographic information of participants to allow for further statistical analysis.

The first group are 27 (out of ~125) *Small and Medium Enterprises (SMEs)* from the West Midlands area in the UK. This constitutes an 21.6% return rate, which compares favourably with completion rates of around 10% reported in previous web-based survey studies of industry participants (Shih and Fan, 2008). The firms are involved in the ARLI project, which supports local businesses in developing products and processes to leverage the use of raw or waste materials. Thus, these companies had already been directly involved in CE practices.

[10] Palafox-Alcantar, P.G.; Hunt, D.V.L.; and Rogers, C.D.F. 2021. Current and Future Professional Insights on Cooperation towards Circular Economy Adoption. Sustainability. 13, 10436, Available at MDPI: https://doi.org/10.3390/su131810436.

The second group were postgraduate students (n = 101), consisting of 13 students from a Business Masters' course (University of Oxford), and 88 MSc students taking the Sustainable Construction module run by the School of Engineering (University of Birmingham). The linking thread between them is that the programme in Birmingham is heavily linked to the Business School, thus the full cohort comes from a range of different backgrounds but all with a focus on business (of which CE could be a key business case driver) and management. The survey was performed before the lecture on CE, and therefore neither group had greater prior knowledge of CE. The students had recently attended lectures in sustainability topics as part of their courses. They can all be described as students who had a genuine interest in sustainability and were sufficiently informed in the topic area. Due to the exploratory nature of the study and the small but high-quality sample, the analysis involved mainly simple statistics.

Table 4–1: Demographic composition of the respondents.

ARLI Companies	**Number**	**%**
Industry sector		
Education	7	25.9%
Medical	6	22.2%
Construction and Land Development	9	33.3%
Agriculture	1	3.7%
Manufacturing	4	14.8%
Size of organisation		
1 - independent	2	7.4%
From 2 to 9	6	22.2%
From 10 to 49	4	14.8%
From 50 to 249	4	14.8%
250 and above	11	40.7%
Position		
Chief Executive Officer	5	18.5%
Director	10	37.0%
Project Champion	7	25.9%
Manager	5	18.5%
Time in position (years)		
Average	7.59	
Minimum, Maximum	1	32
Standard Deviation	8.29	

University Students	**Number**	**%**
Geographic origin		
China	46	45.5%
South and Southeast Asia	8	7.9%
Middle East	5	5.0%
Europe	37	36.6%
Africa	2	2.0%
Americas	3	3.0%
I'd rather not say	0	0.0%
Age group		
18 - 22	30	29.7%
23 - 26	53	52.5%
27 - 30	8	7.9%
31 and older	10	9.9%
I'd rather not say	0	0.0%
Gender		
Female	34	33.7%
Male	67	66.3%
Other	0	0.0%
Programme of study (University)		
Engineering and Management (Birmingham)	88	87.1%
Business Management (Oxford)	13	12.9%

4.2 CE Survey Results

4.2.1 Section 1 – CE awareness

The questions for this section are found in Table 3–2. The first characteristic studied was stakeholders' levels of CE awareness. The first question therein, Q1.1, was used to assess whether participants were familiar with the term 'Circular Economy'. The results validated the initial assumption that most of the participants (both students and companies) were aware, to some degree, of the CE concept. This is further explained by Figure 4–1 showing that nearly half (44.4%) of the business respondents were very familiar with the concept, as the practitioners are actually practicing CE in their jobs. This was as expected since they participated in the ARLI project, as opposed to students of whom only 5.6% understood the concept 'very well'. Approximately one third of the students understand the CE well (31.7%) or very well (5.6%) and only a small portion (7.9%) had never heard of it prior to the CE lecture/course. There may have been a bias here from students wanting to impress teaching staff, however this would have not affected the responses to the rest of the questions.

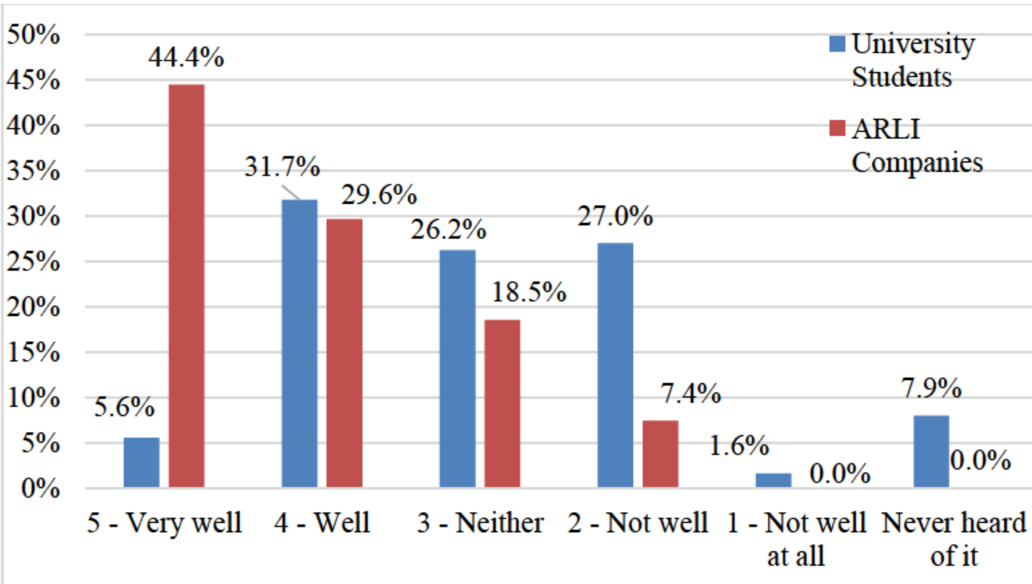


Figure 4–1: Q1.1 – (a) CE awareness of stakeholders.

Figure 4–2 shows that most of the students came from either China or Europe, and they were the ones most familiarised with the CE concept, whereas students from Africa and the Americas were more likely to have never heard of or be unfamiliar with the term. The question was designed based on previous work on measuring the awareness on CE (e.g., Guo et al., 2017; Xue et al., 2010; Liu et al., 2009; Liu and Bai, 2014; Adams et al., 2017; Liakos et al., 2019). The responses being heavily distributed in the centre-options suggest that the students´ responses to this question are deeply subjective. Further research could be helpful to explore this with other questions or more complex statistical tools to determine whether that one student's ′well′ is not the same as another ′not well′ in reality.

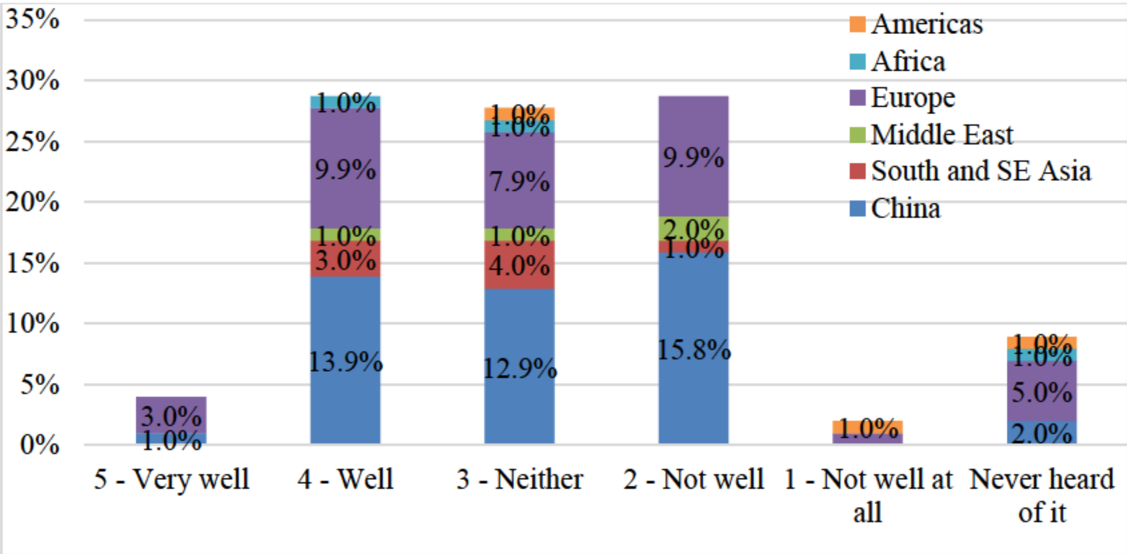


Figure 4–2: Q1.1 – (b) Geographic origin of students.

Some of the respondents wished to elaborate on their thinking regarding the concept. A number of patterns were noticed from the open-ended responses; for example, around considering environmental costs, materials reduction and decreasing waste. Some responses included very close associations between CE and *Industrial Symbiosis (IS)*, for example, A-009: *"...within the business we identify that industrial symbiosis is the circular economy in action – ensuring one organisation's by-products or 'waste' becomes another's raw material – closing loops…"*. For CE, more profound interpretations, keywords were identified, such as A-006: "... *the trading of materials and services with local people and organisations where parties are both customers and suppliers for each other – optimum resource husbandry; ... taking action to improve the efficiency of resource use. If implemented correctly, it leads to cost reductions and improved competitiveness; if implemented badly, it can lead to increased costs…*". While others interpret it as A-002: "... *businesses working together to create a more sustainable supply chain; A-007: ... to provide free electrical power to low-income residents…*".

Q1.2 assessed by how much the stakeholders' interpretation aligns with the 3Rs concept; a contested and arguably limited understanding of what a CE truly is about (Liu and Bai, 2014). Figure 4–3 shows the diversity of responses: a third of both cohort respondents (35.7% and 37.0% respectively) disagreed with the statement, while around a third of them (34.1% and 33.3%) would describe CE *'very similarly'* to the 3Rs concept, and only 18.5% of the companies would not describe CE as only reducing, reusing and recycling. Again, this shows the companies' strong familiarisation with the CE concept due to being directly involved in the ARLI project.

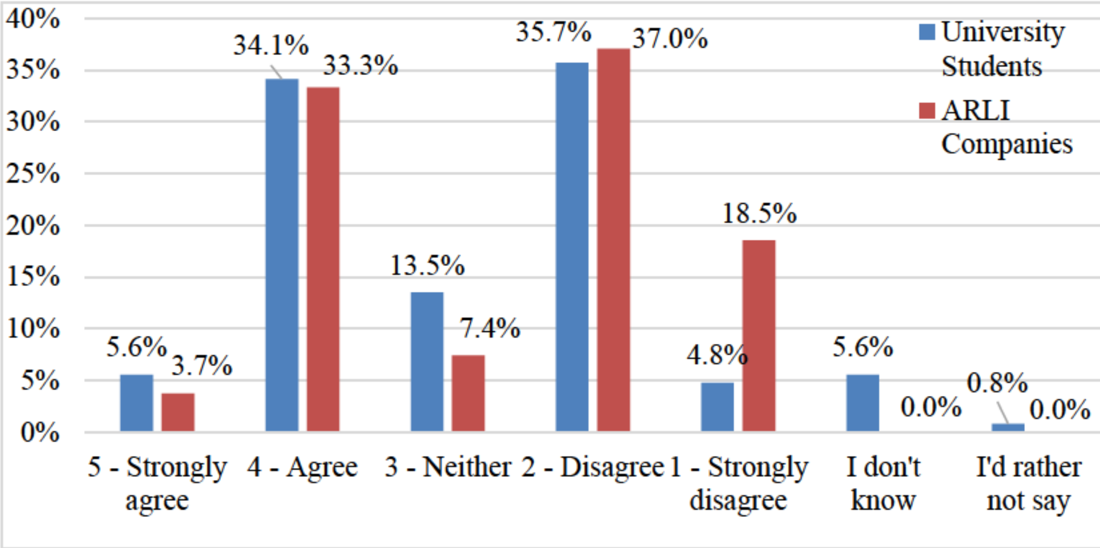


Figure 4–3: Q1.2 – CE and the 3Rs concepts alignment from participants.

Figure 4–4 presents the results from Q1.3, the main categories of CE research and practice selected from different studies (Ferronato et al., 2017; Marios et al., 2018; Smol et al., 2018; De Feo and Williams, 2013). The first observation is that the 3Rs are embedded in the interpretations of both groups of respondents. The *"Design out waste"*, *"Share resources"* and *"Increase exchange"* were selected more frequently by the industry responses. The least identified category was *"Build resilience"* with a selection rate of 49.2% for students and 48.1% for companies, these percentages being less than the value of 69% reported by Smol et al. (2018). The *"I'd rather not say"* and *"I don't know"* options were discarded as no responses were recorded for them, and thus are not depicted in the figure. More discussion of these outcomes is given in Section 6.1.1.

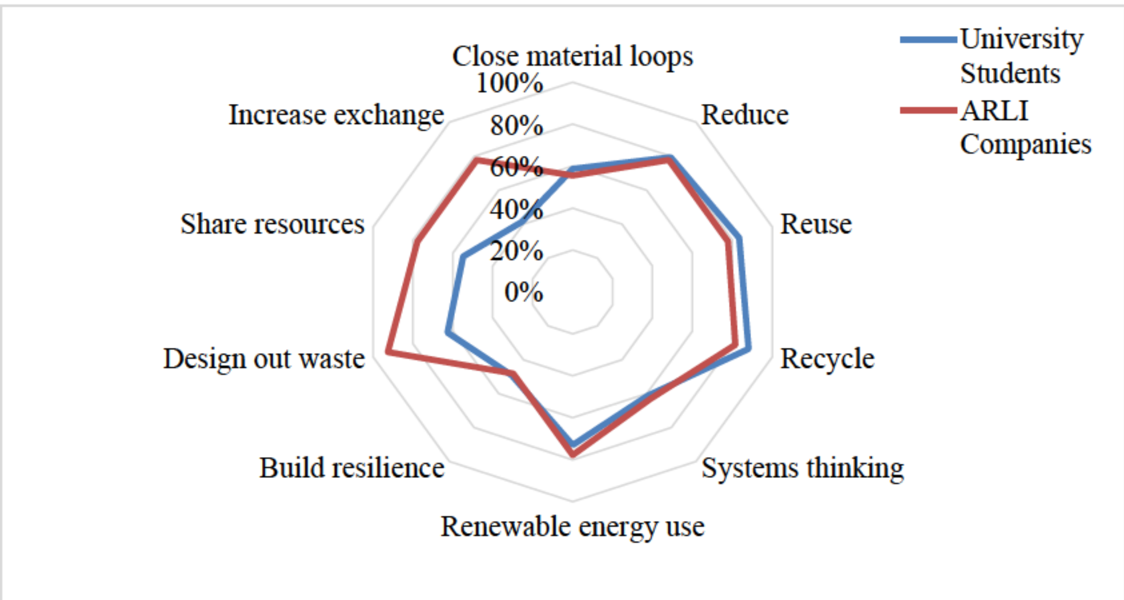


Figure 4–4: Q1.3 – Categorisation of the key principles of CE concept by stakeholders.

4.2.2 Section 2 – CE activities in organisations

The questions in this section were presented in Table 3–3. This section, Q2.1, aimed to learn about which CE practices are most widely adopted and relevant by current and future CE practitioners. This section was mainly adapted from the work of Masi et al. (2018), as they focused on leader firms in the supply chain, and thus this study aimed for SMEs with potential CE arising opportunities. Figure 4–5 shows the results for the respondents' practices related to CE and the average of the categories. The practices are classified into six categories (Masi et al., 2018):

1. Resource and energy utilisation efficiency (Q2.1.1 – Q2.1.4).
2. Investment recovery (Q2.1.5 – Q2.1.11).
3. Eco-design (Q2.1.12 – Q2.1.14).
4. Green purchasing (Q2.1.15 – Q2.1.17).
5. Customer cooperation (Q2.1.18 – Q2.1.20).
6. Internal environmental management (Q2.1.21 – Q2.1.25).

There is a clear difference in the responses from students and companies. Students seemed to rate every item higher than companies. This suggests that the perspectives from students are more optimistic about their future careers and disciplines when compared to the realistic experiences from current practitioners. On average, on a 5-1 scale with 5 being the most important, the highest rated category by both cohorts was *'Resource and energy* utilisation' (4.53 for students and 4.05 for companies). The largest discrepancy was in the category *'Investment recovery'* (4.04 and 2.68 respectively). In terms of separate practices, Students ranked highest *'Reducing waste'* (4.64), *'Reducing pollutant emissions'* (4.63) and *'Recycling materials'* (4.55). *'Adopting a leasing or service-based marketing strategy'* (3.64), *'Taking back products from consumers after the end of their functional life'* (3.77) and *'Taking back products from consumers after the end of their usage'* (3.72) were the lowest ranked categories by the student cohort.

Similarly, Companies ranked highest the options including *'Reducing wastes'* (4.37), *'Reducing material consumption'* (4.22) and *'Designing process for minimisation of waste'* (4.00), showing their priority to be avoiding waste. However, the lowest ranked categories were quite different for the professional practitioner cohort: *'Cascading use of components and materials'* (2.05), *'Refurbishing products'* (2.11) and *'Remanufacturing products'* (2.24). This was perhaps to be expected as the choices provided were based on private companies' practices (Liakos et al., 2019). More discussion is presented in Section 6.1.2.

Figure 4–5: Q2.1 – Relevance of CE practices for students and companies.

4.2.3 Section 3 – Perceived barriers to implementing CE

This section was specifically designed to enquire about the perceived barriers to CE implementation by all participants. The questions were presented in Table 3–4. This section of the questionnaire was designed based on the categorisation of barriers to CE implementation by Kirchherr et al. (2018). Q3.1 explored the cultural barriers, and Figure 4–6 shows its respective results. It should be noted that Ferronato et al. (2017) had additionally investigated related lack of awareness or engagement with CE from manufacturing firms, these were outside the remit of this current research, hence these are highlighted for interest of the reader. In the figure it can be seen that the barrier considered by companies the most important to overcome with an average ranking of 3.74 was *'Hesitant entrepreneurship due to high uncertainty'*, this was closely followed by *'Insufficient cooperation in the value chain'* (3.52); notably this reflects the main barrier that this research is designed to help overcome. Students think that *'Lacking consumer awareness and interest'* (3.98) is the most pressing of the barriers to overcome, being the one with the highest difference with the companies cohort which they ranked lowest (3.18). However, *'Operating in a linear system'* being the lowest ranked by students (3.56). Participants stated additional essential but least urgent cultural barriers such as: A-015: "*Procurement legislation*", S-109: "*Expecting immediate rewards*", S-059: "*Large corporations holding too much power to change the system*", and A-014: "*Insurance policies for CE projects*".

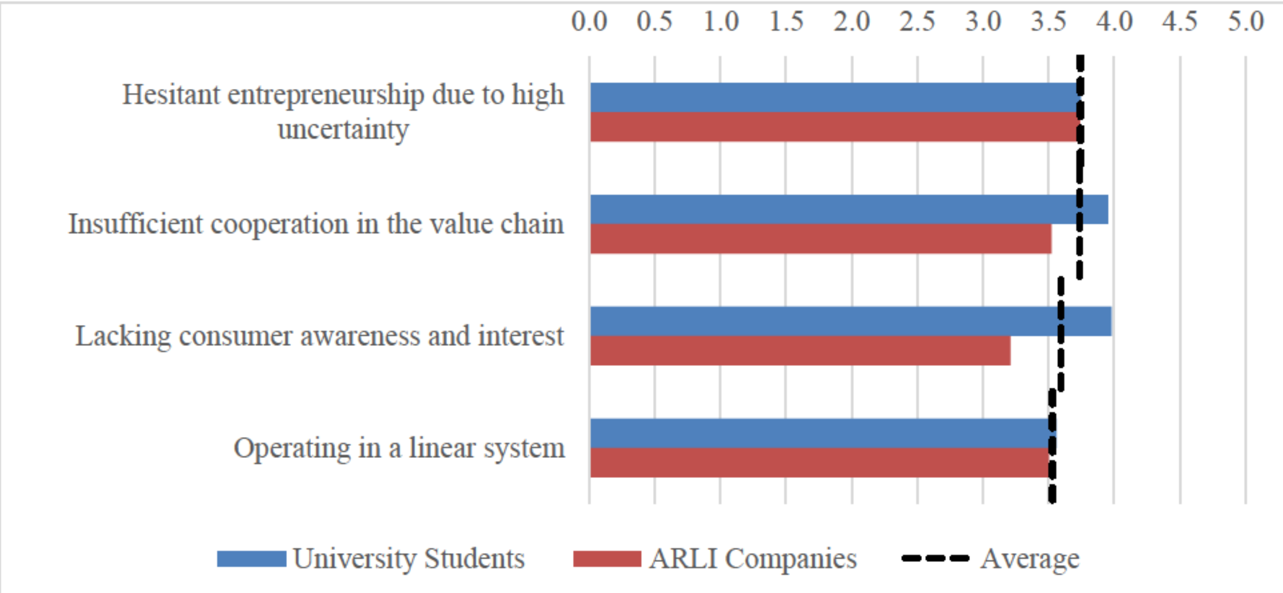


Figure 4–6: Q3.1 – Cultural barriers to adopting CE.

Q3.2 analysed regulatory barriers related to lacking policies in support of CE transition, and Figure 4–7 shows the results. On average, *'Limited procurement practices'* was selected as the most pressing barrier by students (4.20) and the least by companies (3.76). Companies perceived

'Lack of global consensus' as the most critical barrier (3.81), but students selected it as the least urgent of the regulatory barriers (4.01). Finally, *'Hindering regulation'* was neither the least nor the most crucial of the choices for both companies (3.76) and students (4.02). An additional regulatory barrier proposed by company A-021 was "*Insurability*", and student S-090 provided "*Conflicting regulations for example reducing food waste and hygiene regulations*".

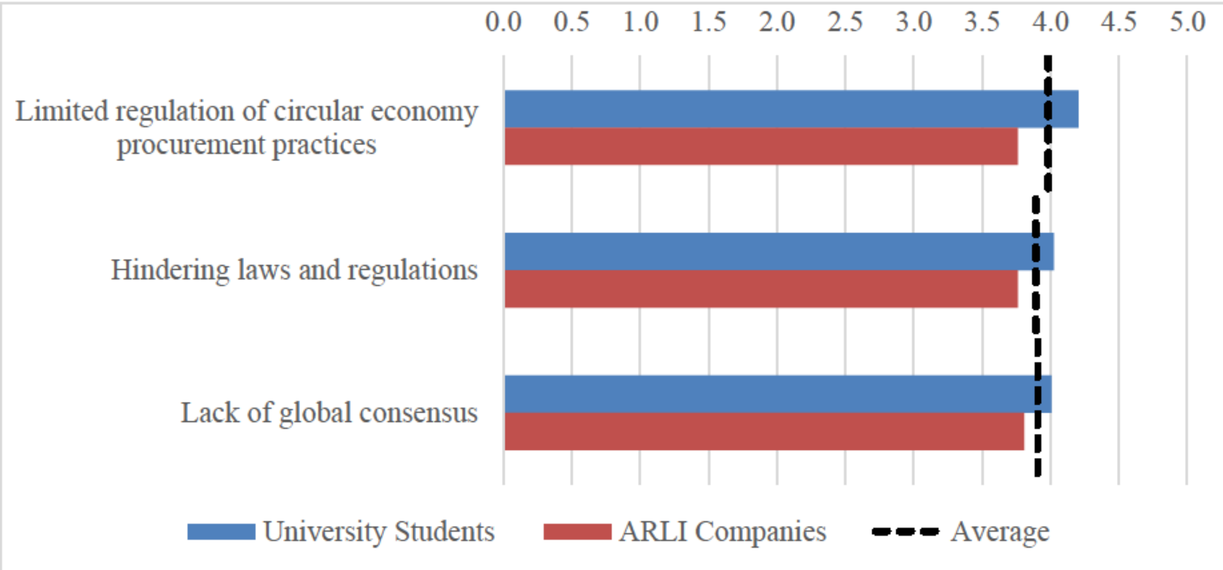


Figure 4–7: Q3.2 – Regulatory barriers to adopting CE.

Q3.3 aimed to shed light on the market barriers, which relate to a lack of economic viability of CE business models, and Figure 4–8 shows their results. On average, the least acute market barriers resulted from '*Low virgin material prices*', particularly for companies (3.28) and for students (3.61); and '*Lack of circular standards*' for companies (3.88) and students (3.85). On the other hand, *'Limited financial support'* was perceived by companies (4.02) as the most critical market barrier; and *'High upfront investment'* was seen by students (4.30) as the most critical barrier in contrast to companies (3.65) as they do not perceive it as much given that they are already involved in ARLI, a project which helped them identify CE opportunities at low initial costs. Additionally, the following barrier was added based on the opinion of a participant E-024: "*all firms, particularly the smallest, need to focus on keeping costs low and making a profit: they will only adopt CE if it is helpful to this*". A few students also wished to expand their responses, such as S-110 *"high market competition and pressure and resources price fluctuation"*: and S-054 *"limited exposure to new markets such as sharing business models"*.

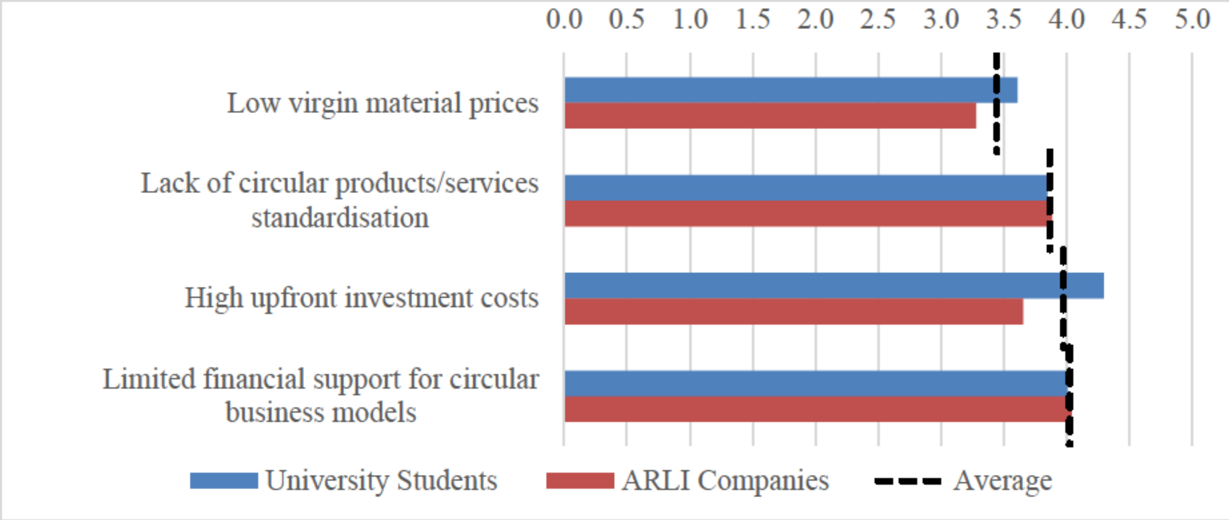


Figure 4–8: Q3.3 – Market barriers to adopting CE.

Finally, Q3.4 studied technological barriers or the lack of proven technology to facilitate CE; Figure 4–9 illustrates the results of this question. The barrier that resulted as the most vital (on average) to overcome was *'Limited ability to remanufacture products'* (3.78) and the least critical was *'Too few large-scale projects'* (3.55). In general, the opinions of the cohorts vary widely concerning these technological barriers. For example, the most critical barrier for students was *'Limited ability to remanufacture products'* (4.02), whilst this was the second most important for companies (3.54). On the other hand, the most critical for companies was *'Lack of data'* (3.77); but this was the least demanding for students (3.73). In terms of additional barriers provided by respondents there were for example: A-007 *"disconnect between research and full-scale project funding"*; S-089 *"issues and inefficiency with recycling materials"*; and S-006 *"development of reverse logistics infrastructure and sharing platforms"*. More discussion is presented in Section 6.1.3.

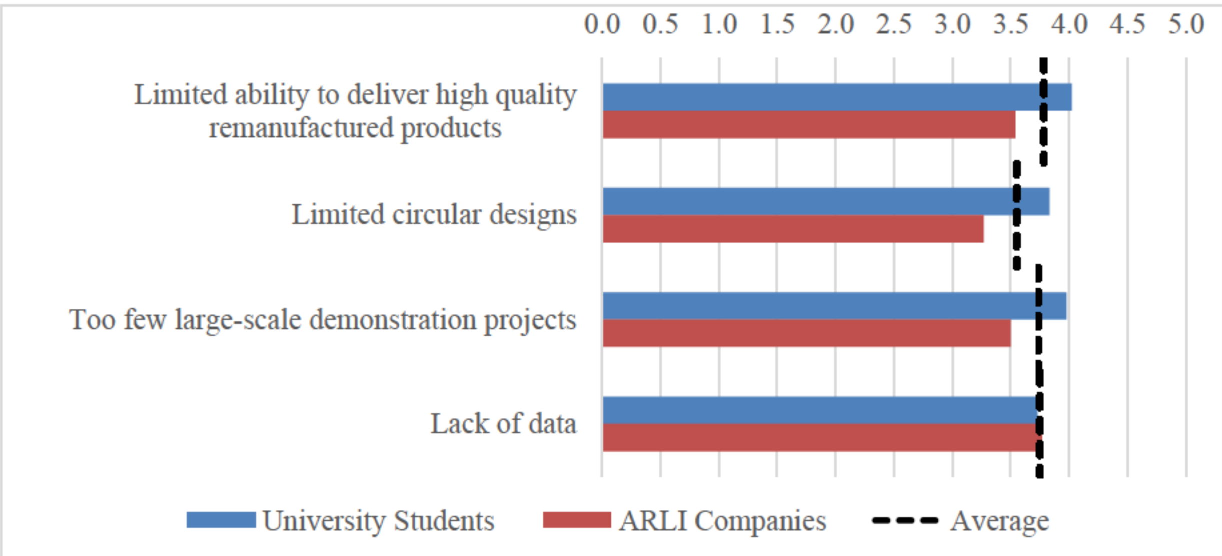


Figure 4–9: Q3.4 – Technological barriers to adopting CE.

Based on the above four figures, the most pressing issues across the findings for students were that regulatory barriers were of critical importance, and that *'High upfront investment'* is the most pressing to overcome by them. This could be related to seeing themselves as more highly aware and in the generation with a more sustainable culture who will achieve the CE transition. On the other hand, companies also perceive the regulatory barriers as the most pressing to overcome. However, market barriers received a lot of attention as well, specifically *'Lack of standardisation'* and *'Limited financial support'*; this leads to an understanding that practitioners focus more on different problems in the CE transition and more support is needed both from government and financial institutions.

4.2.4 Section 4 – Importance of CE principles adoption

This section's questions are presented in Table 3–5. The fourth section of the questionnaire aimed to learn about the respondents' attitudes towards and the perceived importance of adopting CE principles. The first question of the section, Q4.1, enquired about the importance of embracing CE to the companies and disciplines of the students. Figure 4–10 showcases the results. [Liu et al. (2009) investigated the public's attitude towards the future of CE and its development; and Smol et al. (2018) asked the local inhabitants in Malopolska, Poland about their opinion on the development of CE in the region.] There is a clear trend: respondents consider embracing CE as (at least) an important asset to them. For companies, 51.9% selected *'important'* and 37.0% selected *'very important'*, whilst for students, 97.6% (difference of +9%) considered CE as either important or very important to the future of their disciplines and careers. None of the participants thought that CE was not important at all. This might relate to their high awareness. In line with that, even though the principal aim of the project was not CE, it was raised as a promising opportunity on the journey.

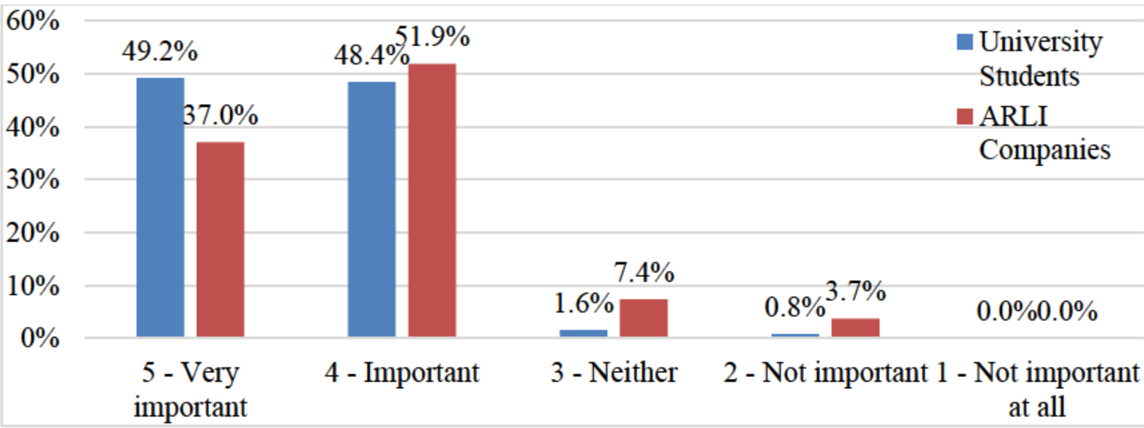


Figure 4–10: Q4.1 – Importance of adopting CE principles in disciplines/organisations.

The second question from this section, Q4.2, asked about the meaning of general waste to respondents. It can be observed from Figure 4–11 that students believed that waste can be dealt with in significantly more alternative ways than companies. The meaning of the waste discarded by manufacturing firms has been previously investigated (e.g. Ferronato et al., 2017; de Feo and Williams, 2013). As expected, the option most selected by both cohorts was recycling with 90.5% and 74.1% respectively for students and companies. Landfill was the least preferred option (3.7%) for companies, significantly less than students at 46.8%, while incineration was likewise considered a more likely outcome by students (44.4%) than companies (22.2%); these findings possibly reflecting a lack of awareness amongst students of the environmental costs involved. Perhaps this is because waste activities at universities are not of the highest order.

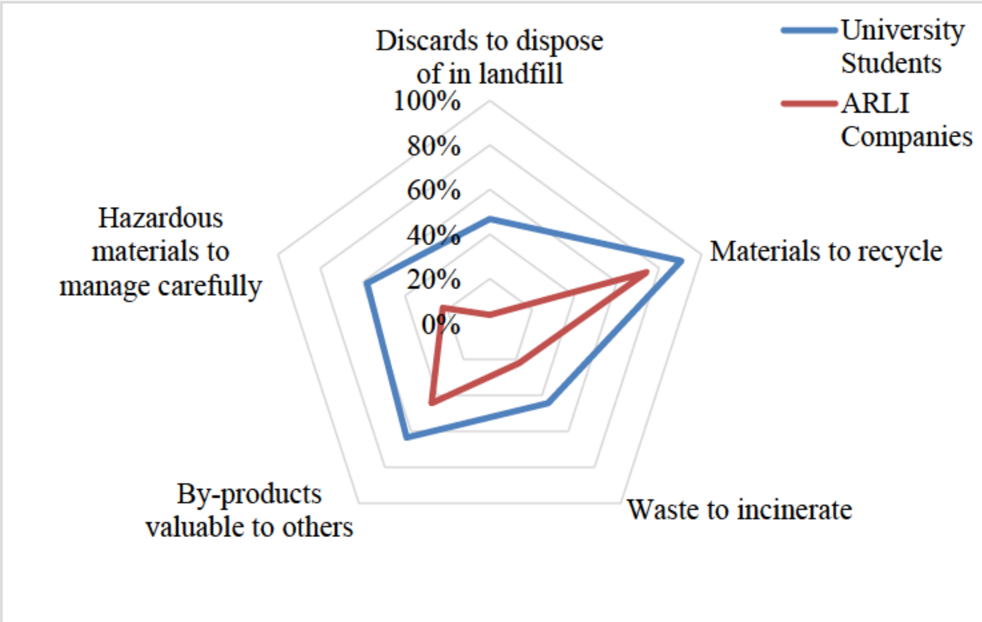


Figure 4–11: Q4.2 – Meaning of waste components to participants.

The results for the final question of this section, Q4.3, which asked about the main enablers of the successful transition to a CE, are shown in Figure 4–12. Herein it is observable that students once again have on average a more favourable opinion of the options provided (excepting *'avoid landfill'*). Students have selected the *'Sustainable business strategy'*, *'Energy savings'* and '*Reduce waste'* options as the most important (with 84.9%, 79.4% and 74.6% respectively), whilst '*Avoid landfill'* and *'Fluctuating resource prices'* were the least important (with 37.3% and 30.2%). On the other hand, ARLI companies' responses aligned strongly with the '*Sustainable business strategy'* being the first enabler of a CE (with 63.0%), whereas the choices with the lowest response rates were *'Fluctuating resource prices'*, *'Entering new markets'* and '*Keeping up with competitors'* (with 25.9%, 22.2% and 18.5% respectively). Again, avoiding waste generation and mismanagement features highly on the ARLI agenda. More discussion is presented in Section 6.1.4.

