UNIVERSITY OF MALTA

Institute for Sustainable Energy

M.Sc. Dissertation

EVALUATING THE POTENTIAL FOR INDUSTRIAL SYMBIOSIS AT THE ĦAL FAR INDUSTRIAL ESTATE

by
Nicholas Vella

A dissertation submitted in partial fulfilment of the requirements of the award of Masters of Science in Sustainable Energy

Copyright

Abstract

The transition from a linear to a circular economy is a multi-faceted endeavour, targeting multiple disciplines, specifically industry. Industrial Symbiosis (IS) is considered to be a prominent means to achieve such a target. Still, IS will not happen by itself, but requires a facilitator who identifies areas of potential collaboration, establishes a suitable communications platform between parties, and highlights the benefits that such a relationship can bring to the participants.

As a case-study, this dissertation will address a local industrial cluster, construe an appropriate methodology to discover the potential for IS within it, and demonstrate how such a process can function as a catalyst towards the formation of symbiotic relationships.

This study, will therefore define the methodology used to perform a 'resource mapping exercise', a process which is necessary to build a dataset of resource flows, which process is followed by an 'opportunity discovery stage' and subsequently the realisation of IS opportunities.

The study has been divided in three thematics, and has produced a set of objectives for each, thereby addressing specific areas of importance for IS, namely a) a Collaborative Capacity thematic, b) an Energy Resource Thematic, and c) a Material resource thematic.

From an administrative perspective, this research highlighted the need to substantiate the technical capacity of the industrial cluster as well as noting the importance of a central facilitator.

The results revealed a series of interesting IS opportunities for both the energy and material resource thematics as well as exposed major contrasts between them. More specifically, for the thermal energy component, the study identified a potential recovery of **c. 106 MWh/Wk**, as well as a potential material resource recovery aspect with estimated carbon footprint savings of **1.3 tonnes of CO_2/Wk**. A number of pre-existing material IS relationships were also identified, with estimated carbon footprint savings of **25.7 tonnes of CO_2/Wk**.

The above results expose a number of opportunities for the recovery and re-circulation of resources, which account for **7.5%** of the material resources identified as entering the cluster as well as c. **23.9%** of the reported heating demand.

Acknowledgements

My appreciation goes to my tutors, Dr. Margaret Camilleri Fenech and Dr. Inġ. Robert Farrugia for their constant advice and guidance, and for the immediate assistance offered, whenever such was necessary. Their direction throughout the various stages of this dissertation were crucial to the realisation of the study.

Special thanks are also extended to Mr. Joe Borg Camilleri and Mr. Chris Galea at INDIS Malta, who supported the concept and assisted with the distribution of the questionnaire. This dissertation owes much to those interviewees and participants to the questionnaire who were ready to give up some of their time for the study.

Last but not least, special thanks go to the various lecturers and staff at the Institute for Sustainable Energy, who, during the duration of the course, helped consolidate the necessary academic acumen required for the completion of this research project.

Not to forget my partner Michelle, family, friends and pets who provided all the necessary moral support.

The end stave of Act 2 of the Opera Valeriana, the last notes composed by Maestro Joseph Vella, my father, who passed away without finishing the work, leaving behind a much greater void than missing notes on a manuscript.

To you Dad, I dedicate this work.

Table of Contents

List of Figures

List of Tables

List of Symbols and Abbreviations

AD - Anaerobic Digestion

Amb. - Ambient

CE - Circular Economy

CSR - Corporate Social Responsibility

CV - Calorific Value

DE - Distributed Economy

dT - Difference/Change in temperature

DSO - Distribution System Operator

EHS - Environmental, Health and Safety

EIP - Eco-Industrial Parks

EU - European Union

GCV - Gross Calorific Value (also referred to as HCV or HHV)

GDPR - General Data Protection Regulations (EU) Regulation 2016/679

HCV - Higher Calorific Value

HHV - Higher heating Value

IE - Industrial Ecology

IES - Industrial Eco System

IO - Input/Output

IS - Industrial Symbiosis

IT - Information Technology

LHV - Lower heating Value

NDA - Non-Disclosure Agreement

NSO - National Statistics Office

Op. - Operating (as in operating temperature)

PXX - Where ‘XX is a number’ - used as a short denomination for Participant ‘XX’

SME - Small and Medium Enterprises

WFD - Waste Framework Directive 2008/98/EC

Wk - Weekly / per week

WTE - Waste to Energy

List of SI units Used

g - gram

J - Joules

k - kilo - (x10^3)

M - Mega - (x10^6)

Wh - Watt Hour

1. Introduction

Reaching the highly ambitious EU2050 climate change targets will require substantial improvement towards the efficient use of resources, be it material as well as energy resources. This is reflected in the European Green Deal strategy [1], which aims at reaching carbon neutrality by 2050. One of the building blocks of such a strategy has been reflected in the Circular Economy Action Plan [2] which plan aims at reducing pressure on resources, while still sustaining economic growth.