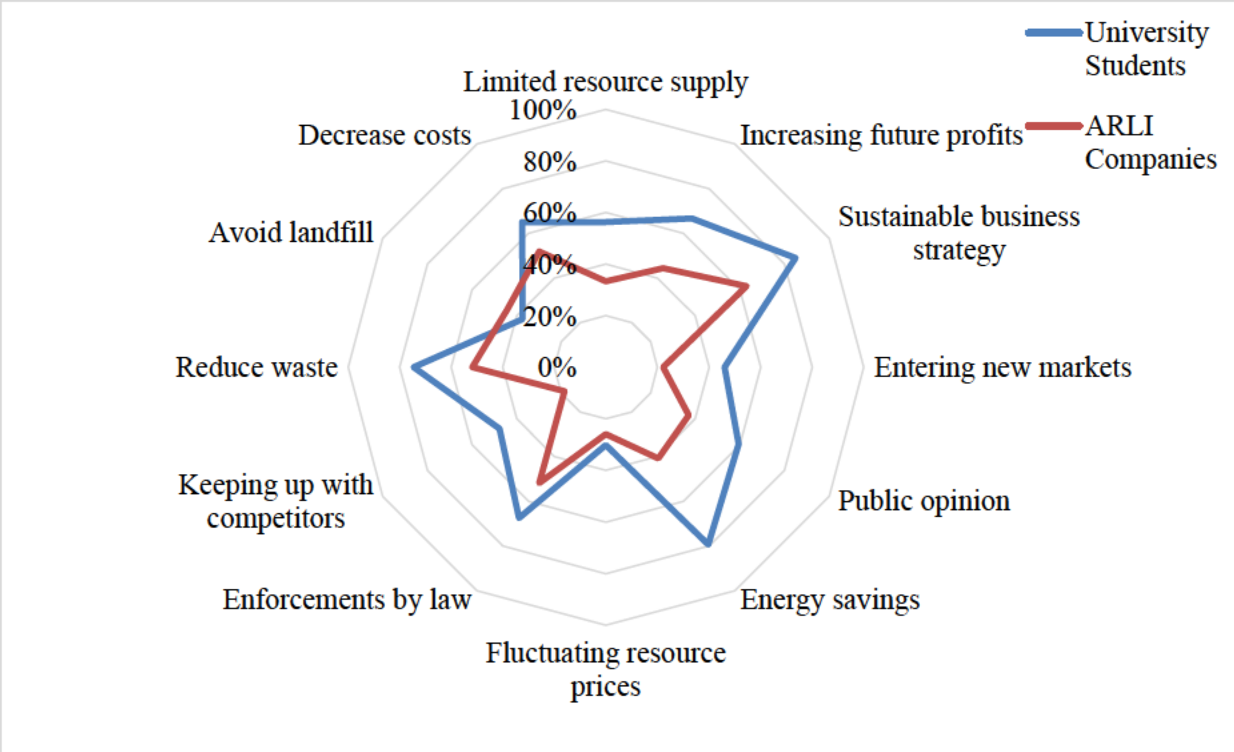


Figure 4–12: Q4.3 – Motivators to encourage CE transition.

The figure shows that there is another clear difference in the opinions from students and companies. Students seemed to perceive these items as higher motivators than companies overall. This suggests that students have a more general vision of what would motivate the transition to a CE, whereas companies seemed to have a more balanced view about the reasons to adopt circularity. Again, this might be related to students being more optimistic in their views and companies more realistic given their practical experience.

4.2.5 Section 5 – Perceptions of other stakeholder groups

The questions from this section were presented in Table 3–6. The first question in this section, Q5.1, explored the level of trust between stakeholders (Figure 4–13). Smol et al. (2018) asked their respondents the reasons for sharing journeys or renting properties directly from owners. The most selected response in that study was due to the lack of trust between participants. The results of this research show a strong agreement for the need for stakeholders' mutual trust if they are to cooperate and successfully adopt CE principles (with 90.5% of students and 77.8% of companies at least agreeing). Few of the responses disagreed, although participant C-018 stated that "*one cannot trust SMEs to do what they have to do; we really need to chase them*". Although not entirely significant for this particular case study, further research could beneficially explore why companies disagree with the trust statement. However, other responses were more optimistic: for example, participant A-013 said that "*these things are not by chance – they take* *hard work, effort and trust. It implies the definition of joint-venture, the need to put things in a legal matter, so everyone gets clearly what to do and what to expect*". This reflects how cooperation between all the participants is recognised as critical. The terms "trust" and "cooperation" do not necessarily end up conflating each other; trust can be a necessary condition to cooperate, or distrust can be the reason stakeholders come together to cooperate.

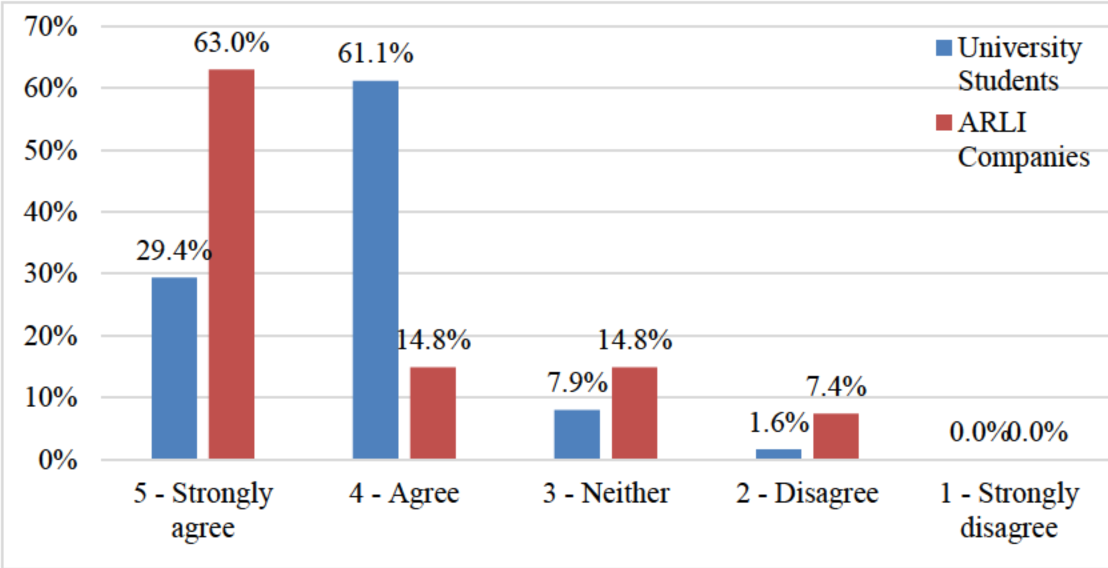


Figure 4–13: Q5.1 – Agreement of respondents to trust other stakeholder groups.

Figure 4–14 shows the results for Q5.2, which asked which actor(s) need to cooperate and therefore should be involved in the *Decision-Making (DM)* associated with new CE waste management strategies for the city. This complemented previous surveys that asked respondents about the levels of CE awareness and participation of a range of participants in within the construction sector (Adams et al., 2017) and found that despite the extensive awareness, the industry as a whole was not clear on what CE could represent for the built environment. Other research (De Feo and Williams, 2013; Ferronato et al., 2017) posed questions about how much local residents are (or should be) involved in new waste management policies.

In this current research the actors who received the higher number of total responses were Local politicians (with an average of 75.8%) and Local policymakers (80.6%). External consultants were considered least important (with only 40.2% of the total responses), followed by Technology suppliers (66.0%). The largest differences between cohorts' viewpoints were for Technology suppliers (with 74.6% and 25.9% respectively for students and companies), followed by Waste management operators (with 81.7% and 37.0% respectively) then Entrepreneurs (73.0% and 37.0%). Perhaps this is because of the business involvement and backgrounds from the students' course, which are heavily focused on taking account of all participants viewpoints, and again the students' optimism regarding the transition to circularity.

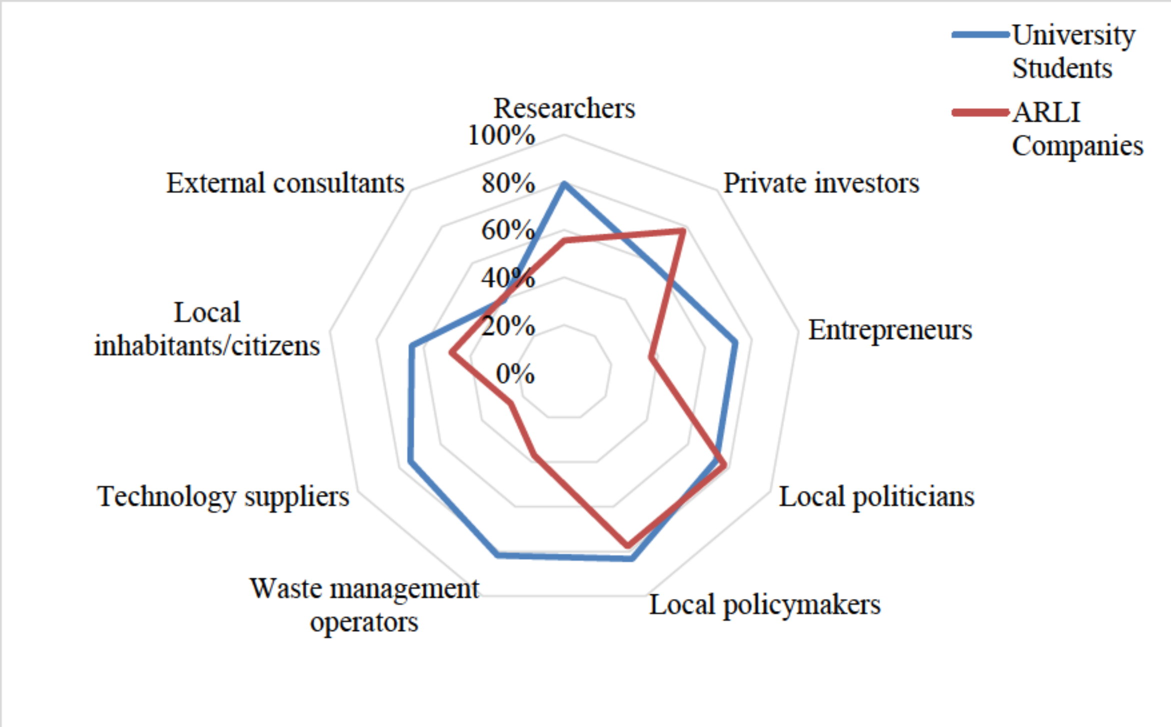


Figure 4–14: Q5.2 – Opinions on actors who need to cooperate when adopting CE in urban waste management.

The last question, Q5.3, addressed how respondents, in this case the ARLI companies alone, perceive power and power trends of stakeholder groups. The results will be contrasted with the results from the Shapley value method (final step in the GT-hybrid tool on Section 5.7.2). The primary (blue) bars on Figure 4–15 show the results for how powerful they are perceived, the stakeholder in the horizontal axis being the one evaluated by respondents. The most powerful stakeholders, in other words, those most able to bring about the transition to a CE, were deemed to be Companies (4.26) followed by Local Government (3.98), with Academic Institutions perceived to be the least influential of them all (2.91). However, as to the perceived trends' power (with increasing power scored as 5 and decreasing scored as 1), Companies and Academic Institutions were both recognised as becoming more powerful (and therefore influential), the latter perhaps because of a renewed tendency, at least in the UK, to 'follow the science'. There was the potential participant bias, for example, since Companies might wish to be seen as saying that Academic Institutions have an outstanding performance because they are both part of a scheme that involves them directly. However, this bias was minimised by having asked the same question to all the other three stakeholder groups as well. On the other hand, Local Government was considered to have decreasing power/influence in CE transition whereas the perceived power of the General Public was considered to remain relatively unchanged. As stated by participant A-013: "*the government has been struggling with budget cuts and the private sector and academy are filling those gaps*".

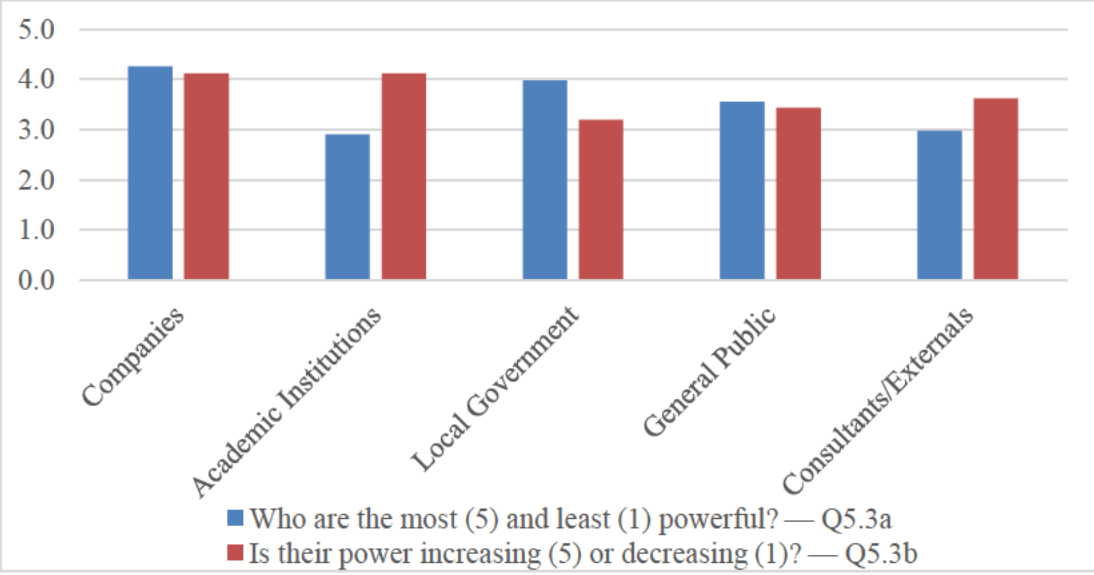


Figure 4–15: Q5.3 – The perceived power and trends of stakeholders' power in the CE transition.

[1] a higher score (5) means the most powerful to the least powerful (1)

The final questions of the survey, Q5.4 and Q5.5, asked openly about which other barriers and enablers the stakeholders could encounter to cooperation towards CE adoption, respectively. After tidying the response database, calculating the word counts and their correlations, word network plots were built to show the correlations of words and the frequency that they were used. In the graphs, the colour of the word shows how many participants used the word, meaning that the lighter the blue the more respondents used it. Also, the thicker the line between words, the more likely they are to appear in the same response (i.e., they are more highly correlated).

Figure 4–16 shows the connections of these relevant words found in the open-ended questions; by analysing the connected dots, they show the topics related to barriers mentioned by participants. From the figure it is observed that there are important but slightly fragmented responses around typical barriers to CE adoption; for example, in relation to the prices of materials, technology being unavailable and waste of companies. Other important CE related bigrams (pairs of successive words) are found around cost transition, differences in information, limited time for implementation, and a clear understanding of benefits and costs in the transition. Responses were widely varied from participants and included:

- A-013: "*...maturity of technology, trapped in a linear system, and the cost of this transition*".
- A-016: "*... compelling interests, adopting new technologies and processes, evaluating different options transparently*".

- A-017: *"…conflicting objectives, different agendas and priorities, how costs to each group are stated"*.
- S-020: *"…poor communication and conflicting objectives/expectations with waste collection system"*.
- S-101: *"…it might be difficult for everyone to see the benefits of circular economy, so it will be hard for them to enter into transition"*.
- S-015: *"…lack of public awareness and pressure; public sector procurement rules …"*.

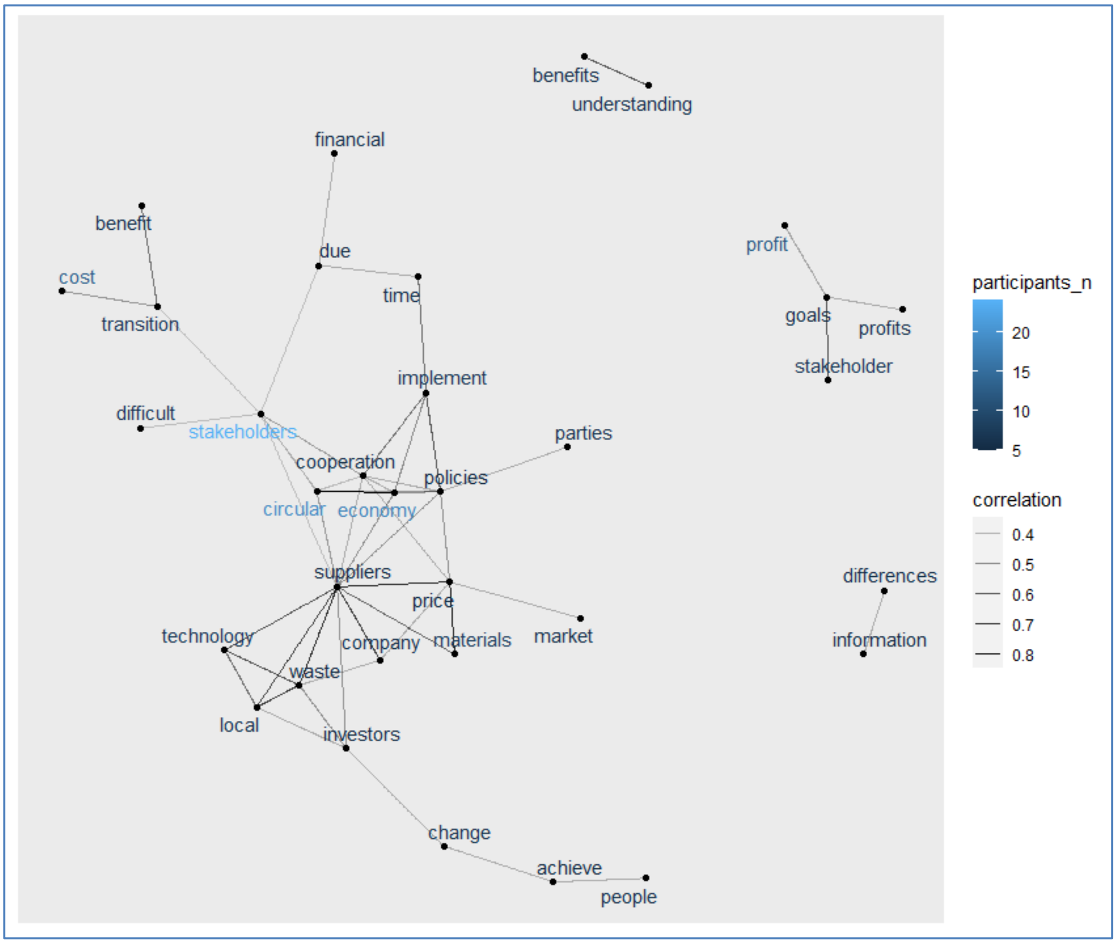


Figure 4–16: Q5.4 – Word network plot for participants' additional barriers to cooperation.

On the other hand, Figure 4–17 shows the plot of words used by respondents used when asked about factors that would facilitate a successful stakeholder cooperation between stakeholders when adopting CE. It is observed that from the respondents' viewpoint there are several ways to improve cooperation amongst stakeholders; for example, providing evidence that solutions are effective, the government offering incentives and policies to local companies and parties. Also as mentioned, making objectives and plans more explicit to all participants, increasing awareness of companies, creating a common understanding, mutual goals, and pairing profits and sustainable development are key to all. Some of the most insightful responses include:

- S-071: *"Policy support and mutual trust between participants, and the public's awareness…".*
- S-073: *"…communication, understand the benefits/plan/work plan from the beginning".*
- S-078: *"…clear evidence to show it is going to generate profit. Enforced by law".*
- A-001: *"…stakeholders need a collaborative and science-informed decision environment…".*
- A-024: *"…It is important to understand customer drivers before trying to implement CE".*

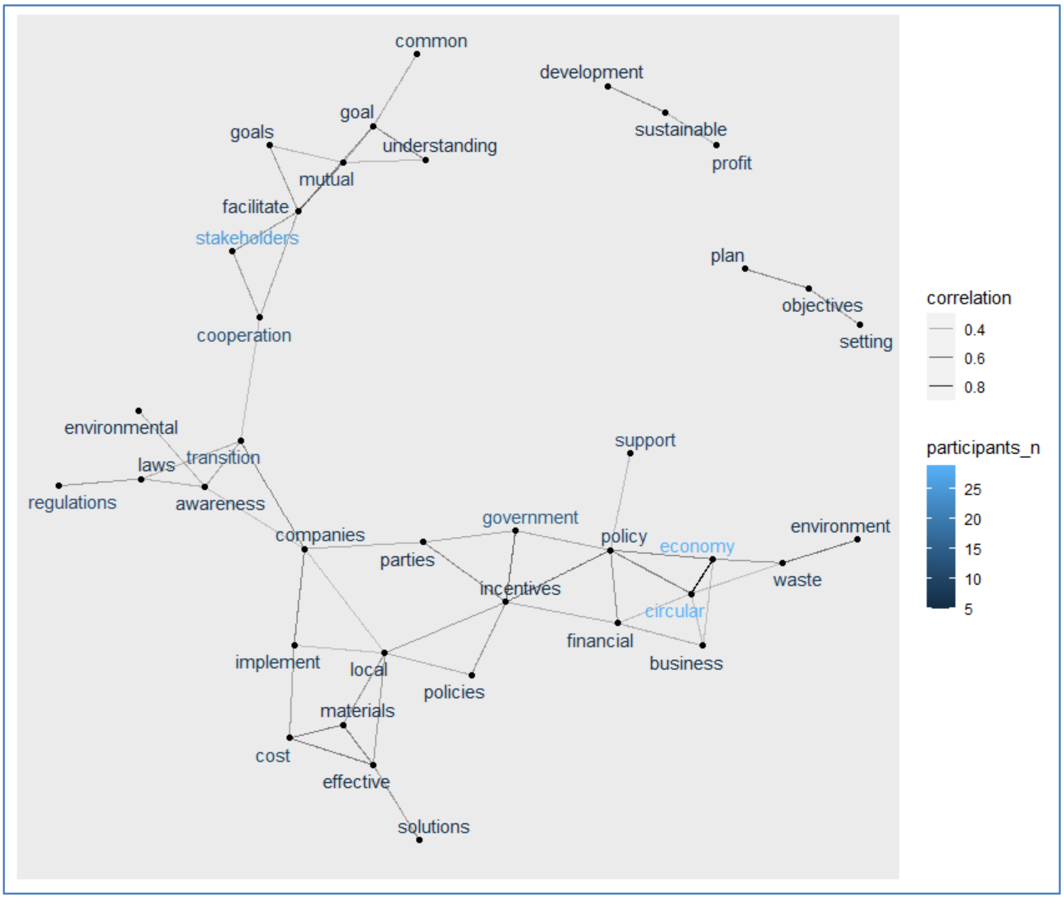


Figure 4–17: Q5.5 – Word network plot for participants' facilitators to cooperation.

More discussion of these outcomes is given in Section 6.3.1. Chapter 5 presents the outcomes from the application of the GT elements tool in the case study site, in other words, the remaining steps of the proposed methodology. Chapter 0 discusses in more depth the results in this chapter; and also contrasts them against the results from Chapter 5.

5 APPLICATION OF THE GAME THEORY (GT)-HYBRID TOOL TO THE CASE STUDY

This chapter addresses the fourth objective (O4) in Table 1–1, which is based upon and draws from findings of O2. It reports on the outlined six-step *Game Theory (GT)*-hybrid methodology introduced in Chapter 0 is applied to the case study site (see Section 5.1 for a general description of the site). Sections 5.2 to 5.7 respectively each present Steps 1 to 6 of the GT- hybrid methodology. For illustration purposes, each step presents an abridged version of the calculations to exemplify what was undertaken. It must be noted that a similar case study site application has already been published within the literature by the author of this PhD[11]. The main difference between this thesis and the published work is that the thesis presents results of a wider and aggregated group of stakeholders.

5.1 Description of the Case Study Site

The case study was conducted in the context of the *Tyseley Energy Park (TEP)* in Birmingham, UK (https://www.tyseleyenergy.co.uk/masterplan/). Many stakeholder groups, such as private investors, academics, local community, and the City Council, are involved in the expansion and rearrangement of the park (see Figure 5–1). Even though the dotted lines are not identified in the figure, they represent the limits of the park (red) the potential expansion with collaboration of neighbouring industries (purple), the ways of access (black) and the current buried waterline that supplies the park (blue). Several changes to the site and the way it operates are aligning to CE principles in its portfolio of business models despite not being in the main initial plan. Successful cooperation would allow the capture of various types of value, many deriving from infrastructure interdependencies, in an energy infrastructure park aiming to become a national exemplar of a large-scale energy and CE demonstration project.

[11] Palafox-Alcantar, P.G.; Hunt, D.V.L.; and Rogers, C.D.F. 2020. A Hybrid Methodology to Study Stakeholder Cooperation in Circular Economy Waste Management of Cities. Energies. 13(7), 1845, Available at MDPI: https://doi.org/10.3390/en13071845.

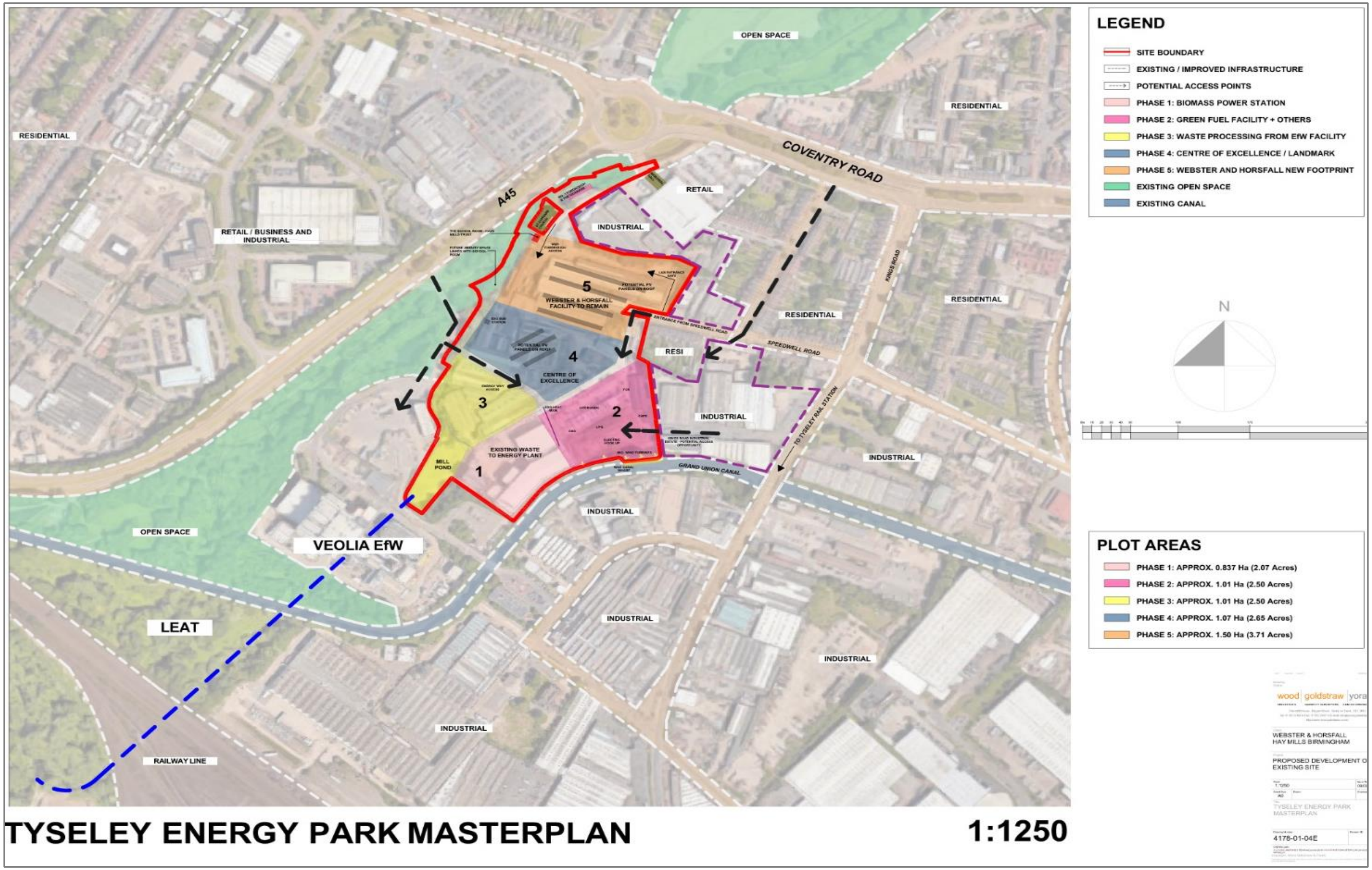


Figure 5–1: The various parts of the masterplan for Tyseley Energy Park (TEP).

[1] Source: https://www.tyseleyenergy.co.uk/masterplan/

The land where the developing project is taking place is privately owned and many business tenants are already well-settled at the site. Other companies have private interests in settling businesses therein with *Industrial Symbiosis (IS)* potential, and universities such as University of Birmingham are interested in the research opportunities arising around renewable energies. The local government owns the incineration facilities and has a contract with a waste management operator to recover energy from a large portion of the *Municipal Solid Waste (MSW)* collected in the city. However, there exist environmental and societal concerns by local inhabitants. Therefore, the government and related companies have requested the help of consultancy services to embrace sustainability and CE opportunities. The small number of potential participants, those engaged in the TEP's activities, were contacted with a relatively high response rate (14 out of 36, approximately 38.9%). However, this part of the research aimed to collect data from those in senior posts and highly aware CE (e.g., sustainability individuals), which would result in few but high-quality responses. The site was chosen because after attending meetings, it was clear that stakeholders had different interests. Some knew what CE was despite not having been the aim of the park, but it was raised as an important opportunity.

Embedding CE in the developing TEP could materialise if stakeholders achieve cooperation between themselves. TEP is a renowned project that proposes to adopt and develop sustainable energy generation technologies for the city, at a time when its current *Energy from Waste (EfW) Municipal Solid Waste Management (MSWM)* contract was due to expire (in 2019 when this research was performed). The project consists of five main phases: 1) investing in a renewable waste wood biomass power plant; 2) the construction of the UK's first low and zero carbon refuelling station for vehicles; 3) implementation of new generation waste reprocessing technologies (the current incinerator contract was renewed when this thesis was written); 4) investment in the Birmingham Energy Innovation Centre (BEIC) to decarbonise electricity and heat (opened in July 2021) towards a net-zero target by 2030; and 5) incubation programmes to support Low Carbon focused SMEs. Opportunities to embrace CE arise from the fact that vast amounts of waste are at risk of remaining untreated when the plant closes unless feasible (preferably sustainable) alternative(s) can be found. Lee et al. (2016) analysed the waste for Birmingham (Figure 5–2). It shows that even though the city has one of the lowest landfill rates in the UK, two-thirds of the total MSW is still incinerated to recover energy. Besides, the energy recovered accounts to 217 GWh annually; however, this is equivalent to just over 1% of the total energy demand of the city (Lee et al., 2016). This casts doubt on the real contribution to the circularity of the city's approach and the need to identify key waste streams to facilitate resource reintroduction into the system. This was another reason for selecting this as a case study site.

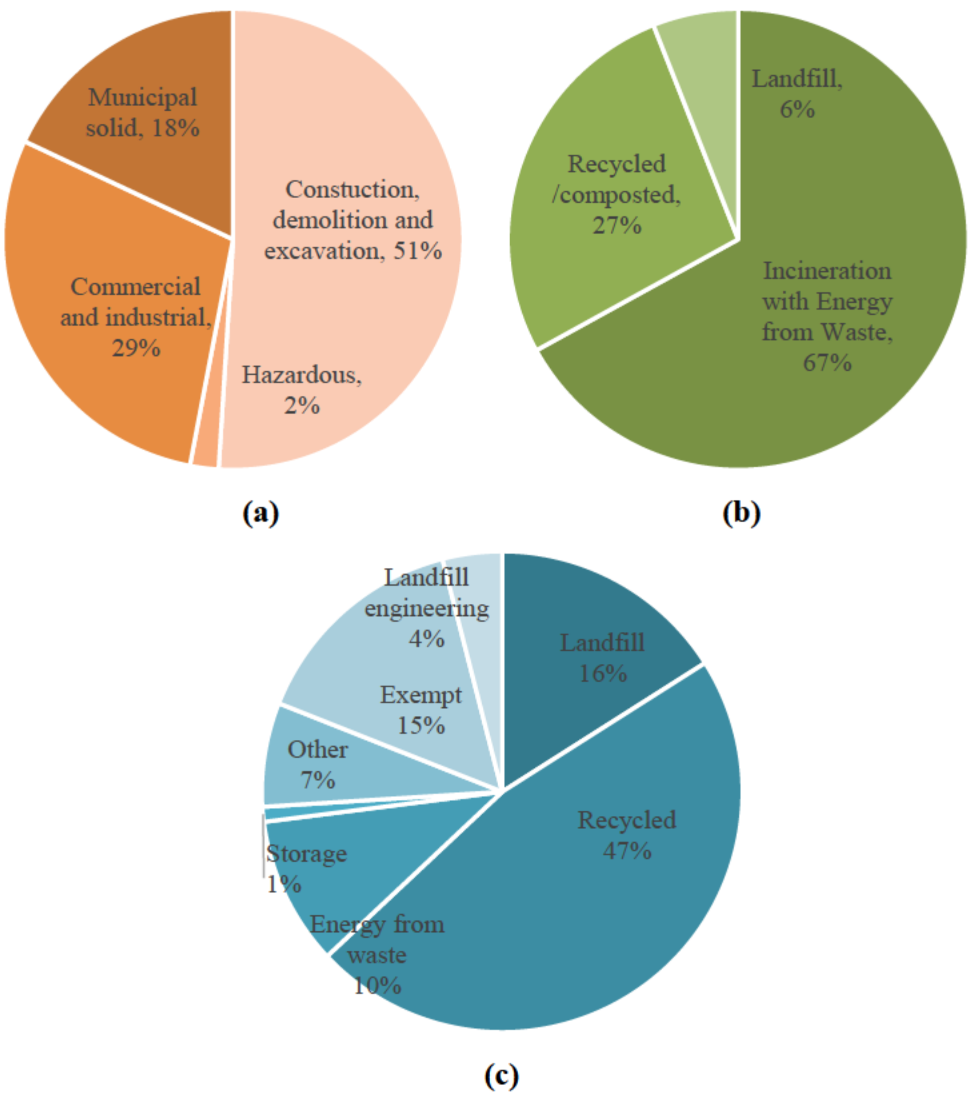


Figure 5–2: Waste flows for Birmingham: (a) Types of waste for Birmingham; (b) Municipal solid waste treatment (2020/21) for Birmingham; (c) All types of waste treatment for Birmingham (amounts in percentage per weight).

Figure 5–2a shows how Construction, demolition and excavation makes up about half of the waste (1.6 million tonnes in 2008), followed by Commercial and Industrial at 29% (923 kt), with municipal waste making up 18% (580 kt) of the total and a small amount (2%) consisting of hazardous waste (64 kt). In 2020-21 Birmingham City Council collected 464 kt of municipal waste. Of this total 405 kt was household waste (87% of municipal waste collected during 2020-21). The amount of household waste collected was 355 kg per person or 695 kg per household. These numbers compare nationally with 420 kg per person and 552 kg per household for England (ONS, 2022). Figure 5–2b shows how Birmingham's municipal waste was processed, with the bulk going to the EfW facility at TEP. Figure 5–2c highlights the influence of the construction sector and its recycling which made up 47% (1.5 Mt) of the waste management of the city. Moreover, landfill accounted for 16% (533kt; which is contributed by Commercial and Industrial and Construction, demolition and excavation waste) of waste disposal. From Figure 5–

2b, two thirds of municipal waste is incinerated, but in terms of the city's waste overall it falls to 10% of the total waste. Only a quarter of the municipal waste is recycled with the remainder (6%) going to landfill.

5.2 STEP 1: Scope of Study and Stakeholders for TEP, Birmingham

During the implementation stage, multiple interests in the negotiation and *Decision-Making (DM)* process result in conflictive objectives derived from the different priorities to each of the participants. In order to better understand each stakeholder's perception of value, a review of previous meetings minutes was performed. This was done to understand the role of each participant and identify the potential respondents to contact for the study. A stakeholder profile brief created by the organisers was privately circulated and this was also reviewed. All these tasks helped comprehend the priorities and (most important) objectives considered from different participants in the development of the *Tyseley Energy Park (TEP)*. However, it was not the aim to influence the outcomes of those meetings. Drawing on the description of the case study area in Section 4.1, and applying Step 1a, the scope of this study is to *'compare Municipal Solid Waste Management (MSWM) or Circular Economy (CE) alternative scenarios for TEP, Birmingham'*. The primary influencing factor is that the current *Energy-from-Waste (EfW)* plant in Tyseley was due to close. City stakeholders have been widely discussing CE opportunities arising from this issue. The Birmingham case study is an academic exercise using a sub-set of real DM from an ongoing process. The author performed solely as an external observer, although the outcomes of the research were shared with the decision-makers.

Applying Step 1b of the methodology (Section 3.2) and drawing on the previous description of the problem and its elements (Section 4.1), the definition of a stakeholder group for this case study was:

1. TEP is a renowned project that aims to incorporate and develop energy generation technologies. Cooperation between stakeholders could allow the successful adoption of CE principles in their portfolio of business models.
2. The land where the TEP is developing is privately owned. Therein companies have private interests in settling businesses and universities have an interest in the research potential. The government owns the incineration facilities and has a contract with a waste management operator to recover energy from a large portion of the *Municipal Solid Waste (MSW)* collected.

3. The respondents in this study (14 from 36 in total); their identities and any information that could enable them to be traced back is not revealed, and they were thus categorised in the most influential stakeholder groups as follows:
   A. Companies – energy sector businesses in the TEP
   B. Academic Institutions
   C. Local Government
   D. General Public
   E. Consultants – Externals who provide consultation services.
4. There were no duplicated stakeholders to remove (Sub-step 4 from Section 3.4.1).

5.3 STEP 2: Indicators Selection and Formulation of CE Scenarios

5.3.1 Step 2a: Indicator selection

Table 5–1 shows the selected indicators for the case study. A thorough and extensive literature review enabled their selection. Their choice was based on being understandable, pragmatic, relevant, representative and able to assess a sustainability dimension (i.e., they all comply with the five recommended properties, see Section 3.4.2.1). They are deemed appropriate to the scale (i.e., city and *Eco-Industrial Park (EIP)* levels). Also, in the design of the survey to stakeholder groups (Step 1c – Section 3.4.1.3), a question asked about their opinion on whether they would exclude any indicators. Conversely, another question asked if they would include any additional indicators. Both questions responses suggested that the selected indicators were appropriate for the CE scenarios.

Table 5–1: Indicators adopted for the evaluation of CE waste management scenarios.

No.	Indicator	Unit	Description of indicator	Objective
1	Investment cost	£M / yr	It measures the amount of £ million invested in a project. It comprises of all costs relating to the purchase of mechanical equipment, technological installations, construction of roads, and other incidental construction work. It does not include maintenance or labour costs.	Minimise
2	GVA impact	£M / yr	It measures the annual gross value-added in total if pursuing a target scenario. It measures the total annual added production value at the end of the year.	Maximise
3	Payback	months	It indicates the time required for a project to recover the money invested. It refers to the period required for the return on an investment to "repay" the sum of the original investment.	Minimise
4	Carbon emissions mitigation	CO_2 kt/yr	A proxy variable of low carbon fuels usage. It reflects the amount of CO_2 emissions in kilotonnes that the project reduces / amount of CO_2 emissions saved by a target scenario.	Maximise
5	MSW generation reduction	%	It measures the total amount of municipal solid waste generated in comparison to a previous set year. It measures the reduction in effluent and waste produced.	Maximise
6	Recycling rate of MSW	%	A primary CE indicator. It measures the recycling rate of municipal solid waste in a specified year in the city. It measures the level of material re-used and recycled in the local area.	Maximise
7	Landfill rate of MSW	%	It measures the rate of MSW not diverted from disposal in the city. An alternative that would ideally be discarded entirely in a future CE. It must consider landfill tax and transport of waste streams.	Minimise
8	Jobs creation	#	The most used social indicator. It measures new jobs created per annum.	Maximise
9	Public awareness and satisfaction	%	It is vital to treat citizens as both stakeholders and customers in the MSWM process. Social acceptability (not meaning it is liked or appreciated) expresses the overview of opinions related to the MSWM system by the local population.	Maximise

In order to study the three acknowledged dimensions of CE and sustainability, three main indicator categories were selected: economic (Indicators 1 to 3), environmental (Indicators 4 to 7) and social (Indicators 8 and 9). Table 5–1 shows the appropriate units of measure and underpinning objective of the indicator (i.e., to minimise versus maximise the quantity). For example, Indicator 1, Investment cost, is one of the most commonly used economic indicators (Wang et al., 2009). Its objective is to minimise, in line with Behera et al. (2012) framework arguing that research performed in EIPs (as in TEP) is meant to develop into a business (profit-led activities), thus aiming to reduce costs.

5.3.2 Step 2b: Construct possible scenarios

In this research study, scenarios for MSWM constructed for Birmingham will be treated as alternatives to evaluate their perceived performance by stakeholders in terms of their benefits and costs. Table 5–2 shows the indicators and the performance levels set within each of the future scenarios. [Note the user could use more indicators than those shown here; an abridged set is used herein to aid understanding of the method.] These values are not predictions (actual complex calculations) but estimated suggestions (basic evaluations) of likely future performance for the year 2035 from data from Birmingham City Council (2014) and International Synergies (2013). This year was chosen because of the data available from reports and it is a reasonable period in the future where estimations are not likely to be subject to radical changes.

Table 5–2: Future CE scenarios matrix for MSWM in Birmingham, UK.

Type	No.	Indicator	Scenarios				Unit
			MF	PR	NSP	FW	
Economic	1	Investment cost[1]	52.3	60.6	68.2	48.5	£M / yr
	2	Gross Value Added (GVA) impact[2]	12.5	15.0	17.0	12.0	£M / yr
	3	Payback[1]	180.0	300.0	360.0	240.0	months
Environmental	4	Carbon emissions mitigation[2]	45.0	55.0	65.0	35.0	CO_2 kt/yr
	5	MSW generation reduction[1]	7.0	8.5	10.0	3.0	%
	6	Recycling rate of MSW[1, 2]	31.5	40.0	50.0	30.0	%
	7	Landfill rate of MSW[1]	6.0	2.5	1.0	5.0	%
Social	8	Jobs creation[1]	2,313	2,937	3,671	2,203	#
	9	Public awareness and satisfaction[1]	44.0	56.0	70.0	42.0	%

[1] (Birmingham City Council, 2014) [2] (International Synergies, 2013)

The results of the FW are the overall figures for the city including both the *'haves'* and *'have-nots'* (see Appendix D). The supporting narrative for these values within each scenario is the following:

For Indicator 1, *Investment cost* (Birmingham City Council, 2014, p.17), the current cost of running TEP EfW plant is £34.5 million per year. This amount was used to calculate a 2% annual increment for the *Market Forces (MF)* scenario (34.5 × $(1+0.02)^{(2035-2014)}$ = 52.3 £M/yr). For *Policy Reform (PR)* a cost of £40.0 × $(1+0.02)^{(2035-2014)}$ = £60.6 million per year, for *New Sustainability Paradigm (NSP)* a higher cost of £45.0 × $(1+0.02)^{(2035-2014)}$ = £68.2 million per year. For *Fortress World (FW)*, the reasoning behind the £32.0 × $(1+0.02)^{(2035-2014)}$ = £48.5

million per year is that expenditure on MSWM will decrease due to lack of funding for CE alternatives.

For Indicator 2, *Gross Value Added (GVA)* impact (International Synergies, 2013, p.4), reports that adopting IS in the site could result in between £12 – 15 million per year. Hence the lowest value was assigned to FW, the highest value is achievable through vigorous policy enforcement, and an intermediate value (£12.5 million per year) for MF. Also, NSP could achieve an even higher (£17 million per year) economic dividend, even though it would take longer to recover the investment.

Indicator 3, *Payback* (Birmingham City Council, 2014, p.14), is based on the remaining TEP incinerator life expectancy – until 2035 and beyond. Thus, the value adopted for MF is the remaining 180 months (15 years), for FW 240 months (20 years), for PR 300 months (25 years), and for NSP 360 months (30 years) in line with the previous indicator which states that this scenario would take longer for the investment to return.

For Indicator 4, *Carbon emissions mitigation* (International Synergies, 2013, p.4), Birmingham has committed to reducing its carbon emissions by 60% by 2027. It is expected to save55 kt of CO_2 with a strong policy implementation by 2027; PR received this value. Without such policies, MF received a 45 kt target, a lower value for FW is assigned, 35 kt; and the highest performance would be for NSP with 65 kt of CO_2 mitigated annually.

For Indicator 5, *MSW generation reduction* (Birmingham City Council, 2014, p.39), reports that there was a 7% reduction of MSW generation during 2009/2010. Thus, MF adopted a constant value, a much lower value of 3% for FW. Through a strong PR, an 8.5% reduction is achievable, and the highest performance again is 10% by the NSP scenario, where the proactive local population is pushing this significant decrease.

For Indicator 6, *Recycling rate of MSW* (Birmingham City Council, 2014, p.39), Birmingham's recycling rate was 31.5% and aims to increase to 40% by 2030 (International Synergies, 2013, p.40). Considering that the rate would not change for MF, it would reach its minimum target in a PR, the rate would decrease to 30% under an FW scenario, and an NSP scenario would surpass the minimum target to 50%.

For Indicator 7, *Landfill rate of MSW* (Birmingham City Council, 2014, p.39), the current landfill rate of the city is 6%. The MF scenario would not present a significant change, whereas the NSP would almost eliminate this option in line with CE principles to 1%. Under strong policies, increasing landfill taxes would bring the rate down to 2.5%. While it would not be a priority in an FW, the rate would decrease to 5% because there would not be technology to treat waste differently than with the incineration plant; as landfill tax increases it would still be cheaper to burn MSW.

For Indicator 8, *Jobs creation* (Birmingham City Council, 2014, p.82), expects that increasing the recycling rate in the UK to 70%, will generate 51,400 new jobs. The case study considered a 10% portion of those jobs would be created for Birmingham and the West Midlands (5,140 – based on population numbers of the UK for the West Midlands). Thus, the calculations for jobs created in each scenario used the proportional rule with the previously set MSW recycling rate. For example, for the FW scenario, using the previously set 30% MSW recycling rate, the ideal 70% MSW recycling rate, 5,140 as the number of jobs that this ideal MSW recycling rate would create for Birmingham and the West Midlands, the new jobs generated are:

$$\text{Jobs creation}_{\text{FW}} = \frac{30\%}{70\%} \times (5{,}140) = 2{,}203$$

For Indicator 9, *Public awareness and satisfaction* (Birmingham City Council, 2014, p.77), present a case study in South Oxfordshire where the authorities have achieved one of the highest recycling rates in the UK, 68%. The resident satisfaction levels for MSW treatment ranged between 91-96%, the case study considered a 95% value. Thus, the calculations for the satisfaction level of each scenario used the proportional rule with the previously set MSW recycling rate. For example, for the NSP scenario, using a 50% recycling rate, the awareness and satisfaction of the public is given by:

$$\text{Public awareness and satisfaction}_{\text{NSP}} = \frac{50\%}{68\%} \times 95\% = 70\%$$

5.4 STEP 3: Subjective Weight Vectors for Indicators

5.4.1 Step 3a: Stakeholders assign scores to indicators (Questionnaire Part 2)

This step asked the five critical stakeholder groups, from 14 participants (shown as A_i to E_i in Table 5–3) to rank the nine indicators (using a '*priority scale*', see Section 3.4.3.1). Stakeholders were told not to use the same ranking number more than once; however, they were allowed to have more than one indicator with the same level of relevance. For example, Stakeholders A_1 and D_1 gave Indicators 1 (Investment cost) and 3 (Payback) the highest ranking of 9. Likewise, Stakeholder C_1 and E_1 gave Indicators 5, 6 and 7 an equal ranking of 3. It was respondent A_2 the only one that deemed Indicator 8 (Jobs creation) to be irrelevant.

Table 5–3: Stakeholders ranking of the selected CE indicators.

Type	Indicator No.	Rank Value	Stakeholders' Responses													
			A_1	A_2	A_3	B_1	B_2	C_1	C_2	C_3	D_1	D_2	D_3	E_1	E_2	E_3
Economic	1	**9**	1, 3	3	2,3	5	5	2	8	5, 6 8	1, 3	2, 8	8	2	1, 4	2, 4 9
	2	**8**	8	1, 9	1,4, 5 6,7	6, 7	4, 6 7	8	2	1, 9	4, 9	4, 9	2	1	2, 5 8	5, 6 8
	3	**7**	9	2	8	3	1, 9	1	1, 4 7	4, 7		5, 6 7	4, 9	3	6	1, 3
Environmental	4	**6**	2			4		4	5, 6 9	2, 3		1	1, 3 6		3, 7	
	5	**5**	4, 5 6, 7			1	2, 8	9	3			3	5	8, 9	9	
	6	**4**		4, 5 6, 7		8	3	3					7	4		
	7	**3**				9		5, 6 7			2, 5 6, 7			5, 6 7		7
Social	8	**2**			9	2					8					
	9	**1**		8												

5.4.2 Step 3b: Pairwise comparison of stakeholders scores

The priority scale helped the stakeholders to simplify the process of pairwise comparing the selected indicators (Table 5–4). A pairwise comparison matrix was produced from the filled-in priority scales (Table 5–3) and by applying Equations (3-1) and (3-2). It is not possible to show the calculations for all pairwise comparisons of all nine indicators and all 14 participants, as there would need to be a total of n*(n-1)/2 comparisons made. Hence the set of pairwise comparisons for Stakeholder B_1 are shown in Table 5–4. For illustration, the examples herein show the calculations associated with Indicator 1 (*Investment cost*). For the first calculation, Table 5–3 (shaded in light grey) shows that Stakeholder B_1 gave *Investment cost* (R_1) a value of 5, and again *Investment cost* (C_1) a value of 5, hence the value of $DV_{1,1} = 1 + (R_1 - C_1) = 1 + (5 - 5) = 1$, likewise:

$$DV_{2,1} = {}^{1}/_{(1 + |R_2 - C_1|)} = {}^{1}/_{(1 + |2 - 5|)} = 1/4$$

$$DV_{3,1} = 1 + (R_3 - C_1) = 1 + (7 - 5) = 3$$

$$DV_{4,1} = 1 + (R_4 - C_1) = 1 + (6 - 5) = 2$$

$$DV_{5,1} = 1 + (R_5 - C_1) = 1 + (9 - 5) = 5$$

$$DV_{6,1} = 1 + (R_6 - C_1) = 1 + (8 - 5) = 4$$

$$DV_{7,1} = 1 + (R_7 - C_1) = 1 + (8 - 5) = 4$$

$$DV_{8,1} = {}^{1}\!/_{(1 + |R_8 - C_1|)} = {}^{1}\!/_{(1 + |4 - 5|)} = 1/2$$

$$DV_{9,1} = {}^{1}\!/_{(1 + |R_9 - C_1|)} = {}^{1}\!/_{(1 + |3 - 5|)} = 1/3$$

Table 5–4: Example matrix of pairwise comparisons for Stakeholder B_1.

			Column indicators								
			C_j								
Row indicators			**C_1**	**C_2**	**C_3**	**C_4**	**C_5**	**C_6**	**C_7**	**C_8**	**C_9**
	Investment cost	**R_1**	1	4	1/3	1/2	1/5	1/4	1/4	2	3
	GVA impact	**R_2**	1/4	1	1/6	1/5	1/8	1/7	1/7	1/3	1/2
	Payback	**R_3**	3	6	1	2	1/3	1/2	1/2	4	5
	Carbon emissions mitigation	**R_4**	2	5	1/2	1	1/4	1/3	1/3	3	4
R_i	**MSW generation reduction**	**R_5**	5	8	3	4	1	2	2	6	7
	Recycling rate of MSW	**R_6**	4	7	2	3	1/2	1	1	5	6
	Landfill rate of MSW	**R_7**	4	7	2	3	1/2	1	1	5	6
	Jobs creation	**R_8**	1/2	3	1/4	1/3	1/6	1/5	1/5	1	2
	Public awareness and satisfaction	**R_9**	1/3	2	1/5	1/4	1/7	1/6	1/6	1/2	1
		ΣC_j	**20**	**43**	**9 4/9**	**14 2/7**	**3 2/9**	**5 3/5**	**5 3/5**	**26 5/6**	**34 1/2**

It must be noted that the $DV_{i,j}$ values in the diagonal should be ones because the comparisons between the indicator in the column minus the indicator in the row result in a subtraction of the same indicator, plus one. The values below the diagonal (shaded in dark grey) must be reciprocal to those above it; because these comparisons are between the same indicators, but oppositely. If the respondent gave two compared indicators the same score, their $DV_{i,j}$ value would be one. For example, Indicators 6 and 7 were ranked equally important by respondent B_1 (Table 5–3), hence their pairwise comparison in Table 5–4 results in one for the $DV_{i,j}$ values. Also note that the lower the ranking assigned to an indicator, the higher value for the sum of the column (ΣC_j) will result. Conversely, the higher the ranking given to an indicator, the lower the value for ΣC_j will be.

5.4.3 Step 3c: Determine subjective weights from stakeholders

Using the outputs from Step 3b, the *Analytical Hierarchy Process (AHP)* technique is now fully applied. For illustration, the examples used are the shaded cells in Table 5–5. First, Equation (3-3) and data from Table 5–4 allow calculating the normalised matrix of pairwise comparisons. The normalised value of the comparison between Indicator 1 and Indicator 1 is $NV_{1,1,} = \frac{DV_{1,1}}{\Sigma\, C_1} = \frac{1}{20} = 0.050$. The process repeats to fill in the table. Second, Equation (3-4), allows the user to calculate the first weight for Indicator 1 being the arithmetic mean of the row of Indicator 1 ($\widehat{R}_1$):

$$I_1 = \frac{1}{9}\sum_{i=1}^{9} NV_i = \frac{1}{9}(0.050{+}0.093{+}0.035{+}0.035{+}0.062{+}0.045{+}0.075{+}0.087) = 0.0585$$

This 0.0585 value represents on a scale from zero to one, how much Stakeholder B_1 considers Indicator 1 to be worth in comparison with the rest of the indicators. Several iterations are required to find the exact weights. For illustration, this text shows only the first iteration. Equation (3-5) is applied to multiply the 1st weights vector by the original matrix of pairwise comparisons (Table 5–4). Thus, the revised (weight) value for Indicator 1 (RV_1) is given by [note 5 to 8 are not shown in the following but are used in the derivation of RV_1]:

$$RV_1 = \textstyle\sum_{i=1}^{9}\left(I_i \times DV_{1,j}\right) = I_1 \times DV_{1,1} + I_2 \times DV_{1,2} + I_3 \times DV_{1,3} + I_4 \times DV_{1,4} + \cdots + I_9 \times DV_{1,9}:$$

$$RV_1 = 0.0585 \times 1 + 0.0205 \times 4 + 0.1235 \times \frac{1}{3} + 0.0848 \times \frac{1}{2} + 0.2761 \times \frac{1}{5} + 0.1841 \times \frac{1}{4} + 0.1841 \times \frac{1}{4}$$
$$+ 0.0403 \times 2 + 0.0282 \times 3 = 0.5363$$

Using Equation (3-6) normalises the revised values. Thus, this gives the second weight value for Indicator 1: $\check{I}_1 = \frac{RV_1}{\Sigma\, RV_i} = \frac{0.5363}{9.4337} = 0.0568.$

Table 5–5: Example normalised matrix of pairwise comparisons for Stakeholder B_1.

		$\widehat{C}_j$									1st	1st	2nd
		$\widehat{C}_1$	$\widehat{C}_2$	$\widehat{C}_3$	$\widehat{C}_4$	$\widehat{C}_5$	$\widehat{C}_6$	$\widehat{C}_7$	$\widehat{C}_8$	$\widehat{C}_9$	weights	iteration	weights
$\widehat{R}_i$	$\widehat{R}_1$	0.050	0.093	0.035	0.035	0.062	0.045	0.045	0.075	0.087	0.0585	0.5363	0.0568
	$\widehat{R}_2$	0.012	0.023	0.018	0.014	0.039	0.026	0.026	0.012	0.014	0.0205	0.1873	0.0198
	$\widehat{R}_3$	0.149	0.140	0.106	0.140	0.104	0.089	0.089	0.149	0.145	0.1235	1.1695	0.1240
	$\widehat{R}_4$	0.100	0.116	0.053	0.070	0.078	0.060	0.060	0.112	0.116	0.0848	0.7912	0.0839
	$\widehat{R}_5$	0.249	0.186	0.317	0.280	0.311	0.358	0.358	0.224	0.203	0.2761	2.6173	0.2774
	$\widehat{R}_6$	0.199	0.163	0.212	0.210	0.155	0.179	0.179	0.186	0.174	0.1841	1.7553	0.1861
	$\widehat{R}_7$	0.199	0.163	0.212	0.210	0.155	0.179	0.179	0.186	0.174	0.1841	1.7553	0.1861
	$\widehat{R}_8$	0.025	0.070	0.026	0.023	0.052	0.036	0.036	0.037	0.058	0.0403	0.3661	0.0388
	$\widehat{R}_9$	0.017	0.047	0.021	0.018	0.044	0.030	0.030	0.019	0.029	0.0282	0.2554	0.0271
$\Sigma\widehat{C}_j$		**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.0000**	**9.4337**	**1.0000**

Note that the sum of the indicator weights must be equal to one. The process iterates until the newly calculated weights are not significantly different from those previously obtained. Table 5–6 shows the final subjective weight vectors for all stakeholders. The bottom row is the IR calculated for the final weights; this will be explained below in Section 5.6.1. A tool based on an adapted Excel template (Goepel, 2013) helped to perform the calculations. Appendix E presents such adapted Excel-based tool. Figure 6–3 in the next chapter visualises these results.

Table 5–6: Subjective weight vectors for respondents.

Type	**No.**	**Indicator**	**Stakeholders**						
			A_1	**A_2**	**A_3**	**B_1**	**B_2**	**C_1**	**C_2**
Economic	1	Investment cost	0.2465	0.1946	0.1087	0.0564	0.0920	0.1540	0.1076
	2	GVA impact	0.0694	0.1335	0.1976	0.0200	0.0392	0.3132	0.1825
	3	Payback	0.2465	0.2884	0.1976	0.1232	0.0269	0.0465	0.0369
Environmental	4	Carbon emissions mitigation	0.0412	0.0429	0.1087	0.0832	0.1535	0.1052	0.1076
	5	MSW generation reduction	0.0412	0.0429	0.1087	0.2799	0.2503	0.0296	0.0600
	6	Recycling rate of MSW	0.0412	0.0429	0.1087	0.1858	0.1535	0.0296	0.0600
	7	Landfill rate of MSW	0.0412	0.0429	0.1087	0.1858	0.1535	0.0296	0.1076
Social	8	Jobs creation	0.1642	0.0173	0.0446	0.0386	0.0392	0.2217	0.2777
	9	Public awareness and satisfaction	0.1087	0.1946	0.0169	0.0271	0.0920	0.0707	0.0600
		IR	1.17%	2.24%	0.69%	2.47%	1.10%	2.66%	0.86%
Type	**No.**	**Indicator**	**Stakeholders**						
			C_3	**D_1**	**D_2**	**D_3**	**E_1**	**E_2**	**E_3**
Economic	1	Investment cost	0.1108	0.2518	0.0458	0.0696	0.2282	0.2123	0.0607
	2	GVA impact	0.0398	0.0335	0.2175	0.1928	0.3194	0.1254	0.1832
	3	Payback	0.0398	0.2518	0.0310	0.0696	0.1614	0.0466	0.0607
Environmental	4	Carbon emissions mitigation	0.0650	0.1701	0.1311	0.1197	0.0483	0.2123	0.1832
	5	MSW generation reduction	0.1897	0.0335	0.0754	0.0427	0.0304	0.1254	0.1032
	6	Recycling rate of MSW	0.1897	0.0335	0.0754	0.0696	0.0304	0.0751	0.1032
	7	Landfill rate of MSW	0.0650	0.0335	0.0754	0.0291	0.0304	0.0466	0.0191
Social	8	Jobs creation	0.1897	0.0220	0.2175	0.2872	0.0756	0.1254	0.1032
	9	Public awareness and satisfaction	0.1108	0.1701	0.1311	0.1197	0.0756	0.0310	0.1832
		IR	0.54%	1.33%	0.81%	1.35%	2.58%	0.81%	0.71%

It must be noted that indicators given the same score using the priority scale (as observed in Table 5–3) will result in an identical subjective weight. For example, respondent A_3 gave Indicators 1 (Investment cost), 4 (Carbon emissions mitigation), 5 (MSW generation reduction), 6 (Recycling rate of MSW) and 7 (Landfill rate of MSW) a ranking of 2, this resulted in the same 0.1087 subjective weight value for all the five of them (see Table 5–6). The results also show that as the respondents assign a higher score to an indicator, it expects to yield a higher subjective weight value for that indicator. Conversely, assigning a lower score will result in a lower subjective weight value. For example, respondent D_3 gave Indicator 8 (Jobs creation) the highest score of 9, which resulted in the highest subjective weight value of 0.2872. At the same time, they ranked Indicator 7 (Landfill rate of MSW) the lowest with a score of 4 yielding the lowest subjective weight value of 0.0291.

5.5 STEP 4: Objective Weights for CE Scenarios

5.5.1 Step 4a: Rescale scenarios performance

Before being able to pairwise compare the scenarios, it is necessary to rescale their suggested performances into the ‘priority scale’ range presented in Table 3–8. However, first, the maximum number of rankings needs to be determined by substituting in Equation (3-7): four being the number of scenarios ("x"), and 0.5 was decided to be the maximum allowed weighting for a single scenario (De Feo and De Gisi, 2010, p.2376) ("y") because it would allow that one single scenario account for up to half of the total weights. Thus, three is the maximum times that a scenario is allowed to be more important than another. The number of levels to use ("c") is three (the top 9 – 7 from the ‘*priority scale*’):

$$c = (4 - 1) \,/\, \big((1 \,/\, 0.5) - 1\big) = 3$$

Using Equations (3-8) and (3-9) in Section 3.4.4.1, Table 5–7 shows the rescaled data for CE scenarios from Table 5–2. For example, for Indicator 1, Investment cost, because the objective of the indicator is to be minimised, the formula to use is Equation (3-9) to rescale the scenario values in Table 5–2, as follows:

$$MF'_1 = \frac{48.5 - 52.3}{48.5 - 68.2} \times (7 - 9) + 9 = 8.6$$

$$PR'_1 = \frac{48.5 - 60.6}{48.5 - 68.2} \times (7 - 9) + 9 = 7.8$$

$$NSP'_1 = \frac{48.5 - 68.2}{48.5 - 68.2} \times (7 - 9) + 9 = 7.0$$

$$FW'_1 = \frac{48.5 - 48.5}{48.5 - 68.2} \times (7 - 9) + 9 = 9.0$$

This example uses the values in between the levels (top 9 – 7 from the ‘priority scale’); thus, the first decimal rounded figure is used for further AHP calculations.

Table 5–7: Rescaled suggested performance of CE scenarios.

	Indicators								
	Investment cost	GVA impact	Payback	Carbon emissions mitigation	MSW generation reduction	Recycling rate of MSW	Landfill rate of MSW	Jobs creation	Public awareness and satisfaction
Scenarios	**C_1**	**C_2**	**C_3**	**C_4**	**C_5**	**C_6**	**C_7**	**C_8**	**C_9**
MF	8.6	7.2	9.0	7.7	8.1	7.2	7.0	7.2	7.1
PR	7.8	8.2	7.7	8.3	8.6	8.0	8.4	8.0	8.0
NSP	7.0	9.0	7.0	9.0	9.0	9.0	9.0	9.0	9.0
FW	9.0	7.0	8.3	7.0	7.0	7.0	7.4	7.0	7.0

5.5.2 Step 4b: Pairwise comparison of scenarios

Similar to the pairwise comparison of the stakeholders ranking, the scenarios rescaled performances are pairwise compared using the *'priority scale'* according to each indicator individually. This process used the output from the previous step in Table 5–7 to create the matrices for each indicator. For illustration purposes, only the matrix for Indicator 1, *Investment cost*, is presented in Table 5–8. The rest of the indicators have their own matrix of pairwise comparisons; while this document does not present them, they follow the same calculating procedure. For the first calculation in Table 5–8, it can be seen from Table 5–7 (shaded in light grey) that for Indicator 1, *Investment cost* (C1) and Scenario MF, the rescaled value of the MF scenario is 8.6, and again the rescaled value of the MF scenario is 8.6. Hence the *Difference Value (DV)* is:

$$DV_{MF,MF} = 1 + (MF_1 - MF_1) = 1 + (8.6 - 8.6) = 1.000\text{, likewise:}$$

$$DV_{PR,MF} = {}^{1}/_{(1 + |PR_1 - MF_1|)} = {}^{1}/_{(1 + |7.8 - 8.6|)} = 0.556$$

$$DV_{NSP,MF} = {}^{1}/_{(1 + |NSP_1 - MF_1|)} = {}^{1}/_{(1 + |7.0 - 8.6|)} = 0.385$$

$$DV_{FW,MF} = 1 + (FW_1 - MF_1) = 1 + (9.0 - 8.6) = 1.400$$

Table 5–8: Example matrix of pairwise comparisons of scenarios for Investment cost (Indicator 1).

Indicator 1: Investment cost		Column scenarios C_j			
Row scenarios		MF	PR	NSP	FW
R_i	MF	1.000	1.800	2.600	0.714
	PR	0.556	1.000	1.800	0.455
	NSP	0.385	0.556	1.000	0.333
	FW	1.400	2.200	3.000	1.000
	ΣC_j	**3.340**	**5.556**	**8.400**	**2.502**

5.5.3 Step 4c: Determine objective weights for scenarios

The AHP technique is similarly applied to determine the objective weights of scenarios. For illustration, the examples to be used are the shaded cells in Table 5–9. First, Equation (3-3) uses data from Table 5–8 to calculate the normalised matrix of pairwise comparisons. The *Normalised Value (NV)* of the comparison for Indicator 1 between Scenario MF and Scenario MF is: $NV_{MF,MF} = \frac{DV_{MF,MF}}{\Sigma C_{MF}} = \frac{1}{3.340} = 0.299$. The process repeats to fill in the table. Second, Equation (3-4) calculates the first weight for Indicator 1 and Scenario MF, being the arithmetic mean of the row of Scenario MF:

$$S_{MF,1} = \frac{1}{4}\sum_{i=1}^{4} NV_{MF,i} = \frac{1}{4}(0.299+0.324+0.310+0.285) = 0.3046$$

Several iterations are required to find the exact weights. For illustration, this text shows only the first iteration. Equation (3-5) multiplies the 1st weights vector by the original matrix of pairwise comparisons (Table 5–8). Thus, the *Revised (weight) Value (RV)* for Scenario MF and Indicator 1 is given by:

$$RV_{MF,1} = \sum_{i=4}^{4}\left(S_{i,1} \times DV_{MF,i}\right) = S_{MF,1} \times DV_{MF,MF} + S_{PR,1} \times DV_{MF,PR} + S_{NSP,1} \times DV_{MF,NSP} + S_{FW,1} \times DV_{MF,FW}$$

$$RV_{MF,1} = 0.3046 \times 1.000 + 0.1856 \times 1.800 + 0.1169 \times 2.600 + 0.3930 \times 0.714 = 1.2231$$

The revised values must be normalised using Equation (3-6). Thus, this gives the second weight value for Scenario MF and Indicator 1: $\check{S}_{MF,1} = \frac{RV_{MF,1}}{\Sigma RV_i} = \frac{1.2231}{4.0132} = 0.3048$.

Table 5–9: Example normalised matrix of pairwise comparisons of CE scenarios for Indicator 1.

		$\widehat{C}_j$				1^{st} weights	1^{st} iteration	2^{nd} weights
		$\widehat{C}_{MF}$	$\widehat{C}_{PR}$	$\widehat{C}_{NSP}$	$\widehat{C}_{FW}$			
$\widehat{R}_i$	$\widehat{R}_{MF}$	0.299	0.324	0.310	0.285	0.3046	1.2231	0.3048
	$\widehat{R}_{PR}$	0.166	0.180	0.214	0.182	0.1856	0.7438	0.1853
	$\widehat{R}_{NSP}$	0.115	0.100	0.119	0.133	0.1169	0.4681	0.1166
	$\widehat{R}_{FW}$	0.419	0.396	0.357	0.400	0.3930	1.5782	0.3933
	$\Sigma\widehat{C}_j$	**1.000**	**1.000**	**1.000**	**1.000**	**1.0000**	**4.0132**	**1.0000**

Table 5–10 presents the final objective weight matrix for all four CE scenarios and all nine indicators after the necessary iterations. Figure 6–4 visually shows these results in the next chapter. Each weighting represents the performance of the scenario in comparison to the rest for each indicator individually. The rightmost column is the *Inconsistency Ratio (IR)* calculated for the final weights (Section 5.6.1 addresses this step).

Table 5–10: Objective weight matrix for the CE MSWM scenarios.

		Scenarios				
	Indicators[1]	**MF**	**PR**	**NSP**	**FW**	**IR**
1	**Investment cost**	0.3047	0.1853	0.1167	0.3933	0.3589%
2	**GVA impact**	0.1509	0.2781	0.4387	0.1323	0.4302%
3	**Payback**	0.4182	0.1860	0.1221	0.2736	0.4564%
4	**Carbon emissions mitigation**	0.1860	0.2736	0.4182	0.1221	0.4564%
5	**MSW generation reduction**	0.2108	0.2934	0.3825	0.1132	0.3526%
6	**Recycling rate of MSW**	0.1552	0.2580	0.4511	0.1357	0.4420%
7	**Landfill rate of MSW**	0.1253	0.2939	0.4200	0.1607	0.4018%
8	**Jobs creation**	0.1552	0.2580	0.4511	0.1357	0.4420%
9	**Public awareness and satisfaction**	0.1479	0.2606	0.4534	0.1381	0.4466%
	TOTAL	1.8542	2.2871	3.2539	1.6049	

[1] Note that the columns and rows of the matrix have been transposed for presentation purposes.

5.6 STEP 5: Ranking Order of the CE Scenarios

5.6.1 Step 5a: Verify both weights consistency

The use of the *'priority scale'* has ensured that there are no inconsistencies in the rankings. However, this must be verified using Equations (3-10) and (3-11). For illustration, this text explains the *Inconsistency Ratio (IR)* of the scenario's comparison for Indicator 1 (IR_1). The final iteration resulted in the maximum Eigenvector or sum of revised values being $\sum RV_1 = 4.0104$ (very similar to that in the first iteration in Table 5–9); the matrix dimension is

4; and the *Random Index (RI)* for a matrix of such dimension is 0.89 (obtained from (Saaty and Tran, 2007, p.966)). Thus, IR_1 is:

$$CI_1 = \frac{\sum RV_1 - k}{k-1} = \frac{4.0104 - 4}{4-1}$$

$$IR_1 = \frac{CI_1}{RI_4} = \frac{0.0035}{0.89} = 0.39\%$$

All the IR values for both the final subjective and objective weights were presented above in the lowest row and the rightmost column in Table 5–6 and Table 5–10, respectively. The IR values are well below the maximum acceptable value (IR<10%).

5.6.2 Step 5b: Determine the preference order of scenarios

This step calculates the *Preferability Indexes (PI)* to reveal the preference order of the CE scenarios for each stakeholder. Table 5–11 shows the indexes for each stakeholder by using Equation (3-12); below them is their ranking order. The sum of the PIs must be 1 for each stakeholder. For illustration, following the example, the PI for Stakeholder B_1 for the MF scenario ($PI_{B_1,MF}$) (shaded in light grey in Table 5–11) is the sum of all the products of each subjective weight ($I_{x,n}$) (shaded in Table 5–6) multiplied by the objective weight $S_{MF,n}$ (shaded in Table 5–10) for the MF scenario and Indicator *n* [Note 5 to 8 are not shown but are included in the formulation of $PI_{B_1,MF}$]:

$$PI_{B_1,MF} = \sum_{n=1}^{9} \left(I_{B_1,n} \times S_{MF,n} \right)$$

$$PI_{B_1,MF} = I_{B_1,1} \times S_{MF,1} + I_{B_1,2} \times S_{MF,2} + I_{B_1,3} \times S_{MF,3} + I_{B_1,4} \times S_{MF,4} + \cdots + I_{B_1,9} \times S_{MF,9}$$

$$PI_{B_1,MF} = 0.0564 \times 0.3047 + 0.0200 \times 0.1509 + 0.1232 \times 0.4182 + 0.0832 \times 0.1860 +$$
$$0.2799 \times 0.2108 + 0.1858 \times 0.1552 + 0.1858 \times 0.1253 + 0.0386 \times 0.1552 + 0.0271 \times 0.1479 = 0.208$$

Table 5–11: Preferability indexes and ranking for the CE scenarios for each stakeholder.