Circular economy is a concept which has been widely discussed at European level, as it offers a possibility to improve the sustainable development of an industry by reducing resource use, reducing waste, relieving supply chain networks and generating green employment [3], although little factual progress has been made in this regard. This is particularly the case for Malta which, as gauged by Marino et al. [4], has registered very little progress in this sector.

Transition from a linear to a circular economy is a multi-faceted endeavour, although one key process towards achieving progress is by primarily targeting industry. Industrial Symbiosis (IS) is considered to be one such tool necessary to achieve a circular economy. The conceptual framework for a circular economy is represented in Figure 1 below.

Figure 1 - Circular Economy - Conceptual Framework. Image Source:[5]

Malta's industry is generally sited in clusters (in industrial estates or industrial parks) [6] thereby facilitating the potential for IS between members of such clusters. Still, IS will not happen by itself, but requires a facilitator/coordinator who identifies areas of potential collaboration, establishes a suitable communications platform between parties, and highlights the benefits that such a relationship can bring to the participants [3]. This project will therefore demonstrate how a similar study can be considered as a necessary catalyst towards the formation of symbiotic relationships.

Chapter 2 introduces various aspects related to IS and summarises the contemporary research done on the subject, thereby highlighting key topics surrounding the formation and sustainability of IS relationships. Chapter 3 defines the boundaries and limitations of this study, and delves into the methodology used to perform a ‘resource mapping exercise’, a process which is necessary to build a dataset of resource flows and which, as shall be furthered in this literature review, is considered as the first step towards an ‘opportunity discovery stage’ and therefore the realisation of IS.

The procedure followed to analyse the dataset, as well as the various aspects of the ‘opportunity discovery stage’ are defined further in Chapter 4. This chapter separates the study into three different thematics, namely a) the collaborative capacity within the cluster, to gauge the cluster’s readiness for IS, b) the energy thematic, focusing on energy related resource streams and opportunities, and c) the material thematic, focusing on material resource related streams and opportunities. Objectives are assigned for each of these thematics.

The results pertaining to each objective are grouped and discussed in Chapter 5. These results will demonstrate how the cluster was identified as being generally open for collaboration and to the concept and benefits of IS.

The results further reveal a series of pre-established relationships within the cluster, as well as other potential relationships which have not, prior to this study, been discovered. The study further exposes an interesting contrast between material and energy resources, before finally establishing benchmark figures for the potential of IS relationships within the industrial estate.

The conclusions of the study are therefore summarised in Chapter 6, while the subsequent Chapter 7 provides a number of possible improvements to the methodology used within this research, as well as suggesting possible future work to develop this research further.

2. Literature Review

2.1 Defining Industrial Symbiosis

While the term "Circular Economy" is relatively modern, the notion of re-using waste materials as a substitute for raw material equivalents is a process which has been suggested more than three decades earlier. It is indeed generally accepted [7] that this concept was first floated in 1989 in a paper by Frosch and Gallopoulos [8], which concept has been coined as "Industrial EcoSystem" (IES).

Li [7] as well as Yeo et al. [9] identified Industrial Symbiosis (IS) as a study area within the thematic of Industrial Ecology (IE), which focuses on the establishment of exchanges and synergies amongst industries, with the ultimate goal of developing an IES. A bibliometric analysis by Barrera et al. [10] noted that these themes are found extensively throughout literature on the subject. The same literature also suggests that research in the field in developed countries has increased considerably in the past decade.

Industrial Symbiosis therefore refers to the function of sharing waste (or rather excess resources, in any form) to offset the need for raw/virgin resources required within an industrial process. This act of substituting traditional product inputs with (otherwise) waste products, leads to an increased recovery of resources, thereby improving both the economic, as well as the environmental performance of such company [11]. This is graphically represented in Figure 2 below.