Stakeholder	Scenarios			
	MF	PR	NSP	FW
A_1	0.258 (2nd)	0.228 (4th)	0.281 (1st)	0.233 (3rd)
A_2	0.261 (2nd)	0.230 (3rd)	0.284 (1st)	0.225 (4th)
A_3	0.229 (3rd)	0.249 (2nd)	0.333 (1st)	0.189 (4th)
B_1	0.208 (3rd)	0.263 (2nd)	0.364 (1st)	0.164 (4th)
B_2	0.189 (3rd)	0.267 (2nd)	0.384 (1st)	0.159 (4th)
C_1	0.193 (3rd)	0.254 (2nd)	0.374 (1st)	0.180 (4th)
C_2	0.183 (3rd)	0.259 (2nd)	0.390 (1st)	0.168 (4th)

Stakeholder	Scenarios			
	MF	PR	NSP	FW
C_3	0.192 (3rd)	0.258 (2nd)	0.384 (1st)	0.166 (4th)
D_1	0.264 (2nd)	0.228 (4th)	0.275 (1st)	0.233 (3rd)
D_2	0.174 (3rd)	0.265 (2nd)	0.411 (1st)	0.150 (4th)
D_3	0.187 (3rd)	0.257 (2nd)	0.395 (1st)	0.161 (4th)
E_1	0.232 (3rd)	0.239 (2nd)	0.313 (1st)	0.215 (4th)
E_2	0.189 (3rd)	0.261 (2nd)	0.395 (1st)	0.155 (4th)
E_3	0.211 (3rd)	0.251 (2nd)	0.346 (1st)	0.192 (4th)

5.6.3 Step 5c: Aggregate stakeholder preferences

This step aggregates the stakeholders' PIs in order to consider the group of stakeholders as a unitary individual. Using Equation (3-13) aggregates the data in Table 5–11 into the stakeholder groups PIs. Table 5–12 presents all these aggregated PIs and these are portrayed in Figure 6–5. For illustration, the calculation for the aggregated PI for the MF scenario from Stakeholder Group A is as follows:

$$\left(\prod_{i=1}^{3} \mathrm{PI}_{A_i,MF}\right)^{\frac{1}{n}} = \sqrt[3]{\mathrm{PI}_{A_1,MF}\cdot\mathrm{PI}_{A_2,MF}\cdot\mathrm{PI}_{A_3,MF}} = \sqrt[3]{0.258 \times 0.261 \times 0.229} = 0.249$$

Table 5–12: Aggregated PIs of stakeholder groups for the CE scenarios.

Stakeholder Group	Scenarios			
	MF	PR	NSP	FW
A	0.249 (2nd)	0.236 (3rd)	0.300 (1st)	0.216 (4th)
B	0.199 (3rd)	0.265 (2nd)	0.374 (1st)	0.162 (4th)
C	0.189 (3rd)	0.257 (2nd)	0.382 (1st)	0.171 (4th)
D	0.209 (3rd)	0.250 (2nd)	0.360 (1st)	0.181 (4th)
E	0.211 (3rd)	0.250 (2nd)	0.352 (1st)	0.187 (4th)

5.7 STEP 6: GT Analysis

5.7.1 Step 6a: Use equilibrium methods

Using the aggregated preferences from Step 5c above, all their possible combinations for the four CE scenarios and the five stakeholder groups are calculated (4^5 = 1,024 combinations). For example, using Equation (3-14) and data from Table 5–12, the combined preference of Stakeholder A to MF, B to FW, C to NSP, D to FW and E to PR is given by:

$$\varphi_{MF,FW,NSP,FW,PR} = \sum PI_{A,MF} + PI_{B,FW} + PI_{C,NSP} + PI_{D,FW} + PI_{E,PR}$$

$$\varphi_{MF,FW,NSP,FW,PR} = \sum 0.249+0.162+0.382+0.181+0.250 = 1.224$$

The total number of payoffs to be calculated are five (one for each stakeholder) per combined preference (i.e. 1,024 × 5 = 5,120 payoffs). For example, from Equation (3-15), the payoffs vector for the combined preference in the example above is:

$$\Pi^{A,MF}_{MF,\,FW,NSP,FW,PR} = \varphi_{MF,FW,NSP,FW,PR} \times PI_{A,MF} = 1.224 \times 0.249 = 0.305$$

$$\Pi^{B,FW}_{MF,\,FW,NSP,FW,PR} = \varphi_{MF,FW,NSP,FW,PR} \times PI_{B,FW} = 1.224 \times 0.162 = 0.198$$

$$\Pi^{C,NSP}_{MF,\,FW,NSP,FW,PR} = \varphi_{MF,FW,NSP,FW,PR} \times PI_{C,NSP} = 1.224 \times 0.382 = 0.469$$

$$\Pi^{D,FW}_{MF,\,FW,NSP,FW,PR} = \varphi_{MF,FW,NSP,FW,PR} \times PI_{D,FW} = 1.224 \times 0.181 = 0.222$$

$$\Pi^{E,PR}_{MF,\,FW,NSP,FW,PR} = \varphi_{MF,FW,NSP,FW,PR} \times PI_{E,PR} = 1.224 \times 0.250 = 0.307$$

$$\Pi_{MF,FW,NSP,FW,PR} = [0.305,\ 0.198,\ 0.469,\ 0.222,\ 0.307]$$

The open-access software Gambit (v15.1.1) helped to perform the *Non-Cooperative Game Theory (NCGT)* equilibrium analysis of payoffs for the stakeholders. These payoffs are a representation of the level of satisfaction obtained by each stakeholder group, for that specific combination of chosen alternative scenarios. Thus, it is of high relevance to uncover the set or the single combination of scenarios which brings equilibrium to the interactive DM. In other words, it is about finding the highest possible satisfaction to each stakeholder (without decreasing that obtained by others). The results in Table 5–13 show that, as initially expected, the calculated *Nash Equilibrium* for the majority of the methods is when all stakeholders select the same NSP scenario ($\Pi_{NSP,NSP,NSP,NSP,NSP}$). The row below the scenarios shows the payoffs.

Table 5–13: Nash Equilibriums for the combined preferences of stakeholders.

Equilibrium Methods	Nash Equilibriums found	Stakeholders				
		A	**B**	**C**	**D**	**E**
Pure strategy equilibria	1	NSP 0.530	NSP 0.661	NSP 0.676	NSP 0.637	NSP 0.622
Minimising Lyapunov function	0	- -	- -	- -	- -	- -
Global Newton tracing	1	NSP 0.530	NSP 0.661	NSP 0.676	NSP 0.637	NSP 0.622
Solving systems of polynomial equations	1	NSP 0.530	NSP 0.661	NSP 0.676	NSP 0.637	NSP 0.622

5.7.2 Step 6b: Apply allocation method

Once the *Nash Equilibrium* is identified, the next step is to analyse how stakeholders should arrange their satisfaction levels to prevent them from abandoning their (assumed) cooperative behaviour. This is done by applying *Cooperative Game Theory (CGT)* allocation methods, which aim to distribute benefits fairly to stakeholders in pre-emptive coalitions to protect cooperation. Thus, it is necessary to calculate each coalition's worth. For example, using Equation (3-16), the benefits of coalition ABCDE (where all stakeholders cooperate and are allocated benefits) for the equilibrium result where all stakeholders select the NSP scenario ($\Pi_{NSP,NSP.NSP,NSP,NSP}$) is as follows:

$$\Pi_{NSP,NSP,NSP,NSP,NSP} = [0.530, 0.661, 0.676, 0.637, 0.622]$$

$$\overline{\Pi}_{NSP,NSP,NSP,NSP,NSP} = 0.625$$

$$\beta^{A,NSP}_{NSP,NSP,NSP,NSP,NSP} = \sum \overline{\Pi}_{NSP,NSP,NSP,NSP,NSP} \times \Pi^{A,NSP}_{NSP,NSP,NSP,NSP,NSP,NSP} = 0.625 \times 0.530 = 0.331$$

$$\beta^{B,NSP}_{NSP,NSP,NSP,NSP,NSP} = \sum \overline{\Pi}_{NSP,NSP,NSP,NSP,NSP} \times \Pi^{B,NSP}_{NSP,NSP,NSP,NSP,NSP,NSP} = 0.625 \times 0.661 = 0.414$$

$$\beta^{C,NSP}_{NSP,NSP,NSP,NSP,NSP} = \sum \overline{\Pi}_{NSP,NSP,NSP,NSP,NSP} \times \Pi^{C,NSP}_{NSP,NSP,NSP,NSP,NSP,NSP} = 0.625 \times 0.676 = 0.423$$

$$\beta^{D,NSP}_{NSP,NSP,NSP,NSP,NSP} = \sum \overline{\Pi}_{NSP,NSP,NSP,NSP,NSP} \times \Pi^{D,NSP}_{NSP,NSP,NSP,NSP,NSP,NSP} = 0.625 \times 0.637 = 0.399$$

$$\beta^{E,NSP}_{NSP,NSP,NSP,NSP,NSP} = \sum \overline{\Pi}_{NSP,NSP,NSP,NSP,NSP} \times \Pi^{E,NSP}_{NSP,NSP,NSP,NSP,NSP,NSP} = 0.625 \times 0.622 = 0.389$$

$$\beta_{NSP,NSP,NSP,NSP,NSP} = [0.331, 0.414, 0.423, 0.399, 0.389]$$

It is essential to analyse every possible coalition that can be formed, in other words, from stakeholders working individually to the case where all of them behave cooperatively. Table 5–14 presents all the possible coalitions to be formed and their $\beta_{NSP,NSP,NSP,NSP,NSP}$ benefits. The rightmost column in Table 5–14 shows the sum of benefits for each coalition, or the coalition's total worth.

Table 5–14: Coalitions of stakeholders for obtained Nash Equilibrium.

Coalition Name	Payoffs $\Pi_{NSP,NSP,NSP,NSP,NSP}$ A NSP	B NSP	C NSP	D NSP	E NSP	$\bar{\Pi}$	Benefits $\beta_{NSP,NSP,NSP,NSP,NSP}$ A NSP	B NSP	C NSP	D NSP	E NSP	Σ β
A	0.530	0	0	0	0	0.530	0.281	0	0	0	0	0.281
B	0	0.661	0	0	0	0.661	0	0.437	0	0	0	0.437
C	0	0	0.676	0	0	0.676	0	0	0.458	0	0	0.458
D	0	0	0	0.637	0	0.637	0	0	0	0.406	0	0.406
E	0	0	0	0	0.622	0.622	0	0	0	0	0.386	0.386
AB	0.530	0.661	0	0	0	0.596	0.315	0.394	0	0	0	0.709
AC	0.530	0	0.676	0	0	0.603	0.319	0	0.408	0	0	0.727
AD	0.530	0	0	0.637	0	0.584	0.309	0	0	0.372	0	0.681
AE	0.530	0	0	0	0.622	0.576	0.305	0	0	0	0.358	0.663
BC	0	0.661	0.676	0	0	0.669	0	0.442	0.452	0	0	0.894
BD	0	0.661	0	0.637	0	0.649	0	0.429	0	0.414	0	0.843
BE	0	0.661	0	0	0.622	0.642	0	0.424	0	0	0.399	0.823
CD	0	0	0.676	0.637	0	0.657	0	0	0.444	0.419	0	0.863
CE	0	0	0.676	0	0.622	0.649	0	0	0.439	0	0.404	0.843
DE	0	0	0	0.637	0.622	0.630	0	0	0	0.401	0.391	0.792
ABC	0.530	0.661	0.676	0	0	0.622	0.330	0.412	0.421	0	0	1.163
ABD	0.530	0.661	0	0.637	0	0.609	0.323	0.403	0	0.389	0	1.115
ABE	0.530	0.661	0	0	0.622	0.604	0.320	0.400	0	0	0.376	1.096
ACD	0.530	0	0.676	0.637	0	0.615	0.326	0	0.416	0.392	0	1.134
ACE	0.530	0	0.676	0	0.622	0.609	0.323	0	0.412	0	0.379	1.114
ADE	0.530	0	0	0.637	0.622	0.596	0.316	0	0	0.380	0.371	1.067
BCD	0	0.661	0.676	0.637	0	0.658	0	0.435	0.445	0.420	0	1.300
BCE	0	0.661	0.676	0	0.622	0.653	0	0.432	0.442	0	0.406	1.280
BDE	0	0.661	0	0.637	0.622	0.640	0	0.423	0	0.408	0.398	1.229
CDE	0	0	0.676	0.637	0.622	0.645	0	0	0.436	0.411	0.401	1.248
ABCD	0.530	0.661	0.676	0.637	0	0.626	0.332	0.414	0.424	0.399	0	1.569
ABCE	0.530	0.661	0.676	0	0.622	0.622	0.330	0.412	0.421	0	0.387	1.550
ABDE	0.530	0.661	0	0.637	0.622	0.613	0.324	0.405	0	0.390	0.381	1.500
ACDE	0.530	0	0.676	0.637	0.622	0.616	0.326	0	0.417	0.393	0.383	1.519
BCDE	0	0.661	0.676	0.637	0.622	0.649	0	0.429	0.439	0.414	0.404	1.686
ABCDE	0.530	0.661	0.676	0.637	0.622	0.625	0.331	0.414	0.423	0.399	0.389	1.956

Table 5–15: Shapley Value results for the benefits of stakeholders.

Allocation Method	Benefits $\beta_{NSP,NSP,NSP,NSP,NSP}$ Stakeholders					$\Sigma\beta$
	A	B	C	D	E	
Shapley Value	0.273 (D)	0.436 (I)	0.455 (I)	0.405 (I)	0.386 (D)	1.956

Table 5–15 shows the *Shapley Value* results. The fairest allocation of benefits corresponds to the five-stakeholder coalition, in other words, when they decide to cooperate and remain in the previously agreed alliance. The letter below each allocated benefit in Table 5–15 indicates whether it should stay the same (S), increase (I) or decrease (D) compared to the initially claimed benefits in the ABCDE coalition in Table 5–14. The sum of the newly proposed distribution must be equal to the total worth of the original coalition. In practice, there might be the case where a coalition has a higher mean benefit ($\overline{\Pi}$), thus, those participants might want to exclude a participant to gain more benefits. However, the *Shapley* Value assumes that they will cooperate and want to share benefits fairly.

This is why this decision support tool becomes relevant to make those sharing benefits visible and clear to all stakeholders. Chapter 0 discusses the implications of this chapter results, alongside those results in Chapter 4. The application of this tool is the first to combine *Scenario Analysis (SA)*, *Multi-Criteria Decision Analysis (MCDA)* and GT to study cooperation of stakeholders in the CE of MSW in cities. This addresses the gap in literature and achieves the main aim of this research.

6 DISCUSSION OF FINDINGS

This chapter discusses the outcomes from the previous two chapters in the following order:

- The discussion of the results from the questionnaire on *Circular Economy (CE)* awareness and other relevant features (Section 6.1).
- The discussion of the results from the six-step *Game Theory (GT)*-hybrid tool applied to the case study site (Section 6.2).
- The discussion and comparison between both the last section of the questionnaire (perceptions of other stakeholders) and the GT-hybrid tool outcomes (Section 6.3).

Also, there is a short Section in between (6.2.1) that performs a sensitivity analysis on the results from the *Analytical Hierarchy Process (AHP)* steps 3 to 5 in the GT-hybrid tool in Chapter 5.

6.1 Discussion of CE Cooperation Features Outcomes

6.1.1 CE awareness

This and the following three sections (i.e., 6.1.2 to 6.1.4) report on the discussions and this has subsequently been published by the author of this thesis[12]. These are the outcomes from Section 4.2.1. The first characteristic that the questionnaire studied was the stakeholders' levels of CE awareness, knowledge and their interpretations. The so-called "*striking gap*" (Liu and Bai, 2014) suggests that awareness is not enough to implement CE; moreover, developing CE behaviour not only depends on increasing the awareness of CE. The first question, Q1.1, assessed whether participants were familiar with the term 'Circular Economy'. The results show that high awareness of CE can lead to excellent practices. In other words, most of the participants claimed to have heard (at least to some degree) of the CE term before, and nearly two-thirds assured (in Q2.1) they aligned to CE some of their activities and characteristics for their products/services.

Regarding the possible limited interpretation to what CE is (Q1.2), Liakos et al. (2019) asked their respondents to rank how much they agreed that a CE is essentially the *3Rs (Reduce, Reuse, Recycle)*. Their results show that around two-thirds did not agree that this is correct. Liu and Bai (2014) asked a similar question to manufacturing firms in China; only a third were aware of what the 3Rs stood for and agreed that they adequately represent a CE. The outcomes from this

[12] Palafox-Alcantar, P.G.; Hunt, D.V.L.; and Rogers, C.D.F. 2021. Current and Future Professional Insights on Cooperation towards Circular Economy Adoption. Sustainability. 13, 10436, Available at MDPI: https://doi.org/10.3390/su131810436.

research validate these by yielding a broadly comparable value of 33.7% of respondents agreeing to a CE being just another buzzword for the 3Rs concept. This might be caused by the 3Rs being the critical association between the environmental and financial aspects on the more technical side of a CE (Liakos et al., 2019).

To expand the previous question, participants were provided with several categories and asked to select those to which a CE aims to contribute (Q1.3). Previous research (Smol et al., 2018) suggested that more than three-quarters of the general public think that the critical characteristics of CE are related to protecting the environment and minimising losses from waste streams. This current research found that most of the participants' opinions were aligned with environmental responsibility; around 75% of respondents were concerned about renewable energy. Also, it was found that the interpretation of participants of what constitutes a CE is strongly related to the 3Rs, with 81.3% of respondents selecting these three options. This research also found that around half of participants (55%) also identified CE's potential to close material loops. The *"Systems thinking"* option did not receive a high number of responses, perhaps because in line with Bocken et al. (2015) this implies helping participants to think about the value captured, missed, destroyed and the new opportunities for the existent systems directly affected by a CE. This means the intended and unintended consequences (both beneficial and challenging) of a CE.

The exceptionally high CE awareness of the respondents can only be compared with the results of the studies performed in China (e.g., Liu and Bai, 2014; Xue et al., 2010). This is explained by the Chinese government efforts to adopt CE for over a decade. On the other hand, this argument also validates the initial aim of this research to survey participants who are highly aware of the CE concept but also familiar with the application of CE and its other implications. If the participants would have been less aware of the CE, the results might have changed significantly in all the other areas, possibly providing widely diverse attitudes towards CE adoption. Further research can expand the survey to less aware participants and compare both cohorts.

6.1.2 Activities and practices related to CE

These are the results from Section 4.2.2. From the reviewed studies, only Masi et al. (2018), Rizos et al. (2017) and Liakos et al. (2019) asked participants explicitly which CE related activities they have adopted in their products or processes. This research asked such questions (Q2.1.1 to Q2.1.25), firstly relating to their activities for the ARLI companies and similarly for their disciplines and careers for students. Therein choices provided to the respondents were based on the main CE processes identified by Masi et al. (2018). Findings show that activities related to the category *“efficient use of resources”* are by far the most importantly considered for students (4.53) and adopted CE activity for companies (4.05), followed by *“eco-design”* for students (4.43) and companies (3.68), and *“green purchasing”* (4.23 and 3.60 respectively). These outcomes are similar to those from Masi et al. (2018), where strategies related to waste minimisation and recovery are the most considered by their industry participants. However, other internal environmental management strategies, such as training for workers and improving environmental audit processes, were also considered relevant to their respondents.

The option *‘reducing wastes’* was the highest ranked by both cohorts (4.64 and 4.37 respectively). This is in line with previous research results (Masi et al., 2018). This was attributed to the fact that the return of investment is expected to be fast, as the CE and sustainability efforts by companies are assumed to be mostly driven by economic incentives as opposed to environmental conservation conscious. Additionally, although efforts to bring about more sustainable business models and preserving the environment have increased consistently, a lack of broader awareness of CE opportunities is hindering the successful adoption of more CE practices in companies and students. With regard to waste management alternatives in practice, Xue et al. (2010) asked about the number of categories into which organisations separate waste. The results from this thesis support the findings by Ferronato et al. (2017) where reducing and recycling alternatives are the most commonly practised by their respondents. In summary the educational output from these contrasting differences between students and companies could be that companies might benefit from new ideas from students being overoptimistic (not that this is negative). Students might need to be in closer contact with the industry to acquire a more realistic sense of the practitioners’ experiences.

6.1.3 CE perceived barriers

This section discusses the outcomes from Section 4.2.3. Research attempting to study the barriers to adopt CE is not uncommon. Although the sectors or areas on which they focus vary, these barriers can be very similar. Table 6–1 shows the comparison of results garnered from this research and those found within reviewed literature on CE. The percentage represents the portion of respondents in each study that identified the CE barriers – this is compared to the results from this research in the right most column. This research used Kirchherr et al. (2018) coding framework as the base of the questions in this section. Although the barriers in each study are not identical, the analysis included is broadly similar and results comparable.

Table 6–1: Comparison between the reviewed literature and this research on CE barriers.

CE barriers		(Kirchherr et al., 2018)	(Xue et al., 2010)	(Ferronato et al., 2017)	(Adams et al., 2017)	(Cother, 2020)	(Masi et al., 2018)	This work	
		Total (Businesses and policy-makers)	Total (Officials)	Total (University students)	Construction Companies	Companies	Manufacturing Companies	University Students	ARLI Companies
Q3.1 Cultural	Hesitant entrepreneurship due to high uncertainty	46%				29%		75%	75%
	Insufficient cooperation in the value chain	38%			79%	36%	20%	79%	70%
	Lacking consumer awareness and interest	47%	64%	50%	77%		79%	80%	64%
	Operating in a linear system	44%				43%	33%	71%	70%
Q3.2 Regulatory	Limited regulation of circular economy procurement practices	24%						84%	75%
	Hindering laws and regulations	37%	29%			14%	35%	80%	75%
	Lack of global consensus	25%						80%	76%
Q3.3 Market	Low virgin material prices	45%					28%	72%	66%
	Lack of circular products/services standardisation	13%	63%					77%	78%
	High upfront investment costs	40%				43%	58%	86%	73%
	Limited financial support	24%						80%	81%
Q3.4 Technological	Limited ability to deliver high quality remanufactured products	11%						80%	71%
	Limited circular designs	29%	36%		81%		63%	77%	65%
	Too few large-scale demonstration projects	24%				36%	47%	80%	70%
	Lack of data	21%					58%	75%	75%

The first barriers investigated are related to culture (Q3.1). The most commonly explored of these is the '*Lack of public awareness and interest'* for students, also being one of the most pressing barriers to adopting CE as comparable with this work and the broader literature base shown in Table 6-1. Remarkably it can be seen that the lack of cooperation in the value chain is one of the most pressing cultural barriers, and more specifically it is acknowledged by companies (Adams et al., 2017; Masi et al., 2018). This is directly in line with the aim of this research – to help in achieving stakeholder cooperation in thus facilitating the CE transition. Finally, *'Hesitant entrepreneurship'* was rated as least pressing to students as they come from or are involved in the Business School.

Regulatory barriers (Q3.2) resulted (on average) to have the lowest perceived values for the reviewed literature; however, this work yielded them as highly relevant. The work from Xue et al. (2010), Cother (2020) and Masi et al. (2018) included very similar but not identical barriers that are compatible with (and categorised as supporting) regulatory barriers. '*Hindering regulation to CE*' is the most critical barrier to overcome, similar barriers such as a *'Lack of supportive policy framework*' (Masi et al., 2018) are defined in the literature. The EU Action Plan is a mechanism that has helped in the removal of the most crucial CE regulatory barriers for the EU (Kirchherr et al., 2018); however, it might still not be the case for the UK and more specifically Birmingham and its surroundings.

Market barriers (Q3.3) are usually the most pressing according to the literature, and in this work, they have resulted as highly critical too. In the literature the lower prices of virgin materials compared to recycled resources is seen as the first deterrent to moving to CE practices (Kirchherr et al., 2018), the results of this work were found to be contrary to this barrier, perhaps because the ARLI companies are already involved in these activities. Likewise, '*High upfront investment costs*' resulted as the second most pressing market barrier on average for both cohorts. Participants in the CE transition must have access to robust capital funding resources (Cother, 2020). Additionally, one of the companies' participants (A-024) mentioned that: "*all firms, but particularly the smaller ones, focus on keeping their costs low whilst making a profit; they will only adopt CE if it helps them with this*". This might be symptomatic of and linked directly with the cultural barrier '*Hesitant entrepreneurship due to high uncertainty*'.

With regard to the technological barriers (Q3.4), the *'Low number of circular designs'* is comparably the most critical barrier in this area. For example, in the construction sector, companies have been reported to mention that buildings and construction works are not designed to be easily reprocessed at their end-of-life (Adams et al., 2017). Likewise, a *'Limited number of* *large-scale demonstration projects'* exist, and this is comparatively another important challenge to overcome. As mentioned by some of the respondents from this research, and whilst not being the main reason to the transition, the ARLI and TEP projects could provide an opportunity to become national exemplars in adopting CE principles.

An observation from the table is that some values expressed seem to be quite different from each other between studies. For example Kirchherr et al. (2018) had lower values than those from Adams et al. (2017); this might be because the former surveyed manufacturing service-businesses and policy-makers whilst the latter worked with construction companies who might have an opposite view regarding the design of products with CE principles in mind. To explain the contrasting results between Kirchherr et al. (2018) and this research, there was a slight difference in the collection of the data. The former asked participants to select the five most pressing from all the barriers, whilst this study asked respondents to rate them via the four different sections.

Overall, the results from Kirchherr et al. (2018) correspond well – in proportion – with this current research, with the exception of technological barriers which received higher response rates in this research. Also, the lower value for hesitant entrepreneurship in this research can be explained by having surveyed participants who see themselves as more proactive towards CE and are well aware of the conditions in their local area, an influencing factor that overlies the difference between business owners (ARLI) and business students.

6.1.4 Importance of a CE development

The outcomes from Section 4.2.4 are discussed herein. Q4.1 studied the importance of embracing CE principles for companies' activities and for students' disciplines. Similar to the focus of this question, respondents in other research (Liu et al., 2009), when asked about their attitudes toward household waste separation and shared-product services, indicated that over half of the local population was interested (and committed) to separate their waste at home to achieve the CE objectives of local government. Another study (Smol et al., 2018) surveyed the confidence of respondents regarding successfully developing a CE, the results showing that more than 80% of the respondents perceive that a CE is achievable and were in favour of its implementation in the region. However, it was recognised that a long-term planning process and additional financial support would be needed. Both of these studies support the results from this current research, in which it was found that nearly 90% of company respondents identified the development of CE as at least *'important'*. Few respondents viewed CE as neither important nor unimportant; however, participant A-024 stated that: "*adopting CE is not the main concern in the development (of the firm), but certainly presents a unique opportunity to apply it as an unintended side effect*".

Q4.2 studied what the components from the waste generated in a respondent's organisation and discipline meant to them. The results shown in Figure 6–1 are very comparable with findings in the literature. In this study, the options '*Discards to dispose of in landfill*' (46.8% and 3.7%), '*Materials to recycle*' (90.5% and 74.1%) and '*Waste to incinerate*' (44.4% and 22.2%) were provided to the respondents (students and companies, respectively). The difference between cohorts regarding the attitude towards landfills is remarkable. Similar responses within the literature received 6.3% for landfill, 77.6% for recycling and 4.1% for incineration (De Feo and Williams, 2013), while respective response rates of 9.5%, 70.3% and 13.1% were recorded by Ferronato et al. (2017). This research included two additional options: *'By-products valuable to others'* and *'Hazardous materials to manage carefully'*. The first option was used to expand the understanding of CE (in line with *Industrial Symbiosis (IS)* practices) and received a high number of responses (63.5% and 44.4%), where the waste generated by the industry is potentially an input for another industrial process. Only 22.2% of companies selected hazardous materials to manage carefully as it requires special treatment (e.g., medical waste) as a waste component. The figure shows no bars for these responses as the previous literature had not provided these response options. Students seemed to not agree with the other responses except for *"Recycle"*, which suggests that even though the *"Landfill"* and *"Incinerate"* options received lower responses, students still were not completely familiar with the CE principles around waste treatment. Future research might look at comparing responses before and after receiving a lecture on circularity.

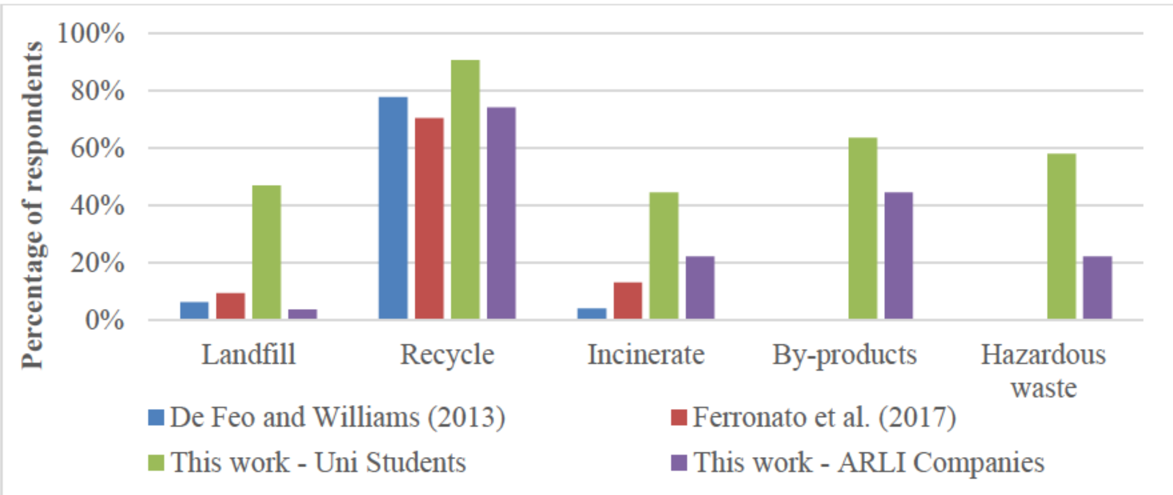


Figure 6–1: Comparison with the literature of the generated waste meaning to respondents.

The last question of the fourth part of the questionnaire (Q4.3) asked about the principal motivators to push forward a CE adoption, and Figure 6–2 shows its comparison with the literature. There are noticeable differences across all of the CE drivers particularly for the ARLI companies. For example, for the *'Keeping up with competitors'* driver, the results of this work are noticeably lower (< 1/7 of values) than those from Adams et al. (2017) and with a smaller difference (< 1/3 of values) with Xue et al. (2010); all with a selection rate of 18.5%, 66.2% and 23.0% respectively. This can be explained by having respondents from a very competitive sector, such as the construction industry. Conversely, for the *'Public opinion'* driver, this research and the results from Adams et al. (2017) demonstrated to be less different (37.0% and 64.8%, respectively) while Xue et al. (2010) are comparably lower (15.9%). This might be related to having adopted CE as a national strategy by China over a decade ago, and thus, the respondents are more aware of CE in China than in the UK. A *'Sustainable business strategy'* resulted in having a more similar outcome for this research and Adams et al. (2017) (63.0% and 72.2% respectively). This might be a result of both the construction and waste-to-energy sectors being in constant pursuit of more sustainable strategies.

It was reported above that over three-quarters of the general public think that the critical characteristics of CE are protecting the environment and minimising losses from waste streams (Smol et al., 2018), while this research found 93% of participants' opinions to be aligned to environmental responsibility. On the other hand, from the consumers' viewpoint, CE was generally perceived by 69% of respondents as a new sustainable business model (Smol et al., 2018), a finding that compares favourably with 84.9% and 63.0% of participants (students and companies respectively) viewing the CE as such (i.e., under *'Sustainable Business Strategy'*) and 66.7% and 44.4% identifying its potential for boosting economic growth (i.e., under *'Increasing future Profits'*).

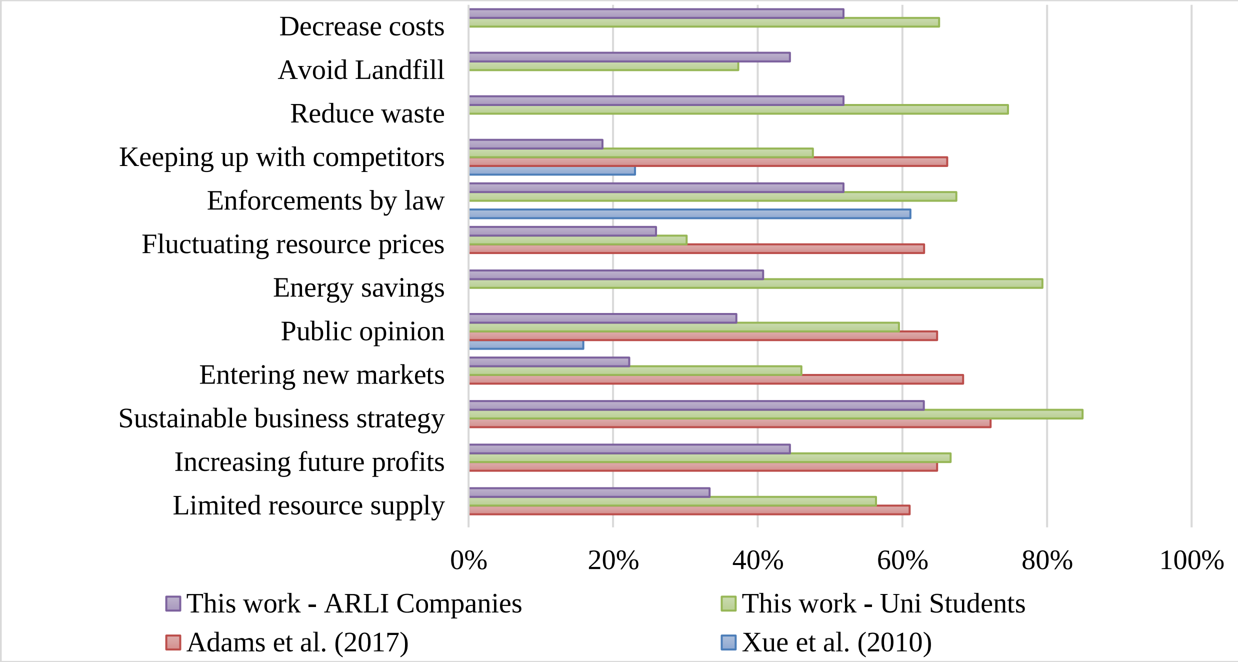


Figure 6–2: Comparison with the literature of potential CE drivers.

6.2 Discussion of the Applied GT-Hybrid Tool Outcomes

[The contents in this section were the basis of the discussions in the article published and mentioned in previous chapters[13].] As mentioned in Section 2.3, there are a minimal number of studies that apply any form of *Game Theory (GT)* in the CE and MSW agendas. This section discusses the results from the proposed hybrid GT-based methodological procedure used to study stakeholder cooperation in a case study of MSW future CE scenarios in a city (i.e., the particular application in the TEP in Birmingham, UK). This discussion is of the outcomes from Section 5.4 onwards.

Firstly, this thesis builds on previous research by Soltani et al. (2016) who utilised GT elements to study group *Decision-Making (DM)* for landfill and *Energy from Waste (EfW)* technology alternatives. In contrast, this research included other CE principles such as MSW generation reduction, recycling and carbon emissions mitigation. Also, their study considered a two-player game; in contrast, this framework considers an expanded n-player game where 14 participants aggregated into five stakeholder groups comprise the case study provided.

By identifying the means to establish equilibrium in the value capture process, it is possible to predict how individuals will behave in an interactive situation (Madani et al., 2015). Prediction of individual stakeholders' actions leads to the formulation of recommendations of how to reach

[13] Palafox-Alcantar, P.G.; Hunt, D.V.L.; and Rogers, C.D.F. 2020. A Hybrid Methodology to Study Stakeholder Cooperation in Circular Economy Waste Management of Cities. Energies. 13(7), 1845, Available at MDPI: https://doi.org/10.3390/en13071845.

decisions which are optimal, feasible and stable for the whole system, and therefore how best to implement CE. In support of this goal, GT is seen by some scholars as a normative tool to suggest how actors should behave (Dufwenberg et al., 2001), and has therefore been an approach worthy of research in the CE and MSW contexts.

Figure 6–3 shows the total aggregated stakeholder groups subjective weights for the indicators (from data in Table 5–6); in which it is observable that the environmental indicators have resulted as of the least concern, alongside the *Public awareness and satisfaction*. Previous findings from Soltani et al. (2016) indicate that industry stakeholders prefer economic indicators, while municipalities consider environmental indicators more important. For this case study, recycling and landfill rates of MSW have yielded the lowest weighted values, whereas the economic indicators resulted in the highest weighted values. Academic Institutions are the most concerned with environmental indicators. The slightly higher value for the reduction of carbon emissions is related directly to the fact that Birmingham committed to reducing its carbon footprint by 60% by 2027 and such target is well-known amongst the city stakeholders (Rogers, 2017; Birmingham City Council, 2014; Gouldson et al., 2013).

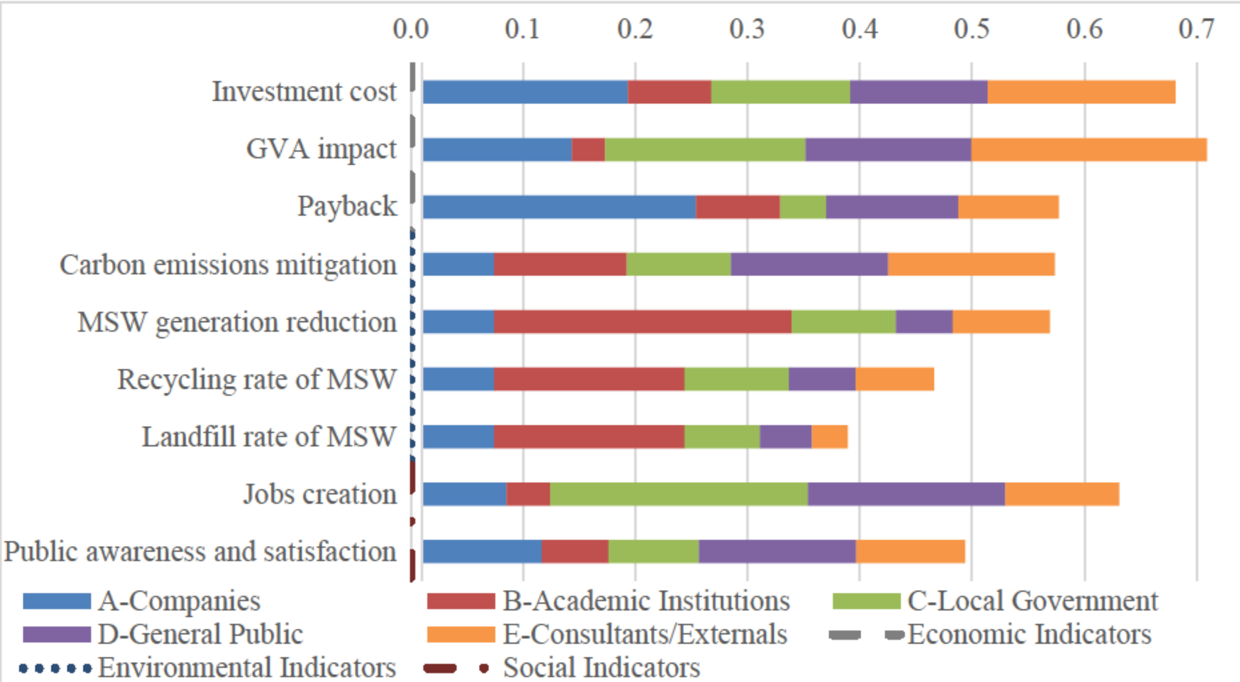


Figure 6–3: Subjective aggregated weight values for stakeholder groups.

An unexpected finding is the low subjective weight for the *Jobs creation* indicator for the General Public Stakeholder 1 (D_1), as observed in Table 5–6. However, their aggregated weight values are the highest for *Jobs creation* compared with any other indicator for Stakeholder Group D. As mentioned by them during the survey: *"[…] it is not just about jobs creation, we need skilled jobs in the area, not simple jobs […]"*. When aggregating the weight value with the other participants in the same group, the total value increased as shown in Figure 6–3. Thus, *Jobs creation* resulted in the third most important indicator for all the stakeholders. Conversely, the most important indicators for the rest of the stakeholders were *Gross Value Added (GVA) Impact* and *Investment cost*. This reinforces the initial expectations that the stakeholders' conflicting viewpoints might well be a significant barrier to cooperation and thus limit the ability to reach the optimal scenario.

The scenario that scored highest in the AHP objective weights (with data from Table 5–10) was *New Sustainability Paradigm (NSP)*, followed by *Policy Reform (PR); Market Forces (MF)* was ranked third, and the *Fortress World (FW)* scenario resulted as the lowest-ranked of all (Figure 6–4).This does not come as a complete surprise given the contrasting positive descriptors of NSP and negative descriptors for FW. As observed, the indicators that contributed the least to NSP were the economic ones (i.e., *Investment cost* and *Payback*). This is comparable with the results from De Feo and Williams (2013) where they stated that when siting the most sustainable MSW facility, participants should neither expect this alternative to return the costs soon nor to expect it would be the least expensive. The argument is that a sustainability strategy is a long-term investment (Geissdoerfer et al., 2017).

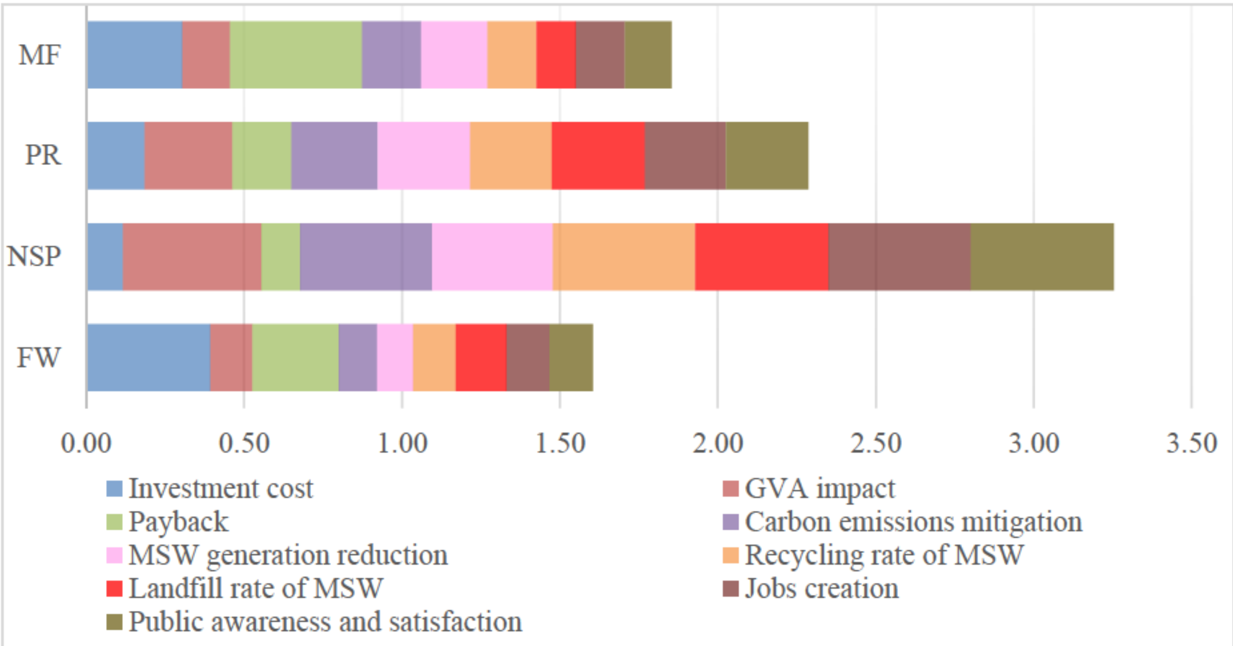


Figure 6–4: Objective weight values for scenarios.

According to data from Table 5–12, NSP also resulted as the most preferred scenario for all stakeholders (Figure 6–5), this is in line with previous observations where 70% of the surveyed stakeholders ranked highest the most sustainable performing composting plant site alternative (De Feo and De Gisi, 2010). The second most preferred scenario is generally PR, except for

Stakeholder Group A (Companies) who ranked MF in second place, meaning that they prefer a business-as-usual scenario over robust policy implementation. Likewise, the third most preferred scenario by almost all stakeholder groups was MF, except as mentioned before, Group A placed PR in the third position. Finally, all stakeholder groups agreed that FW is the worst of the proposed scenarios and thus ranked it in the lowest (fourth position) of preference. Hypothetically, if they already agreed that FW is the least desirable scenario, especially in comparison with NSP, this perspective would imply to them that FW is an unlikely scenario that works for CE. However, the built scenarios were never revealed nor mentioned to participants in order to avoid any bias. This suggested, before the GT analysis that stakeholders most preferred scenario was NSP and hence they would likely be more willing to work jointly towards achieving it. However, it does not necessarily mean that their priorities are aligned, and that stakeholder cooperation would occur naturally. A possible explanation of the responses from Companies standing out against the rest, is because for them the direct cost impact affects them more severely to the point of being determinant to their survival – the two economic indicators (*"Investment cost"* and *"Payback"*) that they highly ranked have a different effect on the result as they were the only ones to be minimised.

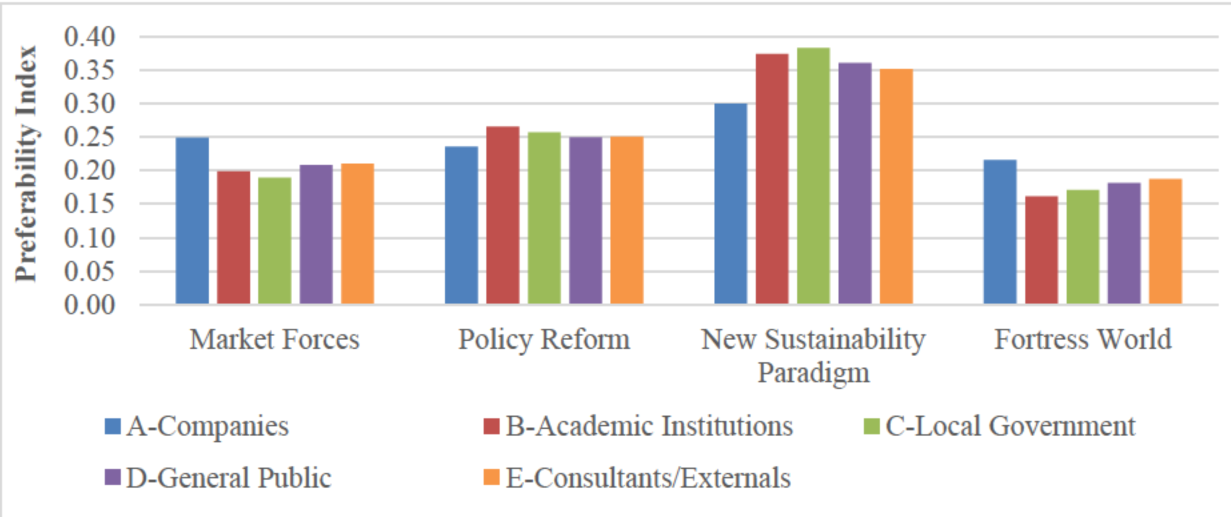


Figure 6–5: Preferability indexes for the CE scenarios for each stakeholder group.

After revealing the preferences of the stakeholders to the CE scenarios, the *Non-Cooperative Game Theory (NCGT)* analysis reported that, as expected, stakeholders achieve their maximum levels of satisfaction (payoff) when all five of them select the NSP scenario; meaning this is [a] '*Nash Equilibrium*'. If any of the participants were to deviate from this selection unilaterally, not only would that result in a decreased *Preferability Index (PI)* for them, but it would also decrease the rest of the stakeholder groups. This combined set of preferences ($\Pi_{NSP,NSP,NSP,NSP,NSP}$) was then used to calculate the benefits system for the stakeholder groups ($\beta_{NSP,NSP,NSP,NSP,NSP}$), which then enabled to carry out the *Cooperative Game Theory (CGT)* analysis.

The first row in Table 6–2 indicates the benefits each group would obtain separately. This implies there is no cooperation, and thus why there is no addition in the rightmost column. The second row compares with the above row and shows the benefits obtained by each stakeholder if they all join a coalition and cooperate, with the letters below each entry showing how the benefits obtained compared to the previous benefits. Some Stakeholders (A and E) can increase their benefits while the rest (B, C and D) exhibit a decrease. In the bottom row, which is compared with the second row, the *Shapley Value* assigns benefits differently, with the letters below indicating how this new allocation compares with the previous case in which all stakeholders cooperate (ABCDE).

Table 6–2: Comparison of coalition distribution of benefits for stakeholders.

Coalition	Benefits $\beta_{NSP,NSP,NSP,NSP,NSP}$ Stakeholders A	B	C	D	E	Σ β
Independently	0.281	0.437	0.458	0.406	0.386	
ABCDE	0.331 (I)	0.414 (D)	0.423 (D)	0.399 (D)	0.389 (I)	1.956
Shapley Value	0.273 (D)	0.436 (I)	0.455 (I)	0.405 (I)	0.386 (D)	1.956

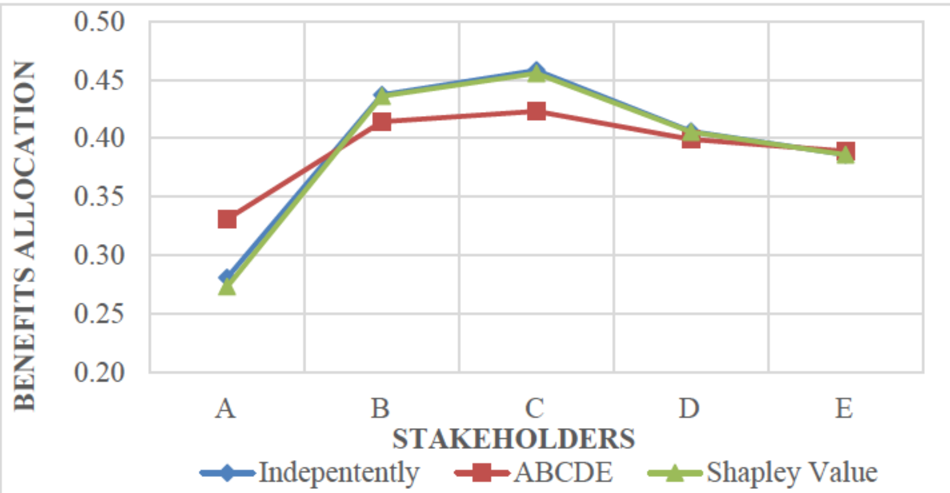


Figure 6–6: Comparison of coalition distributions.

The *Shapley Value* results in slightly lower assignations to all stakeholders than if they work on their own, i.e., when a single stakeholder is in five different coalitions, as shown in the first row in Table 6–2; except Stakeholder Group E (Consultants/Externals) who stay the same. Compared to the values for the ABCDE coalition, the *Shapley Value* benefit allocation for Stakeholders B, C and D, is suggested to increase, because according to the *Shapley Value* definition, their contribution to the coalition influences their allocation. In other words, it is a representation of their bargaining power and, as shown in their independent (topmost row) and ABCDE (middle row) values, their contributions are the highest. Likewise, Figure 6–6 helps in visualising these different outcomes and shows how the *Shapley Value* is assigning the minimum satisfaction levels to stakeholders to deter them from abandoning the coalition while complying with the maximum total amount of benefits that can be shared by the participants.

The *Shapley Value* is an ideal recommended distribution that would give all stakeholders benefits; otherwise, the benefits would only distribute amongst those who entered a coalition. The results suggest that some participants (A and E) decrease their benefits to maintain the coalition since and otherwise, the other stakeholders might be too unsatisfied with the outcome. They would believe that their benefits might increase by working on their own (which would not be possible because the entire payoff model would disintegrate). Thus, some stakeholders should expect to forgo a part of their benefits so that benefits would allocate more fairly. In contrast, those who contribute more to the coalition can expect to receive higher benefits, this aligning with the definition of cooperation. This expected increase and decrease of benefits is consistent with previously reported research (Hiete et al., 2012), which show a fair sharing of savings in energy from intercompany heating and cooling integration.

Finally, these results mean that increasing the satisfaction of Stakeholder Groups B, C and D could help in achieving successful stakeholder cooperation. For this, the analysis recommends tracking back those indicators which these stakeholder groups find more meaningful, and work on maximising their performance depending on their objective. For example, from observing Figure 6–3, if efforts are aimed at further reducing MSW generation, they will increase the satisfaction levels of Stakeholder Group B; despite having little effect on the satisfaction of groups C and D. Likewise, increasing the creation of jobs will increase the satisfaction of both Stakeholder Groups C and D while affecting only slightly Group B. Additionally, increasing GVA impact, despite having little effect on the satisfaction of Stakeholder Group B it will increase that of the rest of the groups.

It must be mentioned that these actions do not affect negatively other stakeholder groups (i.e., A and E in this specific case). However, it will continue contributing to improve their satisfaction levels and thus encourage cooperation towards the NSP scenario (Asgari et al., 2014). As highlighted by Karmperis et al. (2013), the equitable benefit and cost distribution (satisfaction levels) to stakeholders in the management of MSW can increase participants cooperation and ultimately the system's sustainability and facilitate its transition to a more CE.

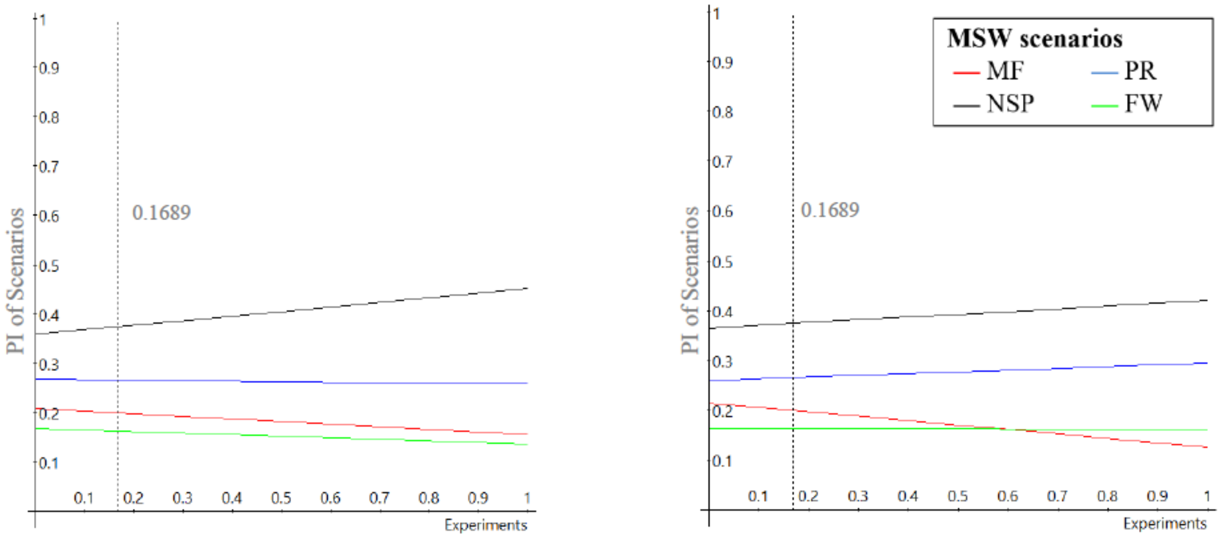
6.2.1 Sensitivity analysis of the results

Since occasionally the criticality of the indicators does not behave as intuitively as one might expect, in other words, a smaller weighted indicator might yield a more significant variation in the final output if a small percentage of its weighting is changed; in which case it is vital that sensitivity analysis of the AHP weights are performed (Triantaphyllou and Sánchez, 1997). Also, performing this analysis helps to test the variability of the selected indicators and scenarios of this analysis (De Feo and De Gisi, 2010); furthermore, this analysis helps in verifying the validity and robustness of the results (Goepel, 2018).

The open-source software SuperDecisions (v3.x) helped to perform the sensitivity analysis. Appendix F presents the complete results of the sensitivity analysis for all indicators for each stakeholder group. A sub-set of these are discussed here.

Because all the stakeholder groups results were comparable and for illustration purposes, this section considers only Stakeholder Group B with two of the indicators (6 and 7) where no serious complications were noted (i.e., '*Recycling rate of MSW*' and '*Landfill rate of MSW*', respectively). Figure 6–7 shows the results of these.

The vertical axis indicates the PI for the plotted scenarios, the horizontal axis indicates the experiments of the analysis (i.e., the hypothetical weights assigned to that indicator). The intersection with the dotted vertical line marks the actual subjective weight that indicator yielded in the previously presented results, in both cases, it was 0.1689. For the *'Landfill rate of MSW'*, there is a point where the MF and FW scenarios lines intersect. This is called a reverse ranking point, and it means that if the weight of Indicator 7 were to increase to 0.6017 (all other indicators assumed constant), the third preference of Stakeholder B would change. In other words, the PI of Scenario MF is outclassed by Scenario FW if the weight of *'Landfill rate of MSW'* increases more than threefold.

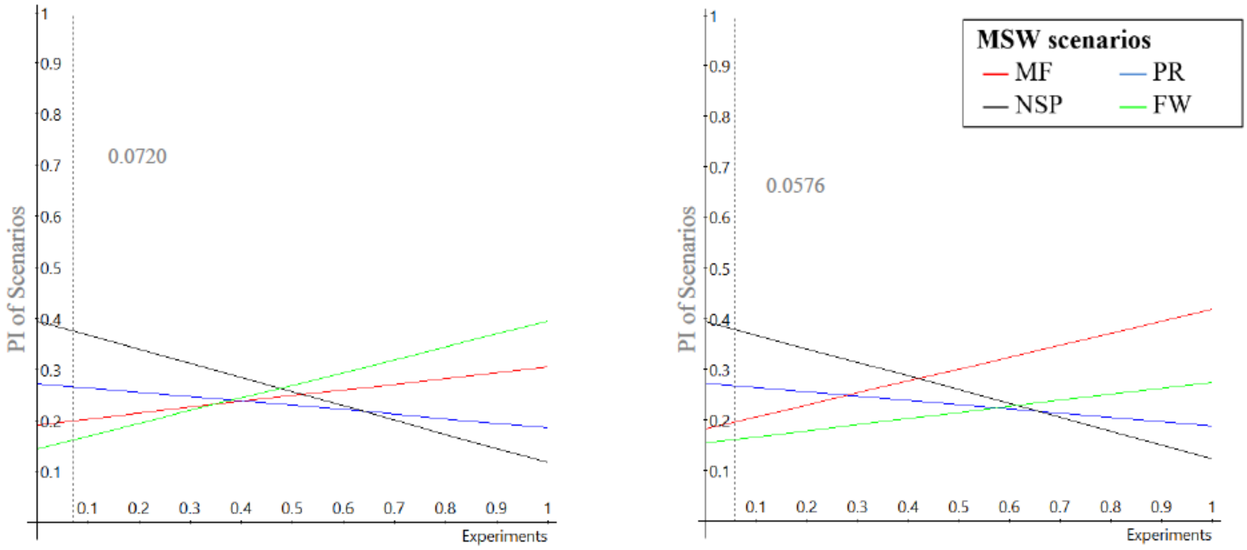


(a) Recycling rate of MSW (Indicator 6) **(b) Landfill rate of MSW (Indicator 7)**

Figure 6–7: Sensitivity analysis results for Stakeholder Group B and Indicators 6 and 7.

On the other hand, two indicators presented several reverse ranking points; they were Indicators 1 and 3 (i.e., *'Investment cost'* and *'Payback'*). Figure 6–8 shows their sensitivity analysis outcomes and the representation of the yielded results. The yielded objective weights were 0.0720 and 0.0576 for Indicators 1 and 3, respectively (see Table 5–6); relatively small weightings compared to the rest of the indicators.

As observed in the figure, there are several rank reverse points (points where the lines of the scenarios intersect, and the preferences are changed). The most important for the analysis is when the NSP ceases to be the most preferred scenario. This means that if Stakeholder Group B changes their ranking of indicators 1 or 3 to make them *extremely important* (i.e., rank them at the top of the 'priority scale') and the rest *irrelevant* (i.e., rank them towards the bottom of the *'priority scale'*); the scenario preferences would invert and NSP would no longer be the most preferred scenario. However, this situation is hypothetical and highly unlikely.



(a) Investment cost (Indicator 1) **(b) Payback (Indicator 3)**

Figure 6–8: Sensitivity analysis results for Stakeholder Group B and Indicators 1 and 3.

A possible explanation to these changes is that contrary to the other indicators, both indicators presented a low performance in the NSP scenario (i.e., the objective weights for Indicators 1 and 3 were comparably depreciated – see Figure 6–4). This results in a rapid change of preferences if the subjective weights of these two indicators suddenly heightened dramatically. However, in practice, these circumstances are not likely to happen, because this sudden increase would also imply a simultaneous sudden plummet of the rest of the indicators.

To summarise, both Indicators 1 and 3 were deemed both necessary and critical to stakeholders (see Figure 6–3), not least because of their sensitive behaviour if their subjective weight is modified. Conversely modifying the subjective weights of the rest of the indicators results in no significant changes in the outcomes. Overall, despite encountering several reverse ranking points, the outcomes of the sensitivity analysis confirmed that the NSP scenario is the most preferable to all stakeholders and that there is a minimum probability that it will change if the subjective indicator weights were altered slightly. Sensitivity of scenarios is not carried out because, as opposed to indicators, the method assumes that scenarios are constant, unchangeable, and constructed from impartial data.

6.3 Contrast of the Questionnaire and GT-Hybrid Tool for Stakeholder Cooperation

6.3.1 Perceptions of other CE stakeholders

[Once again, this section is the basis of a published article by the author of this PhD[14].] This section of the thesis discusses the outcomes from Section 4.2.5, and achieves the final objective (O5) in Table 1–1 which is to compare and contrast the outcomes from O3 and O4. In order to connect the last questions from the previous section, the survey enquired about the trust between stakeholder groups in CE transitioning. This work found that participants believed that trust is vital to achieving cooperation in the CE transition (Q5.1). However, one of the responses mentioned that *Small and Medium Enterprises (SMEs)* are usually not following the advice and thus, cannot be trusted and left to align their CE activities on their own; "*they need to be chased*". Another critical response mentioned that the CE transition does not happen because of luck, but because there must be a joint effort and trust between stakeholders. This survey found the need for trust between stakeholder groups to be vital in CE transitioning, and that any CE project should make explicit what the participants can expect to obtain and to contribute—underlined by mutual (perhaps legislated) trust. Within the literature the only question that previously addressed a trust issue revealed that the main reason for not using a 'sharing' business model was the lack of trust between users themselves (Smol et al., 2018). Further research could help unpick the relationship between trust and stakeholder cooperation through additional questions in the survey or perhaps a more in-depth analysis of respondents' individual experiences and viewpoints towards trusting others.

Q5.2 asked about the opinions of respondents to who should take part in new CE waste management strategies discussions in cities. The results for this research showed that Private investors, Local politicians, Local policymakers, Local inhabitants/citizens and Technology suppliers received the highest number of votes by total respondents. This is therefore comparable with the outcomes from published research (De Feo and Williams, 2013; Ferronato et al., 2017) in which nearly 59% of respondents agreed on including all of the actors asked (technicians, politicians and citizens). However, these papers did not include the wider range of options available in this research (Researchers, Private investors, Local policymakers, Entrepreneurs and Consultants).

[14] Palafox-Alcantar, P.G.; Hunt, D.V.L.; and Rogers, C.D.F. 2021. Current and Future Professional Insights on Cooperation towards Circular Economy Adoption. Sustainability. 13, 10436, Available at MDPI: https://doi.org/10.3390/su131810436.

Finally, the questionnaire in this study explored the willingness to trust other stakeholder groups in the CE transition. The ARLI companies (only) were asked to express how powerful in this CE transition they viewed other stakeholder groups (Q5.3a). An extended analysis of these questions is discussed hereafter.

These results compare with the Shapley value results from the GT-hybrid method (see Section 5.7.2), as displayed in Figure 6–9. The primary (left) axis shows the benefit allocation for the Shapley value results (Figure 6–6). It is worth reiterating that the definition of the Shapley value is the allocation of benefits to each stakeholder, according to their contribution to the coalition. The secondary (right) axis shows the power index which represents (in terms of percentage) how stakeholders perceive the power/influence of each other. As observed, Companies were perceived as the most powerful/influential stakeholder group. However, previous results also showed them to be the least benefitted contributor in the DM process. Academic Institutions, in contrast, were expected to be the least influential, but they are the second most benefitted group contributor in the Shapley value assignation. In line with the literature, local government is generally seen as the key stakeholder expected to drive the CE transition (Xue et al., 2010; De Feo and Williams, 2013; Ferronato et al., 2017). Local government is rated as the second most influential stakeholder, and the Shapley value results show that it is the stakeholder with the most allocated benefits; thus, they should, in theory, take a lead in engendering cooperation amongst the rest of the participants. However, it must also consider the misconception from Robèrt and Broman (2017) who argue that we must not rely entirely on a third party (authority) to drive the CE transition, but it must be a balanced effort from all participants (Grimes-Casey et al., 2007).

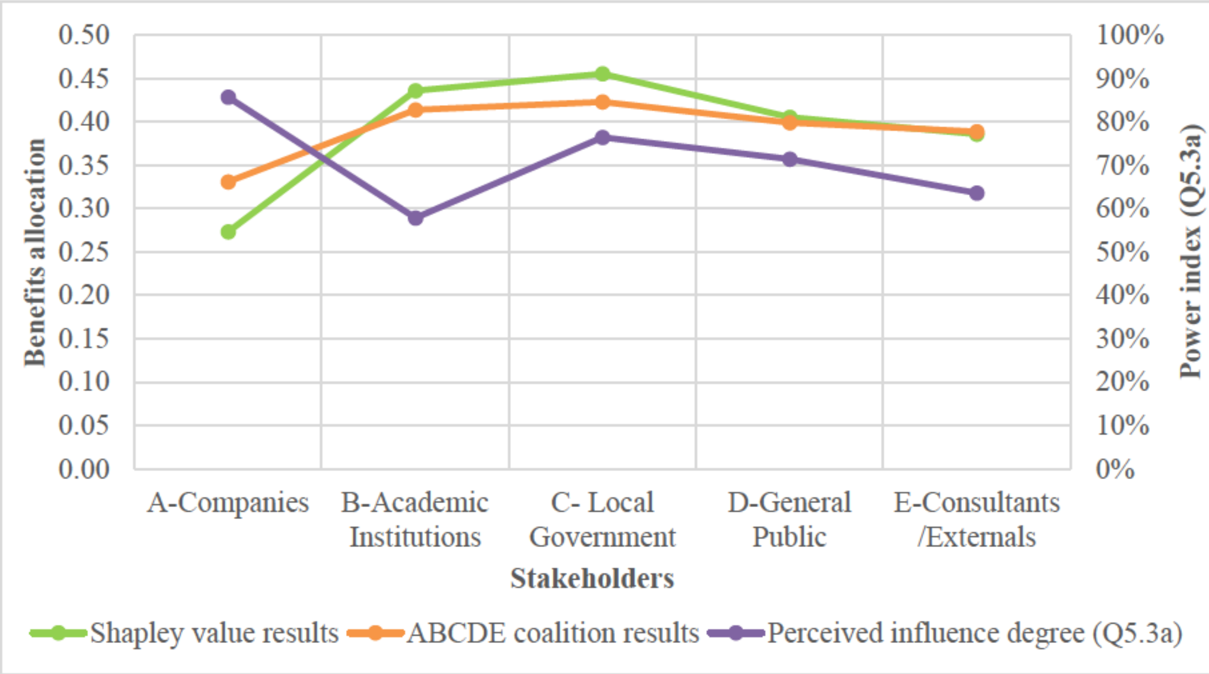


Figure 6–9: Comparison between the perceived influence of stakeholders and Shapley Value results.

Figure 6–10 shows the opinions of whether the stakeholder's influence is increasing, staying the same or decreasing. The primary (left) axis represents the % change in power or the change from the original ABCDE coalition to the suggested *Shapley value* coalition (difference percentage between the second and last rows from Table 6–2 or the first and second lines in Figure 6–9). The secondary (right) axis represents the average results (based on a five-point scale) regarding the trend of each group's influence (see Q5.3b – Figure 4–15). As observed, Companies were considered to have an increasing trend in their influence. However, the *Shapley value* results suggest that their final power (i.e., benefits allocation) might be decreased in this case because of their lower contribution to the coalition. This is to increase the benefits allocated to other stakeholders and to achieve cooperation so that all stakeholders choose the most sustainable scenario (see Section 6.2). Academic Institutions were more influential over time, and the Shapley value results show that their power will increase (by 5.0%). The Local Government also can increase their power (by 7.1%). Consultants/Externals were thought to have increasing influence, but the results show their power would slightly decrease (−0.8%) with the suggested Shapley allocation. The General Public is thought to retain a similar power in the CE DM process, and the results show that their power could also be slightly increased (1.6%) in this particular case study.

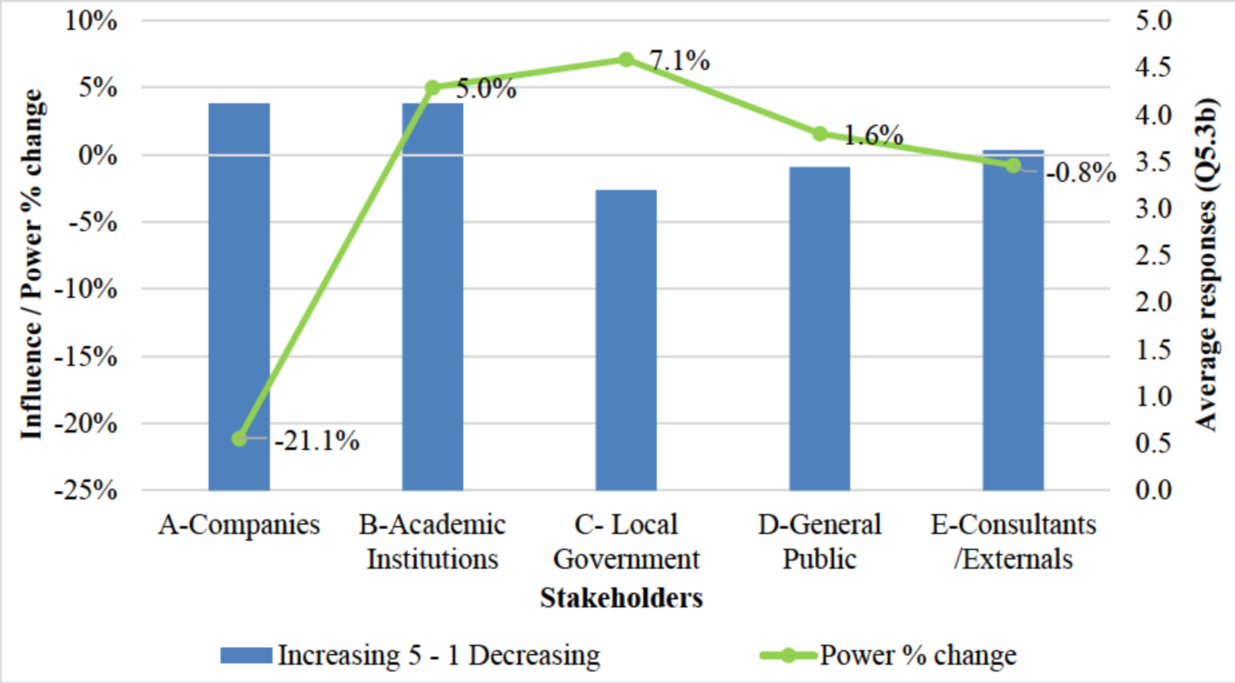


Figure 6–10: Comparison between the perceived trend in influence and power change percentage.

Q5.3b also addressed the effects on stakeholders being affected by the CE transition. Previous work explored only how the CE transition would affect a group (Marios et al., 2018). Their results showed that respondents view a CE as a positive change to reducing waste generation and improving the environmental consciousness of the public. The outcomes of this work showed that the majority of stakeholders are positively affected by the transition to a CE, with the majority being both positively and negatively affected. For example, Companies would welcome the opportunity of developing new business models, but they often must accept significant risks and costs; Governments face these challenges usually under the pressure of budget cuts; the Local Inhabitants need to become yet more informed and aware of these changes. It must also be clarified that the last two figures are not attempting to compare the amounts, but the interpretations of two different ways to measure power or influence of stakeholders.

Benefits allocated reflect the stakeholders' contribution to the coalition. In summary, though there are only a few results from the reviewed articles to compare with those from this work, this may be due to the fact that the literature does not explicitly address the perceptions of other stakeholders in the CE transition. This research provides the first insights into this; the results showed that stakeholder groups are usually ready to trust each other and cooperate to facilitate CE adoption. The next and final chapter expands on this and the possible future research that can continue to help achieve this.

7 CONCLUSIONS

This research presents a novel methodological process to study cooperation between stakeholders when adopting *Circular Economy (CE)* principles in the *Municipal Solid Waste Management (MSWM)* of cities which fulfilled the aim of the thesis. Several researchers have studied CE implementation, and others recognised the relevance of stakeholder cooperation to the successful adoption of CE principles. However, studying cooperation between stakeholders was found as a gap in the CE literature since it has not yet been researched specifically in terms of it being a critical element for the CE transition.

The final chapter presents the conclusions of this doctoral research and comprises these sections:

- The concluding remarks from the findings of this work (Section 7.1).
- The limitations and drawbacks that this research encountered (Section 7.2).
- The suggested future research needs and policy recommendations (Section 7.3).