In keeping up with circular economy terminology, the term 'waste' may no longer be applicable, and therefore starts being referred to as a 'by-product' [12], [13]. As shall be addressed further, the term 'by-product' is considered as being more adapted, as it does not limit the classification to material resources alone, but has a wider scope that should extend to cover other forms of resources including, but not limited to, water and energy. It thus only follows that IS forms the basic building block to foster a circular economy [14], [15].

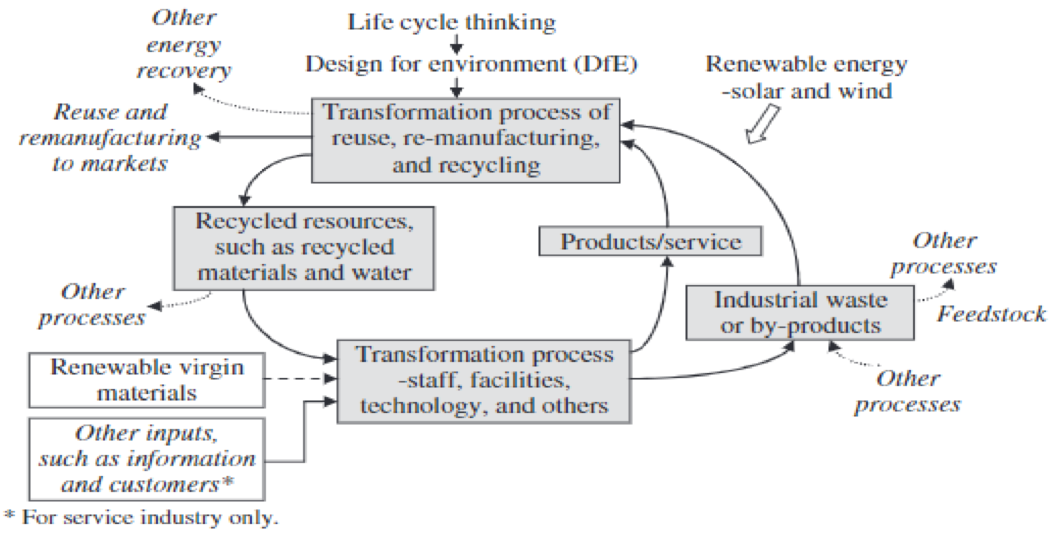


Figure 2 - Closed Loop (Circular Economy) resource flow - source: [7] *Li X, (2018)*

2.2 Benefits of IS

Gibbs and Deutz [13] highlighted that while there has been quite some progress in terms of conceptual research in fields related to IE, the notion remains speculative in nature. This was supported by Korhonen et al. [16], whose paper expanded further on the mechanisms related to IE, and on the need to bridge academia with industry. Academia was in itself identified as one of the potential catalysts to building IS relationships between two players [17].

Notwithstanding the major drive of the EU with regards to promoting a circular economy, as noted by Maqbool et al. [18] in the year 2017 "*only 0.1% of 26 million enterprises are known to be active in IS*".

On the other hand, where symbiotic relationships have indeed been established, it was noted that IS has alleviated supply chain pressures. Furthermore, the demand for by-product resources (waste) was higher in regions where the demand for the raw equivalent resource is limited in supply [12].

Where symbiotic relationships focused on energy recovery, such generation provided for political/legislative mileage as the resultant energy is often considered to be a green/recoverable/renewable source of energy, and therefore eligible for positive rebates (depending on specific country legislation) [19].

Whereas in Malta, generation of electrical energy is currently restricted to either sole use (Directive 2009/72/EC [20]), or subject to a purchase agreement with the sole Distribution System Operator (DSO)[1], as per SL.545.31 [21], on the other hand distribution of thermal energy to third parties is not regulated.

The realisation of symbiotic relationships has had a clear positive influence on the sustainability of an industry, whose outcome resulted in a reduction in pollution and a decrease in use of resources (both material, and energy) [22].

Neves et al. [23] indicated that participants of IS partnerships gauged this success using different criteria, typically measuring progress in terms of reductions in CO_2 emissions, or by reporting (an economic benefit derived from) a reduction in consumption of resources, energy, water, raw materials and fuels. This follows a positive trend of lessening the industrial burden on landfilling and energy generation.

Mirata et al. [22], summarised these benefits in 4 categories as follows:

1. **Environmental**

A reduction in pollutant emissions brought by an improved resource use efficiency, thereby reducing the demand for energy and material resources destined for landfilling.