7.1 Concluding Remarks

Firstly, the objectives of the research presented in Section 1.2 were accomplished by:

- Reviewing existing peer-reviewed and grey literature on survey-based studies that measured CE awareness and other features to develop a taxonomy of CE stakeholder cooperation.
- Reviewing the literature on *Decision Making (DM)* methods used in the CE and *Municipal Solid Waste (MSW)* contexts to identify the advantages and shortcomings of each methodology and establish the research gap.
- Developing a literature-based questionnaire to measure CE awareness and the other identified CE stakeholder cooperation features.
- Developing a *Game Theory (GT)*-hybrid tool that combines the processes of the reviewed DM methodologies to study stakeholder cooperation in the CE adoption of MSW scenarios.
- Applying both the questionnaire and GT-hybrid tool and testing their effectiveness through a case study, and then comparing the findings with the existing literature.

Even when stakeholders share a common goal (e.g., adopting CE), conflicting objectives and priorities between different stakeholders are likely to arise. By providing evidence on stable (equilibrium) and optimal decisions, this research contributes to the DM when adopting CE principles in the MSWM of cities. This GT-hybrid decision support tool facilitates the incorporation of all stakeholders' views by considering their multiple and sometimes conflicting priorities. This research applied the tool with five stakeholders, but more could be added if necessary for other case studies. The proposed GT-hybrid decision support tool balances the overall DM process by harmonising government technical knowledge, private sector profit-led activities and general public needs.

This research is valuable and has contributed to knowledge by:

- Conducting a critical review of survey and questionnaire-based studies that measure CE awareness (see Section 2.2).
- Developing a taxonomy for the implicit characteristics of stakeholder cooperation when adopting CE principles based on the literature reviewed in the previous point (see Table 2–3).
- Being the first to critically review and compare the three most commonly used DM methods against GT in the MSW and CE contexts (see Table 2–4 and Figure 2–6).
- Developing an instrument in the form of a questionnaire to evaluate CE awareness and other stakeholder cooperation features (see Appendix C). Furthermore, this questionnaire is useful because it:
    - Can be used in full or partially to evaluate the progress of CE awareness, benefits, barriers, and the cooperation features it aims to assess.
    - Is easy to adapt to other case studies, and it is simple to apply by non-scientific users.
- Applying both the questionnaire to two distinct cohorts – companies in the ARLI project and Masters students at Birmingham and Oxford Universities – and the GT-hybrid tool in the *Tyseley Energy Park (TEP)* case study in Birmingham, UK (see Chapters 4 and 5).
- The main originality of this research was developing a GT-hybrid methodological tool by combining the reviewed DM methodologies that study stakeholder cooperation when evaluating CE future scenarios (see Figure 3–1). Also, the tool is beneficial because it:
    - Applies not only to MSW scenarios but can be easily adapted to other scopes.
    - Ranks the scenarios with the data of the indicators provided and calculates the preferences of the respondents to these scenarios using a consistent method: the *Analytical Hierarchy Process (AHP)*.

    - The excel-based tool is effortless to use and understand by a wide range of users as it only requires the input of scenarios and the ranking of indicators (see Appendix E) by participants to yield the decision support results.
    - Provides the data to be used directly as input in the Gambit software and "GameTheory" R package to perform the GT analysis.

The application with a case study of hypothetically built CE scenarios in Tyseley tested the efficacy of the suggested framework. The study categorised fourteen key stakeholders in the five most influential stakeholder groups; they then completed both parts of the questionnaire. Statistical analysis was employed to interpret the data collected. For the GT-hybrid tool, the respondents ranked nine selected CE indicators that measured the performance of four constructed future scenarios. The subjective and objective weights were calculated for the stakeholders and scenarios, respectively, and these were then used to obtain the stakeholders' *Preferability Indexes (PI)* and rank their scenarios preferences. The optimal selection of scenarios was determined using a range of *Nash Equilibrium* methods; the *Shapley Value* technique analysed the possible coalitions and the most efficient allocation of benefits.

The following conclusions can be drawn from the findings of the research:

- Studies based on questionnaires and surveys in the CE literature are still usually limited to measuring CE awareness amongst government, general public and firms. Other aspects are commonly researched, such as barriers, enablers, practices and attitudes; however, the relationships with cooperation have not been sufficiently explored.
- From the critical review of the most common DM methods in the CE transition, it also became evident that GT is still an underexplored method in the CE context. GT can help to study cooperation if adequately combined with the other methodologies to embrace their advantages; again, studies that have attempted this are still minimal.
- From the analysis of the results from the application of the survey, it can be concluded that:
    - Stakeholders surveyed had a very high awareness of a CE and its related concepts.
    - The *3Rs principles (Reduce, Reuse, Recycle)* are the main direction that respondents take in their CE practices. While this is not a negative symptom, it reinforces the "*striking gap*" between the self-claimed awareness and the actual practices to develop a CE. In other words, some respondents might claim they are

aware of a CE but have limited practices. For example, students were completing the questionnaire but may have had little practical experience with CE.

  - The cultural and regulatory barriers were the most pressing to overcome, most notably *'Lacking consumer awareness and interest'*, *'Hindering laws and regulations'* and *'Insufficient cooperation'*. The latter is the crucial barrier that the purpose of this research aimed to mitigate as it might also help tackle the two previous and other barriers (see Figure 2–4).
  - The results of the attitudes and willingness to cooperate revealed the encouraging and optimistic thoughts from stakeholders to CE development, despite (as repeatedly mentioned) benefits and costs not always being evident to all participants. Thus, in order to increase even further the confidence of highly motivated individuals and organisations, this research might prove helpful in exposing the benefits and potential pathways of stakeholder cooperation.

- From the analysis of the results from the application of the GT hybrid tool, it is evident that:
  - CE scenario evaluation is mainly driven by economic criteria, especially by industry practitioners and the general public. The government is more inclined to consider both social and economic impacts more important (creating jobs and maximising profits). Environmental criteria, particularly those indicators related to MSW, were found to be of least concern to all stakeholders but Academic Institutions. See Figure 6–3.
  - Without revealing the MSW scenarios and their performance to the respondents, the most sustainable scenario (*New Sustainability Paradigm – NSP*) is consistently selected as the most preferable by all stakeholders.
  - Aggregating the group preferences results in decreasing the final variations. This means that respondents from a single group might have different views, but when aggregated, the extreme rankings will have a smaller impact on the final outcomes.
  - There will always be individual incentives to abandon a coalition but making the participants aware that such behaviour would compromise the entire benefits system should deter them from withdrawing the agreements.
  - The results provide evidence to include all the proposed stakeholders in the DM process of MSW scenarios assessment by showing that the *Shapley Value* allocation takes their satisfaction levels into account. In general, participants agreed that it is necessary to consider every viewpoint.

In summary, the utilisation of AHP for both the subjective and objective weightings not only consider the views and understanding of the stakeholders, but also uses the impartial data of the constructed CE scenarios. The *Shapley Value* allocation of benefits yields a result where all stakeholders share a portion of the benefits; in other words, no coalition where a stakeholder is missing produced an optimal result. However, *Cooperative Game Theory (CGT)* assumes participants are willing to cooperate and agree on forming coalitions. If stakeholders desert the agreement, the coalition and its benefits model break down, and this jeopardises the possibility of reaching the most preferred, or optimal, scenario. The next section presents in more detail these and other limitations that this research faced and the drawbacks it encountered.

7.2 Limitations of the Research

There are certain factors in DM that are extremely difficult to identify and measure; for example, the extremely subjective views on employment in the particular area of Tyseley as briefly presented in Section 6.2. In rationality, there is no room for human emotions or subjective views. This is a limitation of the proposed method and GT, as they are both based on the assumptions that actors are intelligent and rational; they have the same information and can make inferences about it, and they will always seek to maximise their utility, respectively. However, in practise most actors have limited rationality (Li and Fan, 2013) as "rational decision making" and the "rational planning process" assure. Their decisions are bounded by their limited cognitive capacity, restricted time for DM or by incomplete information (Lee, 2011), as well as emotions and previous experiences. While the proposed method complies with these GT assumptions, they also agree with the criticism from rational DM, because scholars widely debate that DM is not always rational (Simon, 1999). However, other social and economic disciplines that fall beyond the scope of this study widely apply rational DM, and that is why it is not explored in more depth.

Some potential biases in the survey responses and the case study site could have arisen. For example, a local bias from how different UK councils deal with MSW might affect respondents' views. However, this bias is acknowledged in each specific case study site as they will have a similar limitation depending on how the policy context shapes local MSW management. Another limitation was that the study focused on a very specific group with 14 respondents; however, this does not compromise its validity or reliability. The intention of the study was to analyse these respondents' preferences and decisions, and the proposed framework can be expanded to different geographies and more heterogeneous case study sites and participants.

The study involved the five most influential actor groups in the particular TEP area; the results showed the most optimal combined scenario for all. While it is relatively uncomplicated to define a comprehensive stakeholder directory, it is difficult to predict whether all actors will continue to comply with GT principles (willingness to cooperate and to compromise) later in the DM process. In this respect, the proposed framework does not consider multiple stages in the DM process or the possibility to introduce new stakeholders at later stages of the DM process. The MSW scenarios were hypothetically built, and used estimations based on current data with the intention to maintain simplicity (as explained in Section 5.3.2); more detailed and specific techniques to build these scenarios would thus be beneficial to the analysis.

Another limitation is the low number of surveys completed for the TEP case study, even though the response rate was relatively high (14 out of 36, approximately 38.9%). The main reason participants may have been discouraged from taking part was perhaps because of the lengthy and time-consuming questionnaire. Thus, the small sample compromises the extent to which it is possible to generalise the results, especially from the local inhabitants. However, the survey aimed to collect data from those in senior posts and highly aware of the CE (such as those responsible for sustainability), which would result in few but high-quality responses. Still, future applications should aim to increase the number of participants to perform more robust and representative analyses.

Multi-Criteria Decision Analysis (MCDA) methods are usually bounded by high subjectivity from the respondents. AHP, utilised in this research, is not the exception; however, the inclusion of experts is usually an effective way to counteract this issue, as this research aimed to do. Likewise, as the number of stakeholders included increased, the necessary calculations and time would increase exponentially; therefore, the case study aimed to restrict the analysis to a modest and representative number of stakeholder groups.

The proposed framework assists in the joint selection of an agreed most preferable scenario for respondents; however, because ‘sustainability’ might have a different meaning depending on each stakeholder’s viewpoint, it might be the case that a perfectly reasonable scenario could never be accepted. Even though other methods or activities could have helped to reveal the preferences of stakeholders to scenarios, the purpose of the tool was to reveal the scenarios’ preferences without revealing them to participants and ranking indicators with MCDA was the most adequate method. This framework estimates the benefits of the stakeholders by calculating their satisfaction levels. However, the questionnaire did not enquire about CE benefits and costs but only about indicators (Section 6 in the questionnaire). Thus, it is evident that further specification and in-depth consideration of the benefits/costs needs to be carried out (i.e., defining whether stakeholders expect environmental, economic, social or other benefits/costs). The section below discusses in detail these and other recommendations for future research.

7.3 Policy Recommendations and Future Work

The suggested alternative decision support tool attempts to provide evidence of how the joint selection of the most sustainable scenario could lead to its realisation and consequently formulate recommendations to achieve it successfully. It certainly is not the solution to complicated DM processes; however, it facilitates them by making difficult decisions more transparent. In essence, the method represents a single stage of the DM process, where it is necessary to include the more often underrepresented general public.

Other tools that could be useful to help stakeholders have a more open and sustained conversation throughout the DM process might include workshops with structured communication techniques (such as the *Delphi Method*) and behavioural economics methods (such as Choice Architecture). Examples of potential users of the framework include but are not limited to policy-makers and local authorities who wish to understand viewpoints from all affected stakeholders in a project, other academics or consultants who might provide mediation services for new projects that could be hindered by conflict.

Governments and businesses can prepare for scarcity of resources if they prioritise their actions appropriately, for example reintroducing materials in the consumption system and embracing servitisation models. However, urgent changes are needed in the mode and pace of a CE delivery. There is a need for leadership from companies to engage with authorities and take this paradigm forward to change the provision of CE. Likewise, the City Council should be proactive in influencing policy to accelerate the CE adoption. The decision support tool in this research could help them to signal cooperative behaviour via showing similar priorities and align their objectives. However, for the specific case in Birmingham, wider recycling and remanufacturing of MSW does not compete with the current practices of incineration, thus demonstrating an urgency for policymakers to support higher rates of recycled materials.

Other recommended directions for the local government to engage the general public is through policy-making that includes raising awareness of waste and circularity issues amongst the local inhabitants of a new project area by marketing campaigns, training and up-skilling of the workforce, seminars, conferences, and information material. Engaging with multiple stakeholder groups is vital to cooperate in this system, while focus groups, meetings and volunteer groups are needed to understand each other's priorities and needs, and perhaps most importantly agree on what to expect (distributions of costs and benefits). In support of these ideas, regulations that bind and commit stakeholders in the CE transition might be needed in terms of law enforcement (e.g., as already done with landfill taxes). Indicators to measure preferences of different stakeholder groups are useful to assess the impact of projects to policymakers and users. More effective platforms to improve information symmetry to all stakeholders would also be helpful, as would getting stakeholders involved in setting the principles along with experts and researchers from an early stage of the project.

A suggested way of achieving cooperation between all stakeholders would be for policies to be implemented which specify certain requirements that must be met, such as a certain percentage of materials on a construction project must come from recycled or re-used sources. Alternatively, government or local politician-led incentive schemes could be introduced to encourage all stakeholders to work together. Impartial mediators and conveners can help facilitate compromise or consensus between stakeholders.

The main academic benefits from this research include that it successfully combined three different methodologies, namely SA, MCDA and GT, to propose an alternative and new decision support tool that studies stakeholder cooperation. The tool also explored a set of indicators that are commonly used to evaluate CE projects, and this can be a benefit to other academics or consultants when deciding on the indicators to use when asking stakeholders their opinions or priorities in new or existing projects. This research can also serve as a trigger for further research to investigate other ways to bring about cooperation in CE adoption situations.

Overall local policymakers should aim to develop a new set of goals that could intrigue, and therefore encourage, stakeholders to follow on with this CE vision, in other words, not only by purely educating them on the reason why this change must happen. Developing different CE case studies that the target audience can relate to and listening to the concerns of individual stakeholders would be beneficial to relieve tensions between participants. However, the fact that a successful transition to a CE will require a balanced and proactive effort from all stakeholder parties, not only a push from governments, must not be overlooked.

This research only considered one case study, the TEP in Birmingham, UK. The site had its own very specific contextual conditions and stakeholders who were influenced by and who affect the project. The reusability of the tool and the questionnaire relies on slight adaptations to measure specific variables in each new case study site and/or samples. The conclusions and recommendations will also vary depending on the sites' different policies on, for instance, public recycling or landfill.

In terms of future work that can build upon that in this thesis, as in many other studies, due to the exploratory nature of the research the study performed a descriptive statistical analysis of the data collected from respondents of the survey cohorts. However, the use of more elaborate statistical techniques can help to improve the analysis, robustness and credibility of the results from the questionnaire. For example, to explore how the subjective questions to participants have different meanings amongst them. It is also recommended that future research should attempt to measure the willingness to cooperate from stakeholders by using other approaches (e.g., willingness to accept /pay methods) to achieve such a CE transition. This was not performed in this research because it was not the main aim of the thesis to find the explanations of the CE awareness from respondents.

Nash Equilibrium and *Shapley Value* are perhaps the most well-known and utilised methods (as in this work) to analyse stability and benefits/costs distribution. However, there are multiple non-cooperative stability definitions techniques that consider interactive DM in several stages (e.g., general and symmetric metarationality, sequential and limited-move stability, and non-myopic). Likewise, there exist multiple cooperative allocation methods in which the benefit/cost allocation varies according to assumptions and definitions (e.g., Nucleolus, and τ-value). Further research could usefully test the proposed framework with other cooperative and non-cooperative GT models and techniques to expand the empirical evidence on how GT can help in improving cooperation opportunities in the CE agenda.

The GT hybrid Excel-based tool described in Chapter 5 and Appendix E, even though simple to use, does not perform the last step of the methodology. The output is the data that transfers to a different software (Gambit) and then transfers again to an R package (*GameTheory*). This jeopardises the analysis by making it possible to mistype a datum while transferring the data. Future work can focus on improving this by directly performing the GT analysis with more powerful programming Excel-based tools; for example, Visual Basic for Applications (VBA). Also, it would be beneficial to gather feedback from users about the tool, how easy it is to use and how impactful are the results yielded. The collection of these evaluations would serve to improve the tool and include more features as necessary.

From the analysis in Section 6.2, because Stakeholder Group B (Academic Institutions) highly ranked MSW generation, in order to increase their satisfaction levels, it is advisable to target efforts at boosting the performance of this indicator. Thus, policies that aim to decrease MSW would increase the chances of cooperation occurring, and, in fact, would make other problems easier to solve as well such as the amount of waste to divert from landfill and/or incineration. This decision support tool can help to show to different stakeholders what is important to each of them.

Also, the outcomes from the GT-hybrid tool make evident what each stakeholder group prioritises. So, everyone knows how to satisfy other groups and others now know how to satisfy them as well. In consequence, they can agree on increasing efforts in whichever indicator they can influence more. For example, Local Government can target reducing MSW generation with policies, Companies can generate more jobs, and Academic Institutions can increase public awareness and satisfaction. All this serves as signalling, a major way to show stakeholders willingness to cooperate.

In summary, CE must be an embedded strategy, as it must involve stakeholders from the beginning. The real challenge for cooperation to genuinely occur remains that there must exist a clear and common understanding between stakeholders of how the loop functions and the impacts (whether beneficial or detrimental) of acting in the supply chain. Thus, negotiations might still be fruitless without extensive communication between stakeholders. It is therefore recommended that such an investment of prior effort and meticulous preparation by adopting this methodological process is likely to lead to the CE scenario outcomes to which we all should aspire.

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Appendix A

Appendix A. List of Publications

[1] Palafox, G.; Lee, S.; Bouch, C.; Hunt, D.; and Rogers, C. 2017. "The Little Book of Circular Economy in Cities: A short guide to Urban Metabolism and resource flows". Imagination Lancaster: Lancaster, UK. ISBN – 978-0-70442-950-5. Available at Liveable Cities: https://liveablecities.org.uk/sites/default/files/outcome_downloads/littlebookofcirculareconomyincities.pdf.

[2] Palafox-Alcantar, P.G.; Hunt, D.V.L.; and Rogers, C.D.F. 2019. A Game Theory Approach to Encourage Stakeholder Cooperation Towards a Circular Economy Waste Management in Cities. Abstract Proceedings of 2019 International Conference on Resource Sustainability - Cities (icRS Cities). Available at SSRN: https://ssrn.com/abstract=3408402.

[3] Palafox-Alcantar, P.G.; Hunt, D.V.L.; and Rogers, C.D.F. 2020. The complementary use of game theory for the circular economy: A review of waste management decision-making methods in civil engineering. Waste Management. 102, 598-612, Available at Elsevier: https://doi.org/10.1016/j.wasman.2019.11.014.

[4] Palafox-Alcantar, P.G.; Hunt, D.V.L.; and Rogers, C.D.F. 2020. A Hybrid Methodology to Study Stakeholder Cooperation in Circular Economy Waste Management of Cities. Energies. 13(7), 1845, Available at MDPI: https://doi.org/10.3390/en13071845.

[5] Palafox-Alcantar, P.G.; Hunt, D.V.L.; and Rogers, C.D.F. 2021. Current and Future Professional Insights on Cooperation towards Circular Economy Adoption. Sustainability. 13(18), 10436, Available at MDPI: https://doi.org/10.3390/su131810436.

Appendix B

Appendix B. Participant Information Sheet, Consent Form and Identification Sheet

Circular Economy in UK firms / University Students Participant Information Sheet

This questionnaire, *which can take up to 15 minutes to complete*, is part of a doctoral student research project. The study is being performed with UK firms / university students. The sections of this questionnaire aim to:

1) Measure circular economy awareness.
2) Find out about circular economy practices within the organisations.
3) Investigate the perceived barriers to implementing the circular economy.
4) Analyse the importance of the circular economy to organisations.
5) Explore the organisations' perceptions of other stakeholder groups.
6) Measure stakeholder groups' preferences of the indicators to evaluate circular economy scenarios.

This questionnaire has been reviewed and received approval from the University of Birmingham Ethical Review Committee (ERN_19-0203A). The results might be published through presentations, journal articles and a doctoral thesis. ***Access to the data from the study will be restricted to the student and supervisors only. Information identifying the respondents or organisations will not be disclosed under any circumstances.***

The questionnaire does not require the respondents to reveal any ethically or commercially sensitive information and the organisations and individuals will remain confidential in the research outputs. Furthermore, to prevent the risk of responses being linked back to participants, any revealing quotes will be excluded from the outputs.

Benefits to you for participating

The outcomes of this survey will be shared with you in the form of a report. Furthermore, you may find that this questionnaire broadens your perspective and raises your awareness of the benefits of the circular economy. We will also provide you with insights on how to generate better (stronger, more diverse) business models. After completion of the questionnaire, a printed copy of the 'Little Book of Circular Economy in Cities' will be sent to you as a gesture of appreciation.

If you have any questions about this questionnaire or the wider research project, please contact:

Giovani Palafox-Alcantar
: [redacted]
: [redacted]

Prof Chris Rogers
: [redacted]
[redacted]

Dr Dexter Hunt
: [redacted]
[redacted]

Thank you for your time and participation

Circular Economy in UK firms / University Students Participant Consent Form

Before the questionnaire starts, it is necessary that you provide your consent for the following:

- I have received enough information about the study prior to responding to this questionnaire.
- I have understood the explanations provided and had all of my questions answered to my satisfaction.
- My participation is voluntary, and I am free to withdraw at any time without giving any reason.
- My identity and the organisation I represent remain confidential and will not be disclosed under any circumstances.
- It is perfectly acceptable to select the "I don't know" or "I'd rather not say" options without providing any explanation.
- I have the opportunity to request any data supplied to be destroyed and eliminated from the study up to two weeks after its collection, without any penalty.
- If I have any questions – before, during or after the study – I can always contact Pablo Giovani Palafox-Alcantar (the researcher responsible for the study) on:
  - ✉: [redacted] ✆: [redacted] and/or:
  - Prof Chris Rogers ✉: [redacted] [redacted]
  - Dr Dexter Hunt ✉: [redacted] [redacted]

Do you agree to take part in this questionnaire?

Yes ☐

No ☐

Please enter the following details for the response to this part of the questionnaire:

Name: ______________________

Signature: ____________________

Date of response: DD MM YYYY

Circular Economy in UK firms / University Students
Participant Identification

Please note this information is for the use of the researcher only. It will be kept confidential and under no circumstances will be revealed.

Participants will be assigned an ID number to keep their responses confidential, it has three elements:

1. The letter to identify the stakeholder group as follows:
   A. Company Please describe briefly: ____________________
   B. Academic Institution
   C. Local Government
   D. General Public
   E. Consultants/Externals
   F. Other(s) Please describe briefly: ____________________
2. A '1' for someone knowledgeable in Corporate Social Responsibility/Sustainability in the organisation, a '0' for someone else.
3. These 3 digits consist of the number of participation (between 01 – 999). This will be provided by the researcher, if not yet received please leave blank.

→ Please connect these elements with dashes. An example ID looks like this: A-1-001

Participant ID: _____ - _____ - __________

→ Please provide the following demographic details:

1) Please specify the name of the organisation you represent in this questionnaire:

______________________________ I'd rather not say ☐

2) Where is your organisation located?

______________________________ I'd rather not say ☐

3) What industry sector do you work in?

______________________________ I'd rather not say ☐

4) What is the main position you occupy in the organisation?

______________________________ I'd rather not say ☐

5) How long have you been in this position and organisation? __________ years/months

I'd rather not say ☐

6) What is the size of the organisation?

1 – independent	☐	From 50 to 249	☐
From 2 to 9	☐	250 and above	☐
From 10 to 49	☐	I'd rather not say	☐

Appendix C

Appendix C. Questionnaire

Circular Economy in UK firms / university students

Section 1: Circular economy awareness

1.1 How well do you understand the concept of 'circular economy'?

Very well 5 4 3 2 1 Not well at all

Never heard of it ☐

I don't know ☐

I'd rather not say ☐

1.2 Do you agree with the following statement?

The 'circular economy' is just another word for reducing, reusing and recycling materials.

Strongly agree 5 4 3 2 1 Strongly disagree

I don't know ☐

I'd rather not say ☐

1.3 Which of the following principles are key to the 'circular economy'? Please tick all that apply:

Close material loops	☐	Renewable energy use	☐
Reduce	☐	Build resilience	☐
Reuse	☐	Design out waste	☐
Recycle	☐	Share resources	☐
Systems thinking	☐	Increase exchange	☐
I don't know	☐		
I'd rather not say	☐		

Other (please specify) ________________________________

Section 2: Circular economy practices

2.1 Please rank the following according to your organisation's case: ***The organisation / discipline (future career) I represent is implementing / not yet considering implementing…***

	Implementing successfully				Not considering it yet	I don't know	I'd rather not say
Reducing energy	5	4	3	2	1	☐	☐
Reducing material consumption	5	4	3	2	1	☐	☐
Reducing pollutant emissions	5	4	3	2	1	☐	☐
Reducing wastes	5	4	3	2	1	☐	☐
Taking back products from consumers after the end of their functional life	5	4	3	2	1	☐	☐
Taking back products from consumers after the end of their usage	5	4	3	2	1	☐	☐
Remanufacturing products	5	4	3	2	1	☐	☐
Recycling materials	5	4	3	2	1	☐	☐
Refurbishing products	5	4	3	2	1	☐	☐
Reusing energy and/or water across the value chain	5	4	3	2	1	☐	☐
Cascading use of components and materials	5	4	3	2	1	☐	☐
Designing products for reduced consumption of material/energy	5	4	3	2	1	☐	☐
Designing products for reuse, recycle and/or recovery of material/component	5	4	3	2	1	☐	☐
Designing process for minimisation of waste	5	4	3	2	1	☐	☐
Selecting suppliers using environmental criteria	5	4	3	2	1	☐	☐
Using renewable energy/material in the production process	5	4	3	2	1	☐	☐
Cooperating with other firms to establish eco-industrial chains	5	4	3	2	1	☐	☐
Adopting a leasing or service-based marketing strategy	5	4	3	2	1	☐	☐
Targeting "green" segments of the market	5	4	3	2	1	☐	☐
Green packaging	5	4	3	2	1	☐	☐
Including environmental factors in the internal performance evaluation system	5	4	3	2	1	☐	☐
Environmental auditing programs such as ISO 14000 certification	5	4	3	2	1	☐	☐
Cross-functional cooperation for environmental improvements	5	4	3	2	1	☐	☐
Eco-labelling of products	5	4	3	2	1	☐	☐
Special training for workers on environmental issues	5	4	3	2	1	☐	☐

Section 3: Circular economy barriers to implementation

Please rank the following barriers according to their level of importance to overcome to your organisation/discipline (future career): Being 5 the most pressing barrier and 1 the least pressing barrier

3.1 Cultural barriers (lack of awareness and/or engagement):	Most				Least	I don't know	I'd rather not say
Hesitant entrepreneurship due to high uncertainty	5	4	3	2	1	☐	☐
Insufficient cooperation in the value chain	5	4	3	2	1	☐	☐
Lacking consumer awareness and interest	5	4	3	2	1	☐	☐
Operating in a linear system	5	4	3	2	1	☐	☐
Other (please specify)________________________________	5	4	3	2	1	☐	☐

3.2 Regulatory barriers (lack of supporting policies):	Most				Least	I don't know	I'd rather not say
Limited regulation of circular economy procurement practices	5	4	3	2	1	☐	☐
Hindering laws and regulations	5	4	3	2	1	☐	☐
Lack of global consensus	5	4	3	2	1	☐	☐
Other (please specify) ________________________________	5	4	3	2	1	☐	☐

3.3 Market barriers (lack of economic viability):	Most				Least	I don't know	I'd rather not say
Low virgin material prices	5	4	3	2	1	☐	☐
Lack of circular products/services standardisation	5	4	3	2	1	☐	☐
High upfront investment costs	5	4	3	2	1	☐	☐
Limited financial support for circular business models	5	4	3	2	1	☐	☐
Other (please specify)________________________________	5	4	3	2	1	☐	☐

3.4 Technological barriers (lack of (proven) technology):	Most				Least	I don't know	I'd rather not say
Limited ability to deliver high quality remanufactured products	5	4	3	2	1	☐	☐
Limited circular designs	5	4	3	2	1	☐	☐
Too few large-scale demonstration projects	5	4	3	2	1	☐	☐
Lack of data	5	4	3	2	1	☐	☐
Other (please specify)________________________________	5	4	3	2	1	☐	☐

Section 4: Circular economy importance

4.1 How important is adopting circular economy principles in your organisation/discipline (future career)?

Very important 5 4 3 2 1 Not important at all

I don’t know ☐

I’d rather not say ☐

4.2 What do the components from the waste generated in your organisation represent to you?

Discards to dispose of in landfill ☐

Materials to recycle ☐

Waste to incinerate ☐

By-products valuable to others ☐

Hazardous materials to manage carefully ☐

I don’t know ☐

I'd rather not say ☐

Other (please specify) ________________________________

4.3. Which of the following do you think would enable your organisation to transition to a more circular economy approach? Please indicate all that apply

Limited resource supply ☐

Increasing of future profits ☐

Sustainable business strategy ☐

Entering new markets ☐

Public opinion ☐

Energy savings ☐

Fluctuating resource prices ☐

Enforcements by law ☐

Keeping up with competitors ☐

Reduce waste ☐

Avoid landfill ☐

Decrease costs ☐

I don’t know ☐

I'd rather not say ☐

Other (please specify) ________________________________

Section 5: Perceptions on other stakeholder groups

Studying the organisations' perceptions of other stakeholders is valuable to understand the potential to cooperate, the level of trust in the coalition and the willingness to share benefits and costs.

5.1 Please indicate to what extent you agree or disagree with the following statement:
It is essential to trust other stakeholders when cooperating in the implementation of the circular economy principles:

Strongly agree 5 4 3 2 1 Strongly disagree

I don't know ☐

I'd rather not say ☐

5.2 Who among the following actors have to take part in the siting of a new waste management facility in the city? Please tick all that apply:

Researchers	☐	I don't know	☐
Private investors	☐	I'd rather not say	☐
Entrepreneurs	☐		
Local politicians	☐		
Local policymakers	☐		
Local authorities	☐		
Land planners	☐		
Transport planners	☐		
Regulatory bodies (emit permits/licenses)	☐		
Waste management operators	☐		
Technology suppliers	☐		
Local inhabitants/citizens	☐		
External consultants	☐		

Other (please specify) ____

5.3 Of the following, which stakeholders are the most/least powerful in the circular economy implementation process? Is their power increasing or decreasing?
Please circle the stakeholders' power of negotiation (on a 5-point scale, being 5 the most powerful and 1 the least powerful; and 5 if their power is increasing and 1 if it is decreasing):

	Most				Least	Increasing				Decreasing	I don't know	I'd rather not say
Companies	5	4	3	2	1	5	4	3	2	1	☐	☐
Academic Institutions	5	4	3	2	1	5	4	3	2	1	☐	☐
Local Government	5	4	3	2	1	5	4	3	2	1	☐	☐
General Public	5	4	3	2	1	5	4	3	2	1	☐	☐
Consultants/Externals	5	4	3	2	1	5	4	3	2	1	☐	☐
Other (please specify)	5	4	3	2	1	5	4	3	2	1	☐	☐

5.4 What barriers to cooperation between stakeholders (i.e., to reach agreements) would you expect in the circular economy transition?

5.5 Likewise, what would facilitate achieving cooperation between stakeholders (i.e., to reach agreements) in the circular economy transition?

Section 6: Stakeholder groups preferences

Circular economy adoption presents many challenges and costs, but it also offers a number of benefits. This section aims to understand what the preferences of the stakeholder groups are, to such indicators from circular economy related scenarios.

For the following questions please consider the table below:

Indicators selected for the evaluation of circular economy scenarios in the city.

No.	Indicator	Unit	Description of benefit/cost	Objective
1	Investment cost	£	It measures the amount of £million invested in a project. It comprises of all costs relating to the purchase of mechanical equipment, technological installations, construction costs, engineering services, etc.	Minimise
2	GVA[15] impact	£ / yr	It measures the annual gross value-added in total. It measures the total annual added production value at the end of the year.	Maximise
3	Payback	months	It indicates the period of time required for a project to recover the money invested. It refers to the period of time required for the return on an investment to "repay itself".	Minimise
4	Carbon emissions mitigation	[16]CO_2 tonnes/yr	*Proxy* variable of low carbon fuels usage. It reflects the amount of CO_2 emissions that are reduced / saved.	Maximise
5	MSW[17] generation reduction	%	It measures the total amount of MSW generated in comparison to a previous year, and the reduction in waste produced.	Maximise
6	Recycling rate of MSW	%	A basic circular economy indicator. It measures the recycling rate of MSW, and the level of materials re-used and recycled in the city.	Maximise
7	Landfill rate of MSW	%	It measures the rate of MSW that is not diverted from disposal in the city. An alternative that must be completely discarded in a future circular economy.	Minimise
8	Jobs creation	#	The most used social indicator. It measures new jobs created per annum.	Maximise
9	Public awareness and satisfaction	%	It is important to treat citizens as both, stakeholders and customers in the MSWM[18] process. Social acceptability expresses the overview of opinions related to the MSWM system by the local population.	Maximise

[15] GVA – Gross Value Added
[16] CO_2 – Carbon Dioxide
[17] MSW – Municipal Solid Waste
[18] MSWM – Municipal Solid Waste Management

6.1 After having a look at the table, would you rule out any of the indicators proposed to evaluate circular economy scenarios in the city? If so, please mention them and briefly explain why they should be eliminated. If more space is needed, please continue on a blank page and attach.

I'd rather not say ☐ I don't know ☐

6.2 Alternatively, are there any other relevant indicators that you would consider including to evaluate circular economy scenarios in the city? If so, please mention them and also consider them for the next questions. If more space is needed, please continue on a blank page and attach.

I'd rather not say ☐ I don't know ☐

Please bear in mind that it is important that you attempt to respond to the following questions from a *stakeholder representative point of view*. Please take as much time as needed to fill in the tables.

6.3 Please fill in the next table following the drawing up instructions below:

- Distribute the *9* indicators among *9* levels of relevancy, in order of decreasing relevance to your organisation.
- The items on the same level have the same relevance.
- Assigning a 9 to the indicator means it is indispensable and assigning a 1 means the indicator is irrelevant.
- Please bear in mind to pairwise compare the items, i.e., avoid any inconsistencies, judge which item is preferred, or whether or not the items compared are identical.
- Warning: do NOT repeat the same number more than once.
- A worked example is provided below.

7								
9								
2	**4**							
6								
1								
5	**3**							
8								

[Example]
1) Investment cost
2) GVA impact
3) Payback
4) Carbon emissions mitigation
5) MSW generation reduction
6) Recycling rate of MSW
7) Landfill rate of MSW
8) Jobs creation
9) Public awareness and satisfaction

Benefits / Costs
1) Investment cost
2) GVA impact
3) Payback
4) Carbon emissions mitigation
5) MSW generation reduction
6) Recycling rate of MSW
7) Landfill rate of MSW
8) Jobs creation
9) Public awareness and satisfaction

Appendix D

Appendix D. Scenarios Detailed Description

Scenario	Description
Market Forces (MF)	This scenario would resemble a world not so very different to the current one. There are little proactive actions to prevent overpopulation or reduce demands. This scenario places social and environmental concerns at a second priority. It has sometimes been referred to as a 'Business-as-usual' scenario (Hunt et al., 2011). There is high uncertainty on resource security and ecological resilience. Maintaining social and economic sustainability is a major challenge in a world of deep inequalities (Hunt et al., 2012a). Materialism and individualism shape economic development and policy is more market led (Boyko et al., 2012). This world allows free market economics to permit unchecked user behaviour and technological efficiency to decade (Hunt et al., 2013). For *Municipal Solid Waste (MSW),* this scenario does not recognise remaining value in waste and the missed opportunities from managing it appropriately. Costs of treating waste remain constant and new technologies are barely developed. The generation rates increase steadily as consumerism drives the world, recycling is seen as a third available option after landfill and incineration. The jobs that MSW management could create are limited to the usual existing and no innovation is neither demanded by the general public nor boosted by governments, but corporations successfully lobby for more relaxed regulations.
Policy Reform (PR)	This scenario is driven by an active government concerned over social conflict, economic instability and environmental deterioration. Consumer behaviour changes are induced by varied social and environmental goals which are highly enforced by strict policy (Hunt et al., 2011). Consumerist values remain largely untouched whilst massive government-led efforts are made to achieve sustainable changes (Hunt et al., 2012a). Strong policies emerge to deal with growing environmental and social consciousness, but such policies also slow trends towards inequalities that open markets can do little to reverse (Boyko et al., 2012). This world enforces technological efficiency improvement by strict policy but unchecked user behaviour persists (Hunt et al., 2013). For MSW, this means more recycling uptakes and higher landfill and incineration taxes. Despite government action to be more sustainable, people are less actively involved in decision-making about local waste management services because policy remains top-down and decisions are still mad by key and influential actors, rather than by the population majority. There is a rigorous approach towards reducing carbon emissions and complying with low MSW generation, landfill and higher recycling rates. Regarding new jobs creation, they would be directly related to the embracing of more sustainable waste management. Public awareness of these concerns would increase gradually however the acceptance of these changes by the general population would not be welcomed at first.

New Sustainability Paradigm (NSP)	This scenario is a 'great transition world' that thrives as a more huma global civilisation rather than locally. Sustainability is adopted willingly by consumers as part of their widely accepted ethos (Hunt et al., 2011). The new mindset is based on human solidarity, ecological resilience, reduced consumerism, universal access to education and health care services, and improved wellbeing. The improves social cohesion minimises conflict; the world is able to confront crises with strong institutions for cooperation and reconciliation (Hunt et al., 2012a). Society is more equitable and access to public green space is high. Due to deep ecological beliefs, strong regulation and a pull from society for much more renewable resources use, there is a high uptake of resource-efficient technologies (Boyko et al., 2012). In this scenario strict policies are rarely required as a driving force for change, individuals and companies change their behaviour and proactively adopt efficient technologies (Hunt et al., 2013). For MSW, investment in long-term sustainable alternatives is not skimped, carbon emissions are a major concern and efforts are directed towards minimising them. Reducing waste generation is well planned because it is acknowledged to help minimise its landfill and incineration. Balanced priorities result in skilled jobs being created and the general population is self-aware of the sustainability issues and proactively pushes decisions to be made in the interest of sustainability, a bottom-up approach.
Fortress World (FW)	In this scenario privileged individuals, the *'haves'*, live inside enclaves that operate similarly to those under MF. The outsiders, the *'have-nots'* have limited resources, capital and access to wellbeing, they need to preserve the scarce resources through a steep change in their behaviour (Hunt et al., 2013). This scenario is recognised as an extreme world where authoritarian response to threat is adopted. A few powerful elites live inside a 'fortress' which hold most of the wealth and wellbeing amenities. An impoverished majority live outside the fortress in unsustainable conditions leading to a world of 'gates' and 'ghettoes' (Hunt et al., 2011). This is a world in which wealth, resources and governance systems erode and alliances form to protect the interests of the elites in their bubbles of privilege. Local pollution within the fortress is reduced through increased efficiency and recycling. Pollution is dispatched outside, contributing further to the extreme environmental deterioration from the unsustainable practices (Hunt et al., 2012a). Planning policies serve to safeguard the resources and quality of life of the privileged rich and to segregate systematically the poorer (Boyko et al., 2012). For MSW, spending on new technologies and infrastructure is only reserved to the privileged, thus resulting in lower profits but extremely unequally distributed in favour of the rich. Carbon emissions are not on the high agenda of the outside population as they cannot afford to adopt cleaner or more sustainable alternatives, thus there is not a major overall emissions reduction. This scenario presents the worst indicator performances for MSW as waste is pushed out form the fortress and barely recovered or reused. Civic activism is not high on the agenda, as the opinion and satisfaction of the general public are not widely considered.

Appendix E

Appendix E. Excel-Based Adapted Tool Manual

This manual intends to show the general overview of the adapted Excel-based tool, how it functions, and the outputs produced, which are then the input for the *Game Theory (GT)* analysis, i.e., *Nash Equilibrium* using open-source software Gambit, and the *Shapley Value* using the R programming package *'GameTheory'* (Cano-Berlanga et al., 2017).

It is paramount to acknowledge that the tool is an adapted and enhanced version of the work from Goepel (2018). The main modifications were as follows; the steps mentioned herein refer to those shown in the manual below:

- It is now possible to insert up to four scenarios, and their performance (Step 1), the tool will automatically rescale them to the desired range value (Step 2).
- The scenarios are also now weighted using the same *Analytical Hierarchy Process (AHP)* method. To do this, the tool added new worksheets. This yields the objective weightings vectors for scenarios (Output 1).
- To calculate the subjective weightings, it is no longer necessary to pairwise compare each of the indicators. By merely introducing the ranking value given, the comparisons are automatically performed (Step 3).
- The results for the final weightings divide into objective and subjective, and automatically newly produced tables and graphs show a better comparison of results (Output 2).
- The tool calculates the aggregated *Preferability Index (PI)* for each stakeholder group from the previous objective and subjective weightings. It also produces a graph to compare the indexes (Output 3).
- The tool calculates the payoffs to transfer to the open-source software Gambit to perform the non-cooperative game theory analysis, i.e., the *Nash Equilibrium* analysis (Step 4).
- The tool calculates all the possible formed coalitions for the *Shapley Value* analysis through the R programming package *'Game Theory'* (Steps 5 and 6).
- Finally, the tool produces a graph that compares the benefit allocation suggestions for the coalition formed (Step 7).

Excel-Based (Analytical Hierarchy Process) Adapted Tool

Overview Manual

Step 1 – Type selected indicators and input scenarios performance

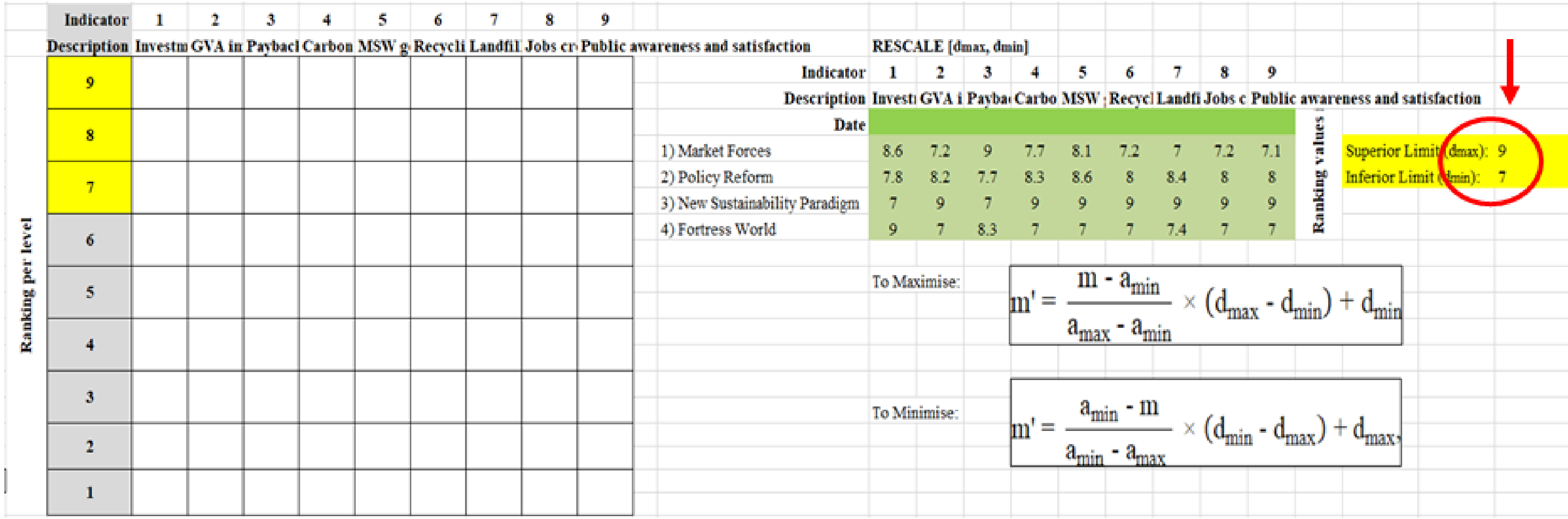
In the 'SCENARIOS' sheet type the selected indicators, description, objective (i.e., maximise or minimise) and their units[1].
Input the suggested performance under *Market Forces, Policy Reform, New Sustainability Paradigm* and *Fortress World* columns.

Type	No.	Indicator	Description of indicator	Objective of indicator	Scenario 1 *Market Forces*	Scenario 2 *Policy Reform*	Scenario 3 *New Sustainability Paradigm*	Scenario 4 *Fortress World*	Scenario 2030 *TODAY (baseline)*	Unit
	1	Investment cost	The most used economic indicator. It measures the amount of million GBP invested in a project. It comprises of all costs relating to: the purchase of mechanical equipment, technological installations, construction of roads and connections, engineering services, and other incidental construction work. Does not include maintenance or labour costs.	Minimise	46.4	53.8	60.6	43.1		£M / yr
	2	GVA impact	It measures the annual gross value-added in total if pursuing a target scenario. It measures the total annual added production value at the end of the year.	Maximise	12.5	15.0	17.0	12.0		£M / yr
	3									
	4									
	5									
	6									
	7									
	8									
	9									

[1] The tool currently allows for a maximum of nine indicators

Step 2 – Insert the new limits to rescale the performance of the scenarios

In the ‘SC_AHPchart’ sheet introduce the superior and inferior limits for the performance of the scenarios to be rescaled[2].



Indicator	1	2	3	4	5	6	7	8	9
Description	Investi	GVA i	Payba	Carbo	MSW	Recycl	Landfi	Jobs c	Public awareness and satisfaction
Date									
1) Market Forces	8.6	7.2	9	7.7	8.1	7.2	7	7.2	7.1
2) Policy Reform	7.8	8.2	7.7	8.3	8.6	8	8.4	8	8
3) New Sustainability Paradigm	7	9	7	9	9	9	9	9	9
4) Fortress World	9	7	8.3	7	7	7	7.4	7	7

Superior Limit (dmax): 9
Inferior Limit (dmin): 7

To Maximise:

$$m' = \frac{m - a_{min}}{a_{max} - a_{min}} \times (d_{max} - d_{min}) + d_{min}$$

To Minimise:

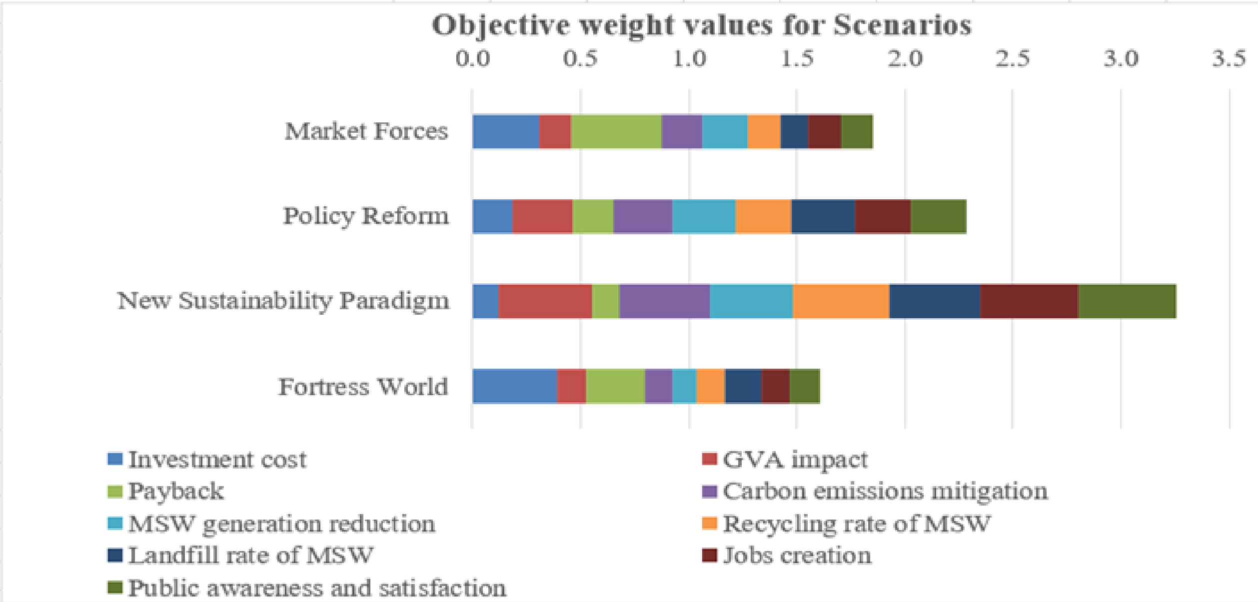
$$m' = \frac{a_{min} - m}{a_{min} - a_{max}} \times (d_{min} - d_{max}) + d_{max}$$

[2] The tool automatically rescales the previously provided values to the new values within the new limits [d_{max}, d_{min}]

<u>Output 1</u> – Objective weights for scenarios

In the 'SC_WeightVectors' sheet, the tool will produce the vectors of objective weights for each scenario and their inconsistency ratios[3].

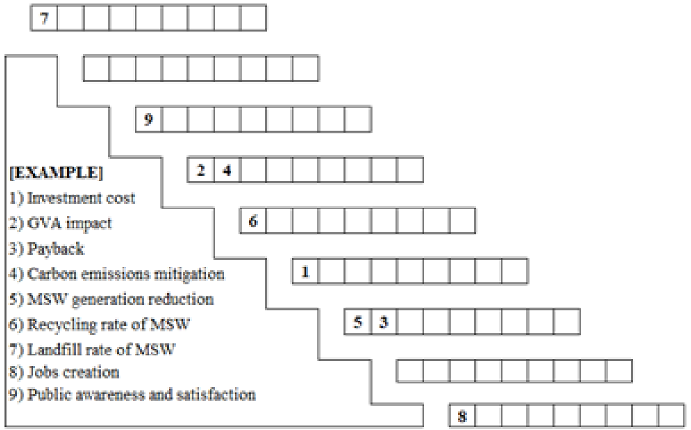
No.	Scenarios	Indicators											
		Investm	GVA im	Paybacl	Carbon	MSW ge	Recyclir	Landfill	Jobs cr	Public a	TOTAL	(%)	Rank
1	Market Forces	0.3047	0.1509	0.4182	0.1860	0.2108	0.1552	0.1253	0.1552	0.1479	1.854	20.602	3
2	Policy Reform	0.1853	0.2781	0.1860	0.2736	0.2934	0.2580	0.2939	0.2580	0.2606	2.287	25.412	2
3	New Sustainability Paradigm	0.1167	0.4387	0.1221	0.4182	0.3825	0.4511	0.4200	0.4511	0.4534	3.254	36.154	1
4	Fortress World	0.3933	0.1323	0.2736	0.1221	0.1132	0.1357	0.1607	0.1357	0.1381	1.605	17.832	4
	TOTAL	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	9.000	100.000	
	INCONSISTENCY RATIO	0.39%	0.43%	0.46%	0.46%	0.35%	0.44%	0.40%	0.44%	0.45%			



[3] The tool automatically produces a graph to compare each indicator between scenarios.

Step 3 – Insert the ranking values that each respondent assigned to the indicators

In the 'SH_AHPchart' sheet[4], the tool needs the manual introduction of the ranking value in the "priority scale" for each respondent[5].



Stakeholder Group		A1	A2	A3	B1	B2	C1	C2	C3	D1	D2	D3	E1	E2	E3
Participant ID		A-1-04-	A-1-05-	A-1-06-	B-1-01-	B-0-10-	C-0-03-	C-1-11-	C-1-12-	D-1-07-	D-0-13-	D-0-14-	E-1-02-	E-1-08-	E-1-09-
Ranking per level	9	1, 3	3	2, 3	5	5	2	8	5, 6, 8	1, 3	2, 8	8	2	1, 4	2, 4, 9
	8	8	1, 9	1, 4, 5, 6, 7	6, 7	4, 6, 7	8	2	1, 9	4, 9	4, 9	2	1	2, 5, 8	5, 6, 8
	7	9	2	8	3	1, 9	1	1, 4, 7	4, 7		5, 6, 7	4, 9	3	6	1, 3
	6	2			4		4	9, 5, 6	2, 3		1	6, 1, 3		3, 7	
	5	4, 5, 6, 7			1	2, 8	9	3			3	5	8, 9	9	
	4		4, 5, 6, 7		8	3	3					7	4		
	3				9		5, 6, 7			2, 5, 6, 7			5, 6, 7		7
	2			9	2					8					
	1		8												

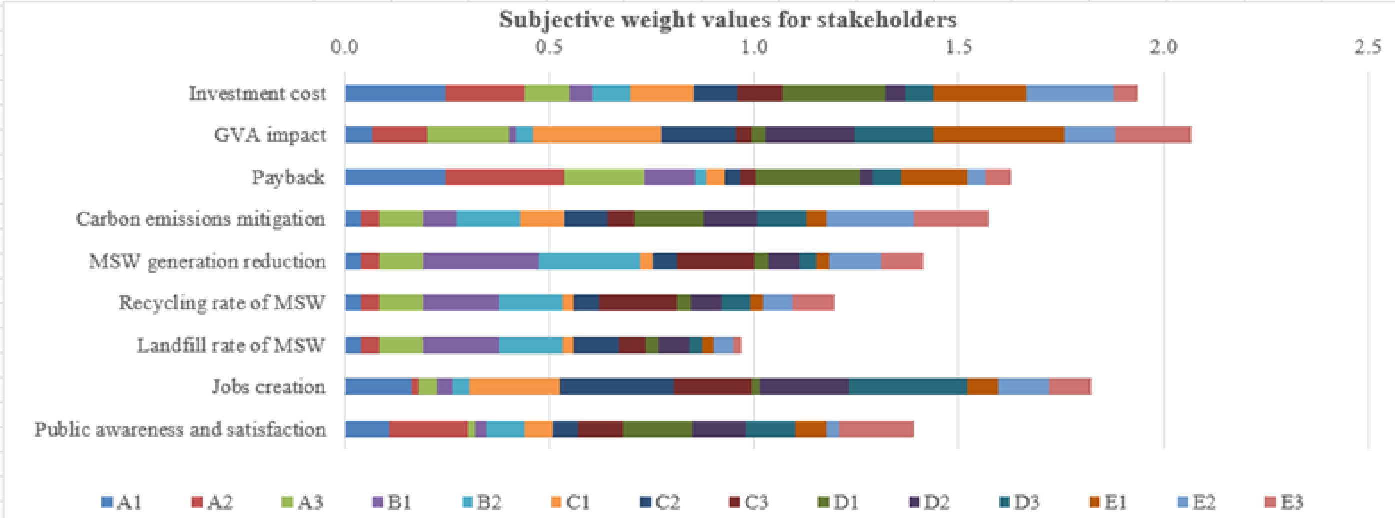
Stakeholder Group	A1	A2	A3	B1	B2	C1	C2	C3	D1	D2	D3	E1	E2	E3							
Participant ID															15	16	17	18	19	20	
Date																					
1) Investment cost	9	8	8	5	7	7	7	8	9	6	6	8	9	7							Ranking values in "priority scale"
2) GVA impact	6	7	9	2	5	9	8	6	3	9	8	9	8	9							
3) Payback	9	9	9	7	4	4	5	6	9	5	6	7	6	7							
4) Carbon emissions mitigation	5	4	8	6	8	6	7	7	8	8	7	4	9	9							
5) MSW generation reduction	5	4	8	9	9	3	6	9	3	7	5	3	8	8							
6) Recycling rate of MSW	5	4	8	8	8	3	6	9	3	7	6	3	7	8							
7) Landfill rate of MSW	5	4	8	8	8	3	7	7	3	7	4	3	6	3							
8) Jobs creation	8	1	6	4	5	8	9	9	2	9	9	5	8	8							
9) Public awareness and satisfaction	7	8	2	3	7	5	6	8	8	8	7	5	5	9							

[4] The tool currently allows for a maximum of 20 respondents.
[5] For example, for respondent E2 indicators 1 and 4 received the ranking value of 9.

Output 2a – Subjective weights for stakeholders

In the ‘SH_WeightVectors’ sheet, the tool will produce the vectors of subjective weights for each respondent and their inconsistency ratios[6].

No.	Indicator	Stakeholders														TOTAL	(%)	Rank
		A1	A2	A3	B1	B2	C1	C2	C3	D1	D2	D3	E1	E2	E3			
1	Investment cost	0.2465	0.1946	0.1087	0.0564	0.0920	0.1540	0.1076	0.1108	0.2518	0.0458	0.0696	0.2282	0.2123	0.0607	1.939	13.850	2
2	GVA impact	0.0694	0.1335	0.1976	0.0200	0.0392	0.3132	0.1825	0.0398	0.0335	0.2175	0.1928	0.3194	0.1254	0.1832	2.067	14.764	1
3	Payback	0.2465	0.2884	0.1976	0.1232	0.0269	0.0465	0.0369	0.0398	0.2518	0.0310	0.0696	0.1614	0.0466	0.0607	1.627	11.620	4
4	Carbon emissions mitigation	0.0412	0.0429	0.1087	0.0832	0.1535	0.1052	0.1076	0.0650	0.1701	0.1311	0.1197	0.0483	0.2123	0.1832	1.572	11.230	5
5	MSW generation reduction	0.0412	0.0429	0.1087	0.2799	0.2503	0.0296	0.0600	0.1897	0.0335	0.0754	0.0427	0.0304	0.1254	0.1032	1.413	10.091	6
6	Recycling rate of MSW	0.0412	0.0429	0.1087	0.1858	0.1535	0.0296	0.0600	0.1897	0.0335	0.0754	0.0696	0.0304	0.0751	0.1032	1.199	8.561	8
7	Landfill rate of MSW	0.0412	0.0429	0.1087	0.1858	0.1535	0.0296	0.1076	0.0650	0.0335	0.0754	0.0291	0.0304	0.0466	0.0191	0.968	6.917	9
8	Jobs creation	0.1642	0.0173	0.0446	0.0386	0.0392	0.2217	0.2777	0.1897	0.0220	0.2175	0.2872	0.0756	0.1254	0.1032	1.824	13.027	3
9	Public awareness and satisfaction	0.1087	0.1946	0.0169	0.0271	0.0920	0.0707	0.0600	0.1108	0.1701	0.1311	0.1197	0.0756	0.0310	0.1832	1.391	9.939	7
	TOTAL	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	14.000	100.000	
	INCONSISTENCY RATIO	1.172%	2.239%	0.688%	2.467%	1.103%	2.664%	0.861%	0.543%	1.327%	0.808%	1.346%	2.576%	0.807%	0.706%			

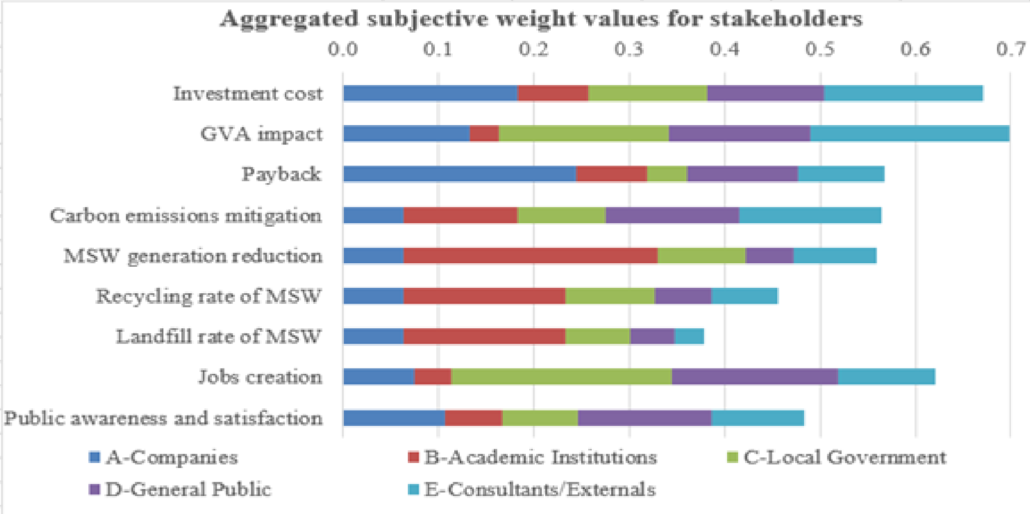


[6] The tool automatically produces a graph to compare each respondent between indicators.

Output 2b – Aggregated subjective weights for stakeholder groups

In the 'SH_WeightVectors' sheet, the tool will also produce the vectors of aggregated subjective weights for each stakeholder group[7].

		Stakeholder Group				
	Indicator	A-Companies	B-Academic Institutions	C-Local Government	D-General Public	E-Consultants/Externals
1	Investment cost	0.1833	0.0742	0.1241	0.1224	0.1671
2	GVA impact	0.1335	0.0296	0.1785	0.1479	0.2094
3	Payback	0.2442	0.0751	0.0411	0.1175	0.0896
4	Carbon emissions mitigation	0.0643	0.1183	0.0926	0.1403	0.1479
5	MSW generation reduction	0.0643	0.2651	0.0931	0.0505	0.0864
6	Recycling rate of MSW	0.0643	0.1696	0.0931	0.0595	0.0696
7	Landfill rate of MSW	0.0643	0.1696	0.0674	0.0460	0.0320
8	Jobs creation	0.0753	0.0389	0.2297	0.1755	0.1014
9	Public awareness and satisfaction	0.1067	0.0595	0.0805	0.1403	0.0966
	TOTAL	1.0000	1.0000	1.0000	1.0000	1.0000

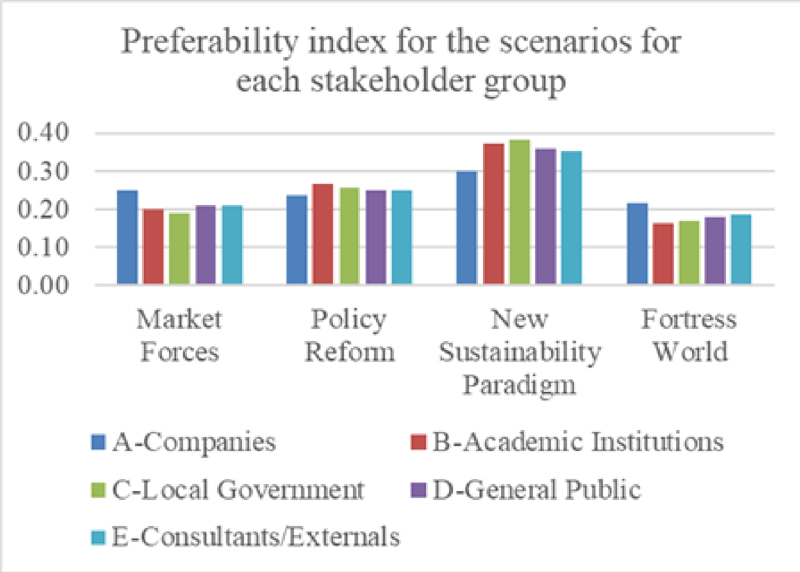


[7] The tool automatically produces a graph to compare each stakeholder group between indicators.

Output 3 – Aggregated subjective weights for stakeholder groups

In the 'Preferability Index' sheet, the tool will automatically produce the preferability indexes for each stakeholder group[8].

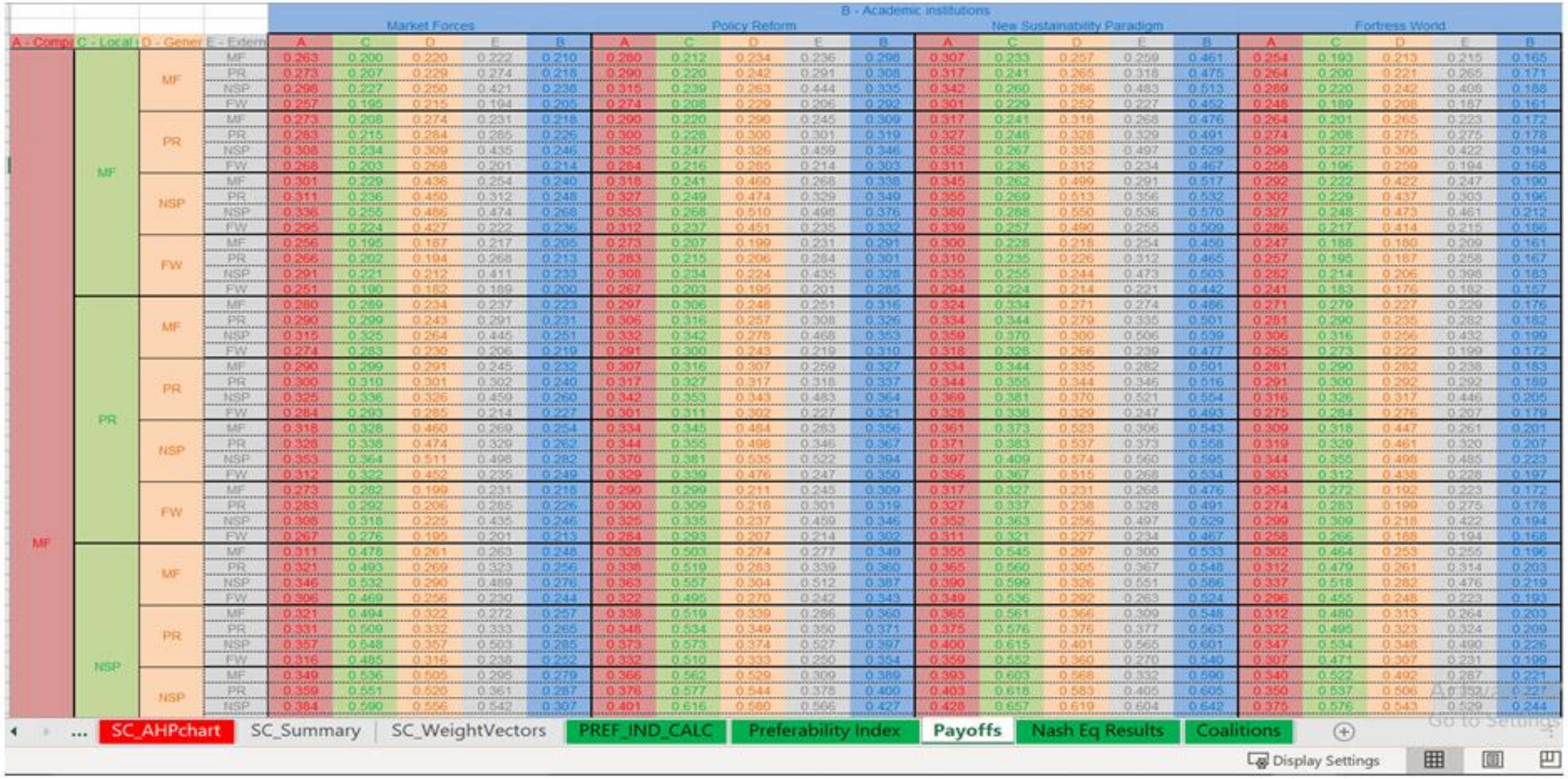
Stakeholder Group	Scenarios			
	MF	PR	NSP	FW
A	0.249 (2nd)	0.235 (3rd)	0.299 (1st)	0.215 (4th)
B	0.199 (3rd)	0.265 (2nd)	0.374 (1st)	0.162 (4th)
C	0.189 (3rd)	0.257 (2nd)	0.382 (1st)	0.171 (4th)
D	0.205 (3rd)	0.249 (2nd)	0.355 (1st)	0.178 (4th)
E	0.210 (3rd)	0.250 (2nd)	0.350 (1st)	0.186 (4th)



[8] The tool automatically produces a graph to compare each stakeholder group preferences.

Step 4 – Transfer the payoffs data to perform the game theory analysis

In the 'Payoffs' sheet, the tool calculates all the payoffs for the stakeholder groups for the non-cooperative game theory analysis[9]. These data need to be transferred to the open-source Gambit software available at http://www.gambit-project.org/.



[9] For this example, the total number of payoffs calculated was five (one for each stakeholder group) per combined preference (i.e. 1,024 × 5 = 5,120 payoffs).

Step 5 – Introduce the Nash equilibrium results

In the 'Coalitions' sheet, introduce the Nash Equilibrium results in the yellow cells from the Gambit software. The tool will calculate all the possible formed coalitions.

						0.530	0.661	0.676	0.637	0.622								
						Payoffs PI_"NSP,NSP,NSP,NSP,NSI							Average Payoffs "φ"_"NSP,NSP,NSI					
	Stakeholders					A	B	C	D	E			A	B	C	D	E	
Coalition Name	A	B	C	D	E	NSP	NSP	NSP	NSP	NSP	Σ	Π̄	NSP	NSP	NSP	NSP	NSP	Σ
A	A					0.530	0	0	0	0	0.530	0.530	0.281	0	0	0	0	0.281
B		B				0	0.661	0	0	0	0.661	0.661	0	0.437	0	0	0	0.437
C			C			0	0	0.676	0	0	0.676	0.676	0	0	0.458	0	0	0.458
D				D		0	0	0	0.637	0	0.637	0.637	0	0	0	0.406	0	0.406
E					E	0	0	0	0	0.622	0.622	0.622	0	0	0	0	0.386	0.386
AB	A	B				0.530	0.661	0	0	0	1.191	0.596	0.315	0.394	0	0	0	0.709
AC	A		C			0.530	0	0.676	0	0	1.206	0.603	0.319	0	0.408	0	0	0.727
AD	A			D		0.530	0	0	0.637	0	1.167	0.584	0.309	0	0	0.372	0	0.681
AE	A				E	0.530	0	0	0	0.622	1.151	0.576	0.305	0	0	0	0.358	0.663
BC		B	C			0	0.661	0.676	0	0	1.338	0.669	0	0.442	0.452	0	0	0.894
BD		B		D		0	0.661	0	0.637	0	1.299	0.649	0	0.429	0	0.414	0	0.843
BE		B			E	0	0.661	0	0	0.622	1.283	0.642	0	0.424	0	0	0.399	0.823
CD			C	D		0	0	0.676	0.637	0	1.314	0.657	0	0	0.444	0.419	0	0.863
CE			C		E	0	0	0.676	0	0.622	1.298	0.649	0	0	0.439	0	0.404	0.843
DE				D	E	0	0	0	0.637	0.622	1.259	0.630	0	0	0	0.401	0.391	0.792
ABC	A	B	C			0.530	0.661	0.676	0	0	1.867	0.622	0.330	0.412	0.421	0	0	1.163
ABD	A	B		D		0.530	0.661	0	0.637	0	1.828	0.609	0.323	0.403	0	0.389	0	1.115
ABE	A	B			E	0.530	0.661	0	0	0.622	1.813	0.604	0.320	0.400	0	0	0.376	1.096
ACD	A		C	D		0.530	0	0.676	0.637	0	1.844	0.615	0.326	0	0.416	0.392	0	1.134
ACE	A		C		E	0.530	0	0.676	0	0.622	1.828	0.609	0.323	0	0.412	0	0.379	1.114
ADE	A			D	E	0.530	0	0	0.637	0.622	1.789	0.596	0.316	0	0	0.380	0.371	1.067
BCD		B	C	D		0	0.661	0.676	0.637	0	1.975	0.658	0	0.435	0.445	0.420	0	1.300
BCE		B	C		E	0	0.661	0.676	0	0.622	1.959	0.653	0	0.432	0.442	0	0.406	1.280
BDE		B		D	E	0	0.661	0	0.637	0.622	1.920	0.640	0	0.423	0	0.408	0.398	1.229
CDE			C	D	E	0	0	0.676	0.637	0.622	1.936	0.645	0	0	0.436	0.411	0.401	1.248
ABCD	A	B	C	D		0.530	0.661	0.676	0.637	0	2.505	0.626	0.332	0.414	0.424	0.399	0	1.569
ABCE	A	B	C		E	0.530	0.661	0.676	0	0.622	2.489	0.622	0.330	0.412	0.421	0	0.387	1.550
ABDE	A	B		D	E	0.530	0.661	0	0.637	0.622	2.450	0.613	0.324	0.405	0	0.390	0.381	1.500
ACDE	A		C	D	E	0.530	0	0.676	0.637	0.622	2.465	0.616	0.326	0	0.417	0.393	0.383	1.519
BCDE		B	C	D	E	0	0.661	0.676	0.637	0.622	2.597	0.649	0	0.429	0.439	0.414	0.404	1.686
ABCDE	A	B	C	D	E	0.530	0.661	0.676	0.637	0.622	3.127	0.625	0.331	0.414	0.423	0.399	0.389	1.956

Step 6 – Transfer the total coalition values to perform the allocation method

In the ‘Coalitions’ sheet, the rightmost column is the total value of each coalition, which needs to be transferred to the R programming package ‘GameTheory’ available at https://cran.r-project.org/web/packages/GameTheory/index.html.