2. **Economic**

A reduction in supply chain costs, a reduction in costs for the purchase of primary resources, as well as a reduction in waste management costs.

3. **Commercial (Business)**

Improved relationship with suppliers, distributors as well as participating neighbouring industries, besides a favourable claim for an improved corporate social responsibility (CSR) profile.

4. **Social**

The creation of a cleaner and safer work environment and neighbourhood.

[1] In Malta's case, this role has been assigned to Enemalta Plc.

2.3 Influence of Geographic Proximity

While IS synergies are more typically facilitated between industries which are within neighbouring locations, geographic proximity should not limit the creation of IE. This notion was explored in depth by Lombardi et al. [24] who posited that geographic proximity was an irrelevant parameter.

This was a slightly more modern take, given that older literature [25] tended to indicate physical proximity as an important attribute for the successful implementation of IS.

Literature also tended to establish the boundaries of the study, ranging from the micro scale (within the same enterprise) to the national scale (IS as policy making) [3]. By means of comparison, this study is constrained to a smaller confined cluster (medio scale).

The specific characteristics defining Ħal Far Industrial Estate is explained in further detail in Section 3.1.2 below.

2.4 Industrial Symbiosis for Energy

Whereas colloquially, the term waste resource is typically associated with solid waste (such as MSW, RDF and the like), the scope of this current study sees to include a wider definition, thereby including waste energy, which thematic is often overlooked. An in-depth analysis of available literature performed by Fraccascia et al. [15] noted that out of 682 papers reviewed, the energy based IS thematic only featured in 14% (96) of them.

Such interest was predominantly observed in more recent publications. Interest in energy-themed IS featured regularly in, amongst others, contributions (post 2005) by Mirata et al., such as [3], [19], [22], [26], [27], who used (mostly) energy-based IS relationship case studies as basis for their analysis.

As was noted earlier, legislative barriers may prove to be constraining towards the local distribution of electrical energy, this due to the Internal Market in Electricity Directive [20], however IS opportunities may exist for other forms of energy, where such limitations do not apply.

Other than electrical energy which excess generation, subject to DNO limitation, can be technically easily redirected to the grid, other forms of energy may also present opportunities for IS within the designated cluster. While thermal energy is likely to be the prevalent energy type (given the abundance of chilling/heating systems in the cluster), other potential sources such as chemical or radiant energy may also be available.

In contrast however, other sources such as nuclear, are unlikely to be encountered within the designated cluster. Even if such sources happen to be encountered, the rigid regulatory framework within which such resource is delimited, would make IS unsustainable. In such respect, focus should be maintained on the more common forms of energy.

In their study, Butturi et al. [28] investigated the use of renewable energy sources within EIP’s, further suggesting that through IS (i.e. by sharing their excess resources with neighbouring entities), energy production plants can be better optimised for a more efficient throughput.

Fraccascia et al. [15] furthered their work by classifying energy based IS into three categories (as illustrated in Figure 3 below). This classification shall form the basic classification tool required during the ‘opportunity discovery stage’ discussed in section 4.3, and is namely:

1) **Energy Cascade**

To include instances where waste energy from one industry is of sufficiently high quality to be recovered for use by another organisation (or, in the case of larger establishments, another division within the same organisation).

2) **Fuel Replacement**

For instances where waste materials can be made available to substitute fossil fuels for fuel-based processes (e.g. gas/HFO/coal fired boilers)

3) **Bioenergy Production**

For instances where organic waste can be made available to produce bioenergy, spent oils used to produce biofuels, and waste materials converted to energy (Waste-to-Energy facilities - WTE).