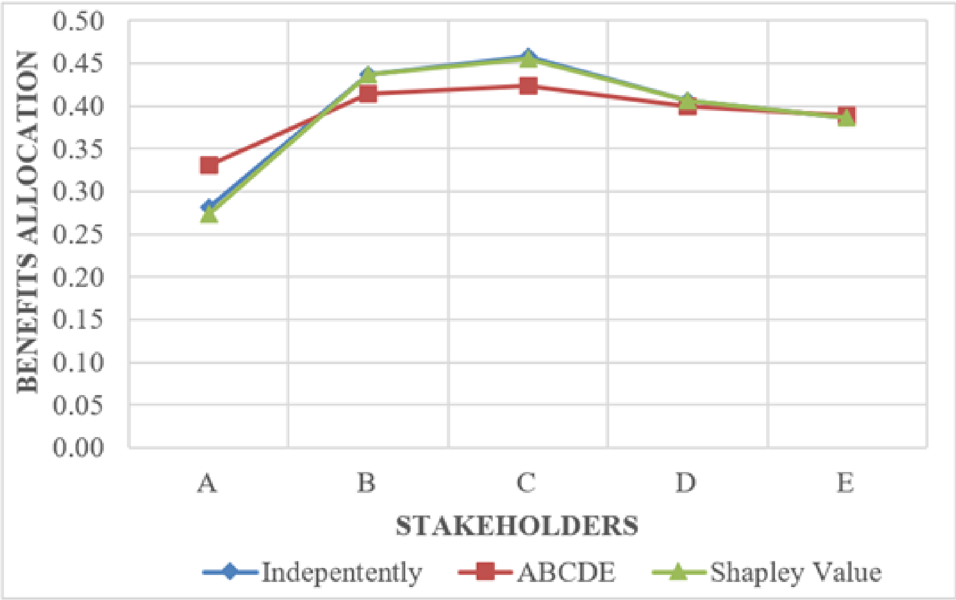
						0.530	0.661	0.676	0.637	0.622								
	Stakeholders					Payoffs PI "NSP,NSP,NSP,NSP,NSI							Average Payoffs "φ" "NSP,NSP,NSI					
						A	B	C	D	E			A	B	C	D	E	
Coalition Name	A	B	C	D	E	NSP	NSP	NSP	NSP	NSP	Σ	$\bar{\Pi}$	NSP	NSP	NSP	NSP	NSP	Σ
A	A					0.530	0	0	0	0	0.530	0.530	0.281	0	0	0	0	0.281
B		B				0	0.661	0	0	0	0.661	0.661	0	0.437	0	0	0	0.437
C			C			0	0	0.676	0	0	0.676	0.676	0	0	0.458	0	0	0.458
D				D		0	0	0	0.637	0	0.637	0.637	0	0	0	0.406	0	0.406
E					E	0	0	0	0	0.622	0.622	0.622	0	0	0	0	0.386	0.386
AB	A	B				0.530	0.661	0	0	0	1.191	0.596	0.315	0.394	0	0	0	0.709
AC	A		C			0.530	0	0.676	0	0	1.206	0.603	0.319	0	0.408	0	0	0.727
AD	A			D		0.530	0	0	0.637	0	1.167	0.584	0.309	0	0	0.372	0	0.681
AE	A				E	0.530	0	0	0	0.622	1.151	0.576	0.305	0	0	0	0.358	0.663
BC		B	C			0	0.661	0.676	0	0	1.338	0.669	0	0.442	0.452	0	0	0.894
BD		B		D		0	0.661	0	0.637	0	1.299	0.649	0	0.429	0	0.414	0	0.843
BE		B			E	0	0.661	0	0	0.622	1.283	0.642	0	0.424	0	0	0.399	0.823
CD			C	D		0	0	0.676	0.637	0	1.314	0.657	0	0	0.444	0.419	0	0.863
CE			C		E	0	0	0.676	0	0.622	1.298	0.649	0	0	0.439	0	0.404	0.843
DE				D	E	0	0	0	0.637	0.622	1.259	0.630	0	0	0	0.401	0.391	0.792
ABC	A	B	C			0.530	0.661	0.676	0	0	1.867	0.622	0.330	0.412	0.421	0	0	1.163
ABD	A	B		D		0.530	0.661	0	0.637	0	1.828	0.609	0.323	0.403	0	0.389	0	1.115
ABE	A	B			E	0.530	0.661	0	0	0.622	1.813	0.604	0.320	0.400	0	0	0.376	1.096
ACD	A		C	D		0.530	0	0.676	0.637	0	1.844	0.615	0.326	0	0.416	0.392	0	1.134
ACE	A		C		E	0.530	0	0.676	0	0.622	1.828	0.609	0.323	0	0.412	0	0.379	1.114
ADE	A			D	E	0.530	0	0	0.637	0.622	1.789	0.596	0.316	0	0	0.380	0.371	1.067
BCD		B	C	D		0	0.661	0.676	0.637	0	1.975	0.658	0	0.435	0.445	0.420	0	1.300
BCE		B	C		E	0	0.661	0.676	0	0.622	1.959	0.653	0	0.432	0.442	0	0.406	1.280
BDE		B		D	E	0	0.661	0	0.637	0.622	1.920	0.640	0	0.423	0	0.408	0.398	1.229
CDE			C	D	E	0	0	0.676	0.637	0.622	1.936	0.645	0	0	0.436	0.411	0.401	1.248
ABCD	A	B	C	D		0.530	0.661	0.676	0.637	0	2.505	0.626	0.332	0.414	0.424	0.399	0	1.569
ABCE	A	B	C		E	0.530	0.661	0.676	0	0.622	2.489	0.622	0.330	0.412	0.421	0	0.387	1.550
ABDE	A	B		D	E	0.530	0.661	0	0.637	0.622	2.450	0.613	0.324	0.405	0	0.390	0.381	1.500
ACDE	A		C	D	E	0.530	0	0.676	0.637	0.622	2.465	0.616	0.326	0	0.417	0.393	0.383	1.519
BCDE		B	C	D	E	0	0.661	0.676	0.637	0.622	2.597	0.649	0	0.429	0.439	0.414	0.404	1.686
ABCDE	A	B	C	D	E	0.530	0.661	0.676	0.637	0.622	3.127	0.625	0.331	0.414	0.423	0.399	0.389	1.956

Step 7– Insert the Shapley value results

In the 'Coalitions' sheet, the tool requires the results obtained from the R programming package from the Shapley value allocation method in the yellow cells[10].

	Average Payoffs "φ"_"NSP,NSP,NSI					
Allocation	Stakeholders					Σ β
	A	B	C	D	E	
Shapley Value	0.273 (D)	0.436 (I)	0.455 (I)	0.405 (I)	0.386 (D)	1.9561
Nucleolus	(D)	(D)	(D)	(D)	(D)	0.000
Nucleolus	(D)	(D)	(D)	(D)	(D)	0.000

	Average Payoffs "φ"_"NSP,NSP,NSI					
Allocation	Stakeholders					Σ β
	A	B	C	D	E	
Independently	0.281	0.437	0.458	0.406	0.386	1.968
ABCDE	0.331 (I)	0.414 (D)	0.423 (D)	0.399 (D)	0.389 (I)	1.956
Shapley Value	0.273 (D)	0.436 (I)	0.455 (I)	0.405 (I)	0.386 (D)	1.956

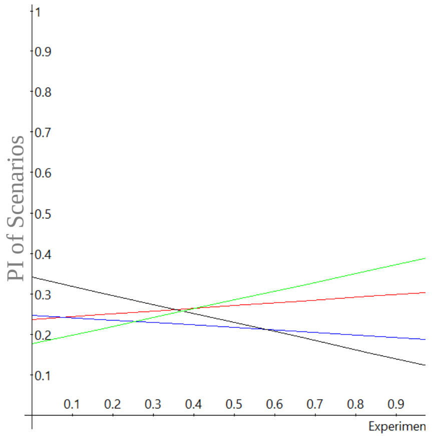


[10] The tool automatically produces a graph comparing the different benefits allocations of stakeholder groups.

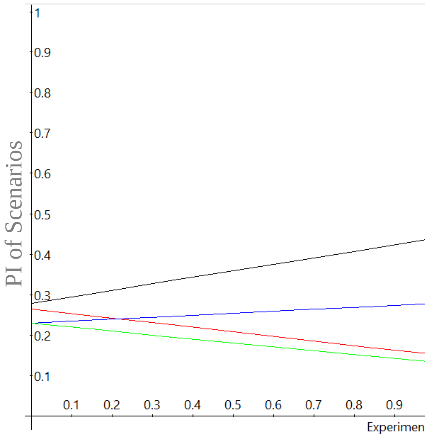
Appendix F

Appendix F. Sensitivity Analysis Results

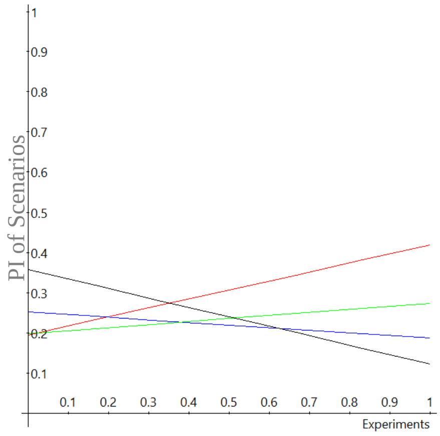
Appendix F – 1: Sensitivity analysis results of indicators for Stakeholder Group A.



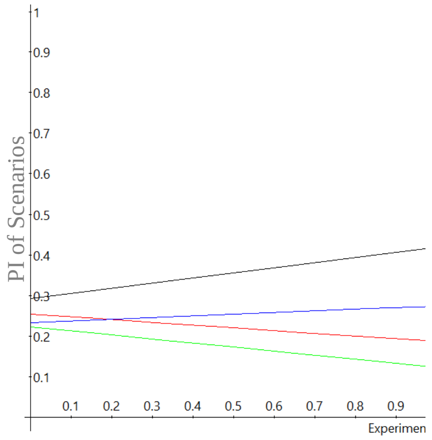
1 – Investment cost



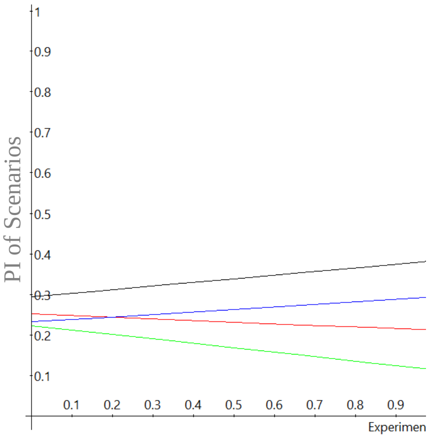
2 – GVA impact



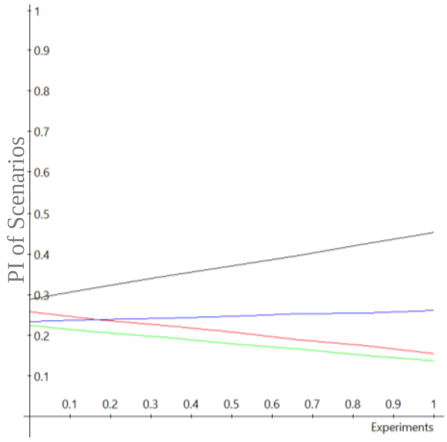
3 – Payback



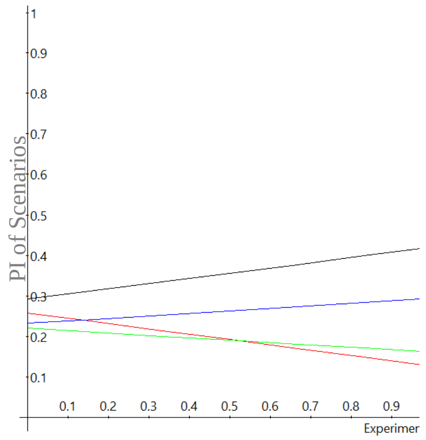
4 – Carbon emissions mitigation



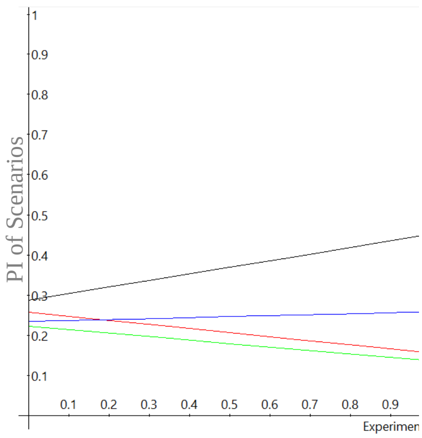
5 – MSW generation reduction



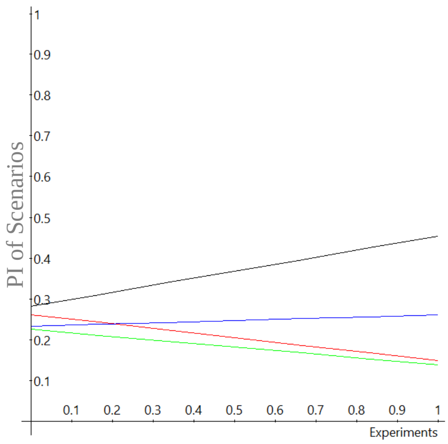
6 – Recycling rate of MSW



7 – Landfill rate of MSW



8 – Jobs creation



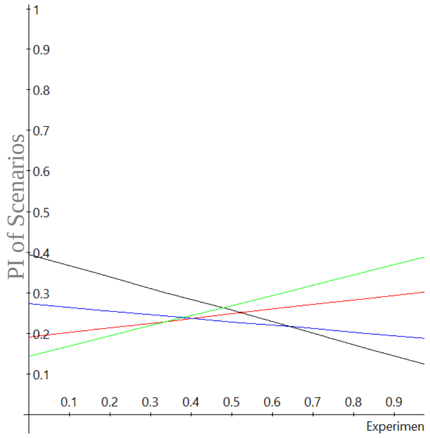
9 – Public awareness and satisfaction

MSW scenarios

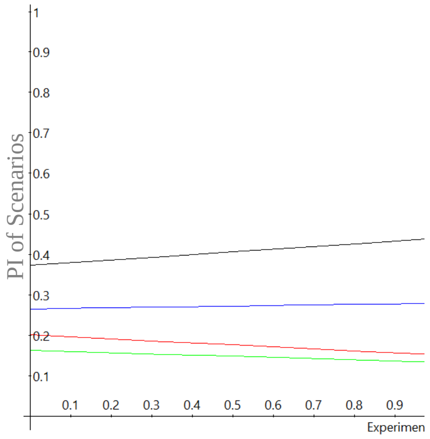
— MF — PR

— NSP — FW

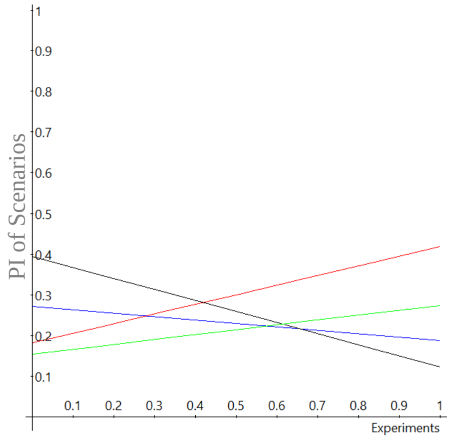
Appendix F – 2: Sensitivity analysis results of indicators for Stakeholder Group B.



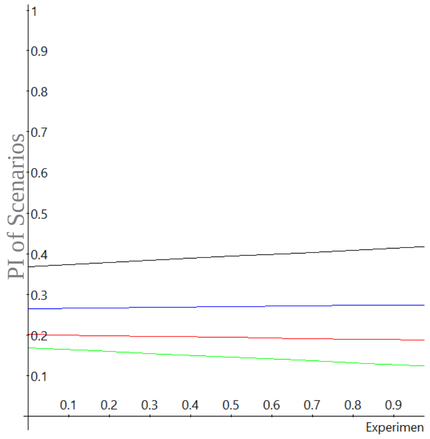
1 – Investment cost



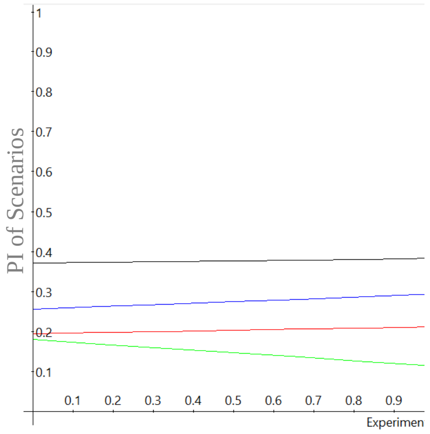
2 – GVA impact



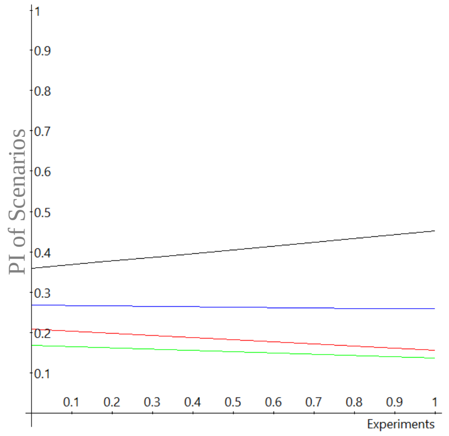
3 – Payback



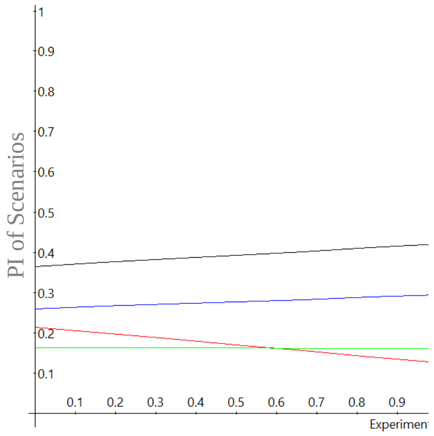
4 – Carbon emissions mitigation



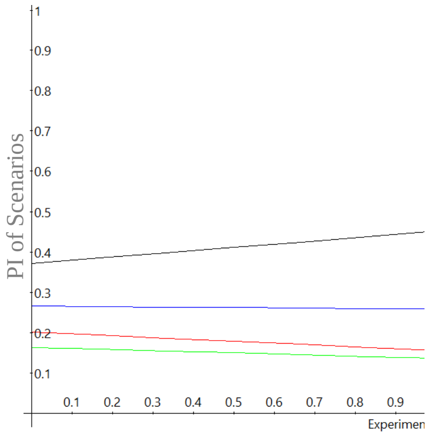
5 – MSW generation reduction



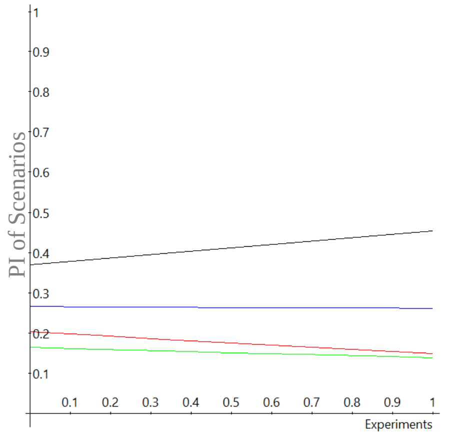
6 – Recycling rate of MSW



7 – Landfill rate of MSW



8 – Jobs creation



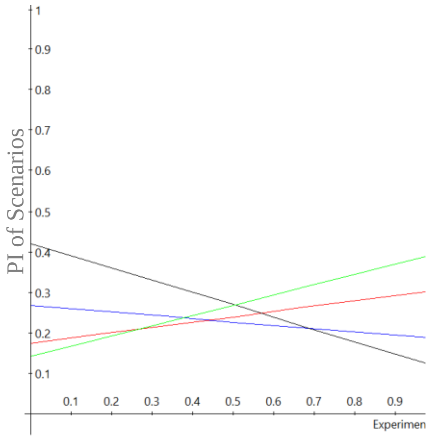
9 – Public awareness and satisfaction

MSW scenarios

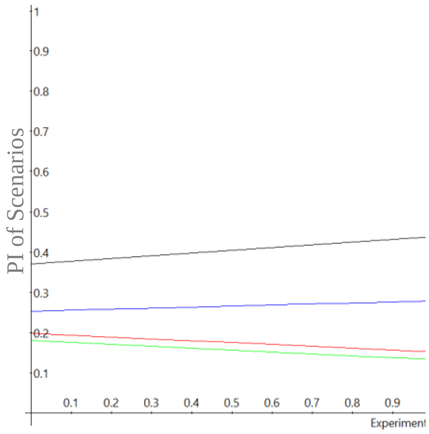
— MF　— PR

— NSP　— FW

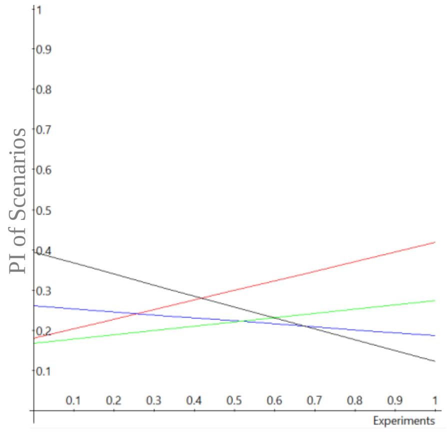
Appendix F – 3: Sensitivity analysis results of indicators for Stakeholder Group C.



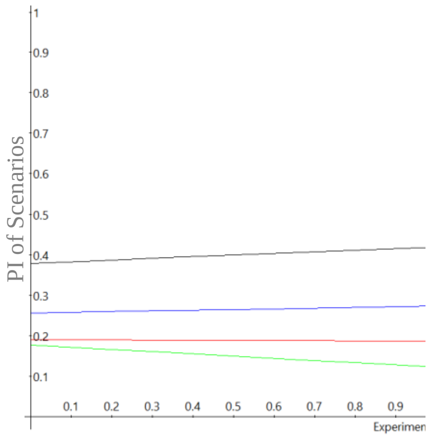
1 – Investment cost



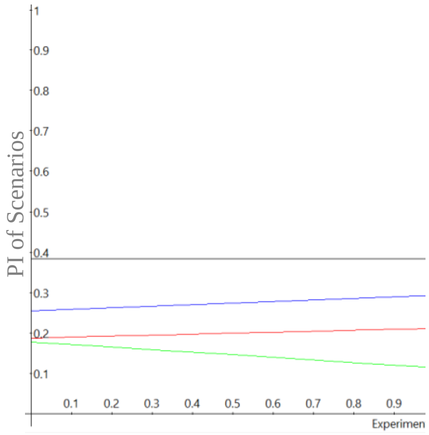
2 – GVA impact



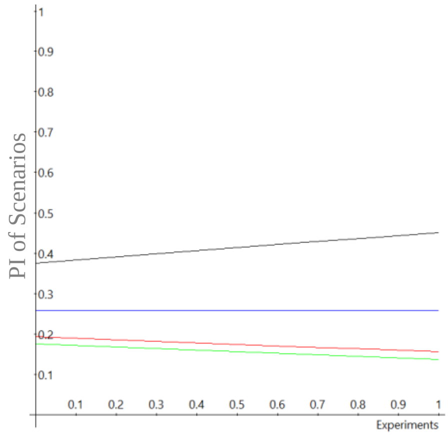
3 – Payback



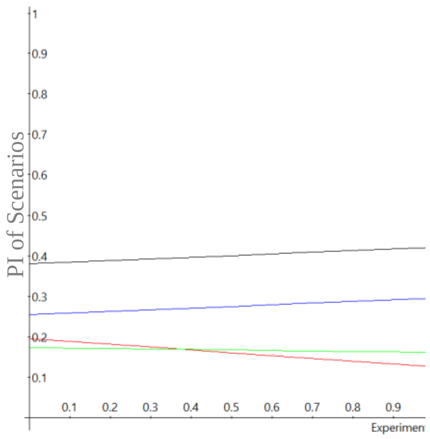
4 – Carbon emissions mitigation



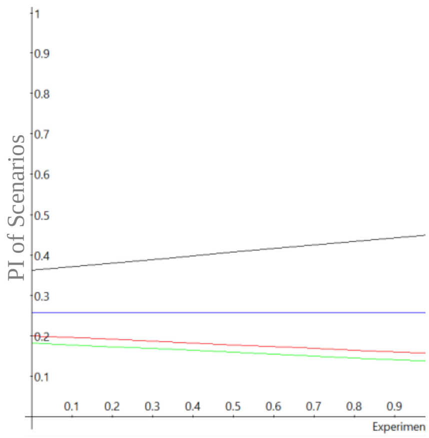
5 – MSW generation reduction



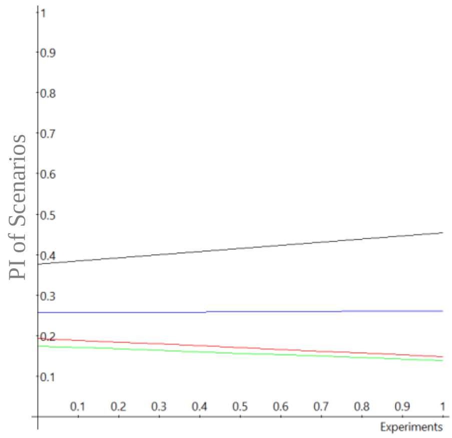
6 – Recycling rate of MSW



7 – Landfill rate of MSW



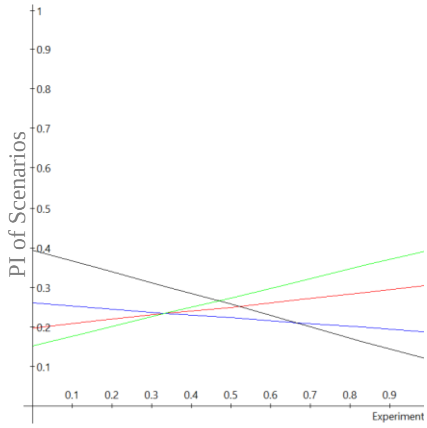
8 – Jobs creation



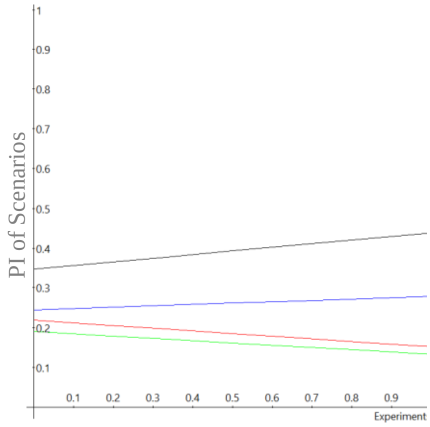
9 – Public awareness and satisfaction

MSW scenarios
— MF — PR
— NSP — FW

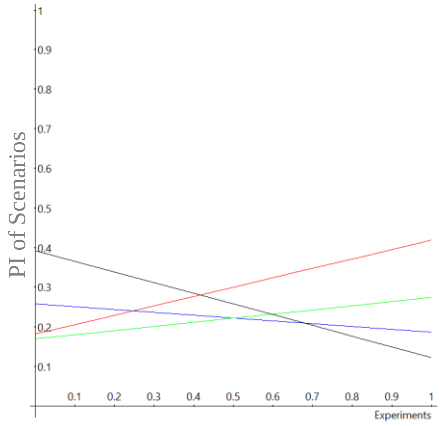
Appendix F – 4: Sensitivity analysis results of indicators for Stakeholder Group D.



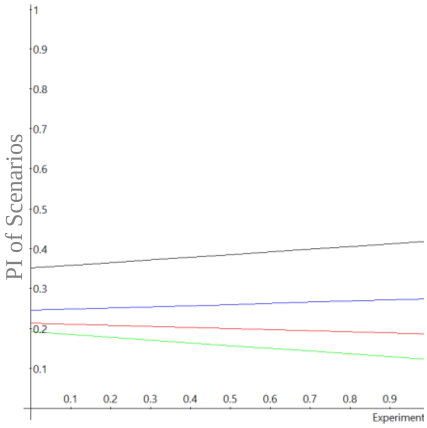
1 – Investment cost



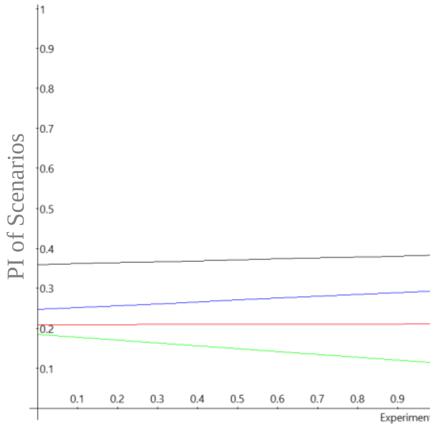
2 – GVA impact



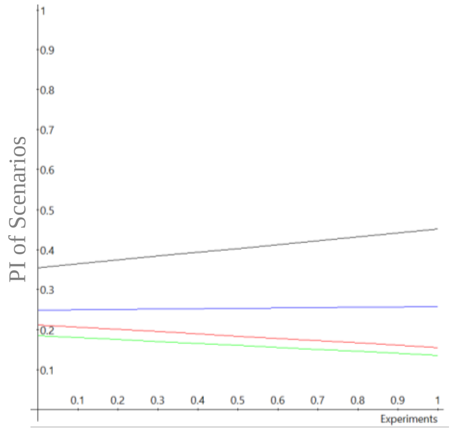
3 – Payback



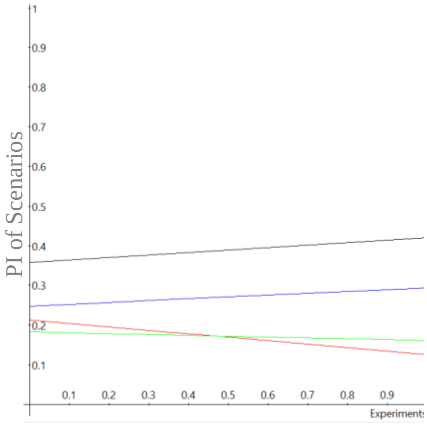
4 – Carbon emissions mitigation



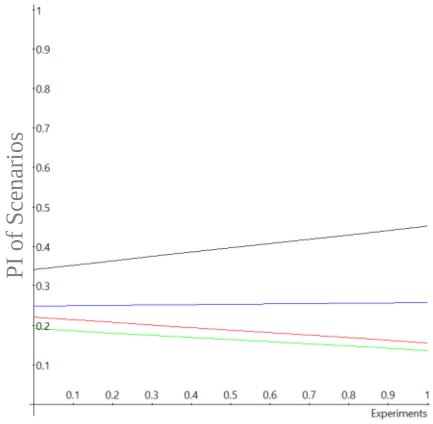
5 – MSW generation reduction



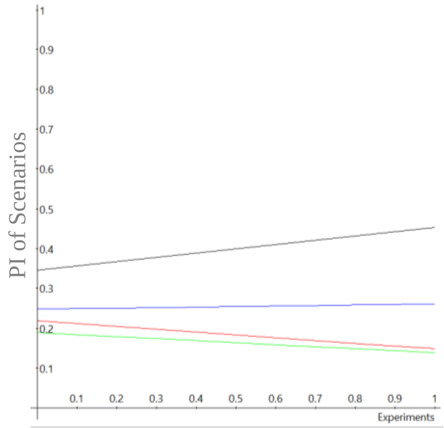
6 – Recycling rate of MSW



7 – Landfill rate of MSW



8 – Jobs creation



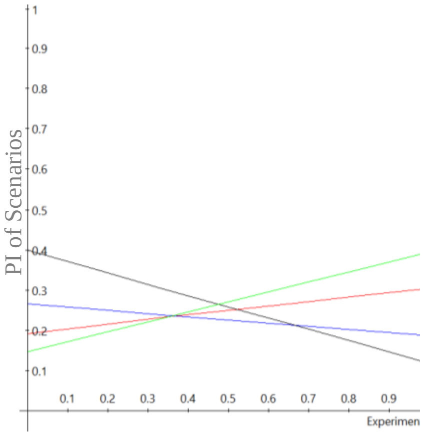
9 – Public awareness and satisfaction

MSW scenarios

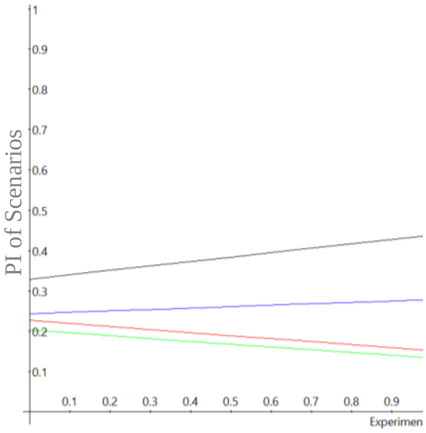
— MF — PR

— NSP — FW

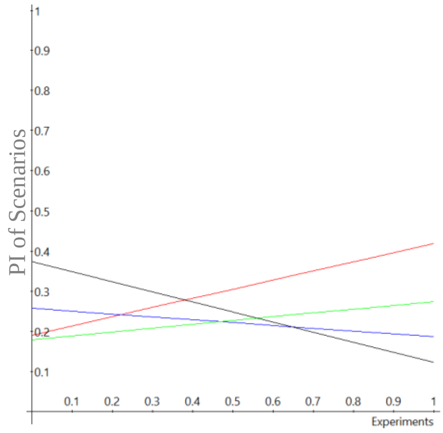
Appendix F – 5: Sensitivity analysis results of indicators for Stakeholder Group E.



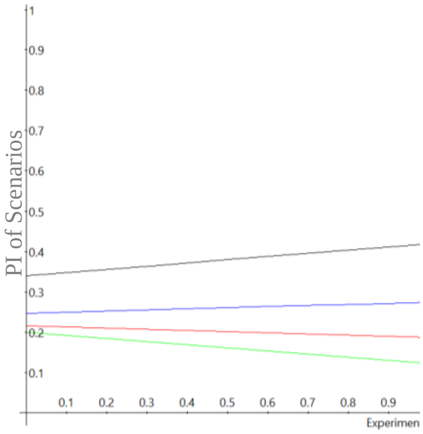
1 – Investment cost



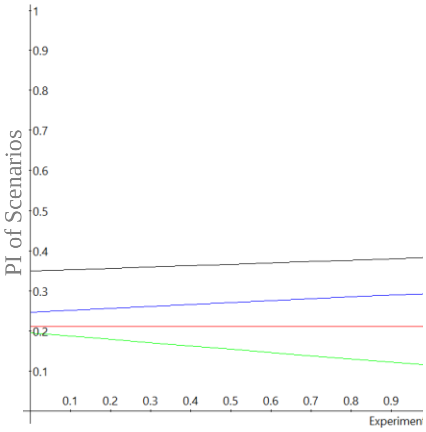
2 – GVA impact



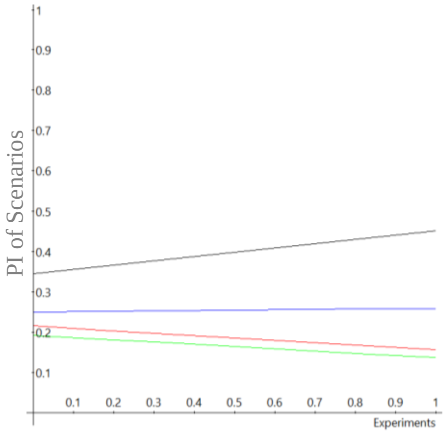
3 – Payback



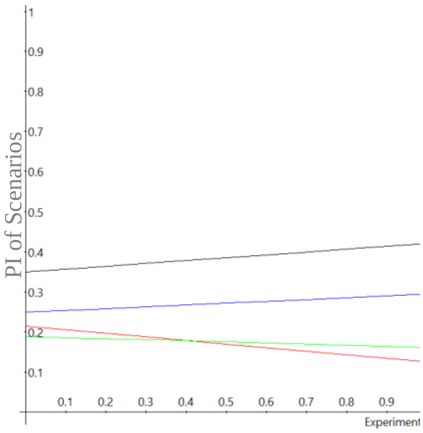
4 – Carbon emissions mitigation



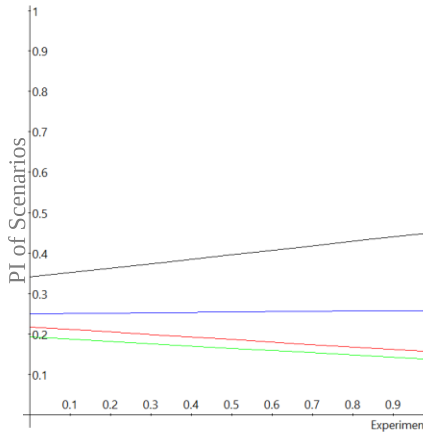
5 – MSW generation reduction



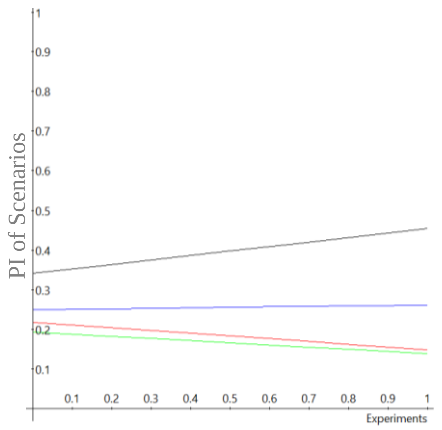
6 – Recycling rate of MSW



7 – Landfill rate of MSW



8 – Jobs creation



9 – Public awareness and satisfaction

MSW scenarios

— MF — PR

— NSP — FW