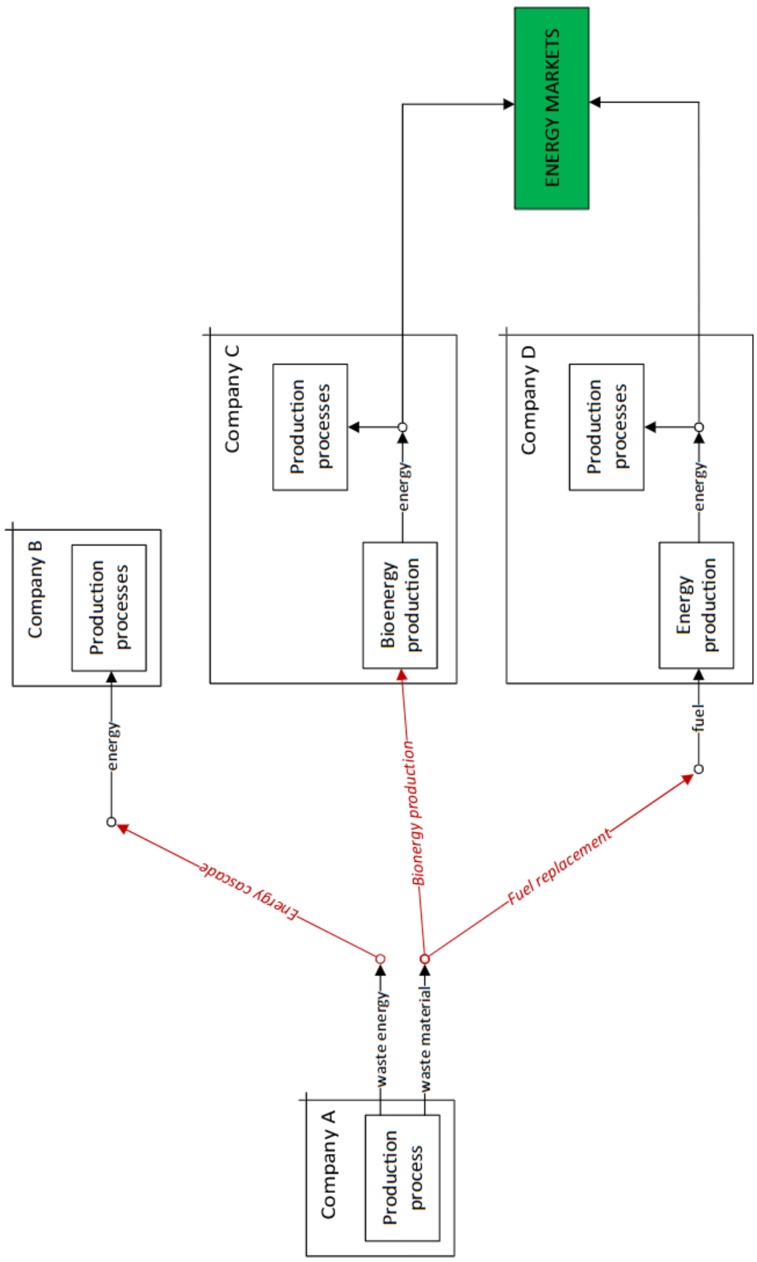


Figure 3 - Energy Based IS classification according to Fraccascia et al. [15] *(image reproduced from same source)*

A prima facie, given the local limitations (in terms of cluster size), (2), and (3) seem unlikely, or rather, would need to be addressed on a national scale, rather than at the medio scale (as in the case of the Ħal Far Industrial estate). Nevertheless, it may be premature to exclude at design stage, and it is certainly interesting to analyse the availability and magnitude of such possibility as part of this study, given that such information is currently absent.

2.5 Sustainability of IS Practices

It is widely acknowledged that the text-book case study examining practical applications of both Industrial Symbiosis and Industrial Ecology is the industrial site of Kalundborg[2], Denmark, which site has been widely referenced in most of the available literature on the subject [7]–[10], [12], [13], [18], [29]–[32], and coined as the first Eco-Industrial Park (EIP), as well as being identified as a textbook take on what was termed as a Distributed Economy (DE).

Johansson et al. [27] define a DE as being one formed by a cluster of industries which achieve their economies (savings) through inter-regional networking of smaller/regional industries, rather than through enlarging the size of an industry's production/output such as would be achieved by the classic 'economies of scale'.

As defined by Lowe [25], the goal of an EIP is a planned development aimed at fostering an Industrial EcoSystem (IES) which, through a series of IS relationships, improves the economic performance of the participating companies while reducing their environmental impact.

Irrespective of the performance of Kalundborg, a participating industry's economic achievement through IS is noted as being fundamental to support a sustainable symbiotic relationship. As suggested by Fuentes et al. [10], it may be reasonable to also understand the effects of resource price fluctuations on the capacity for by-product sharing between industrial activities.

In much of the literature related to the subject, the Kalundborg example has been over-cited [13], leading others, as far back as 2001 [33], to question the liberal use of the term EIP. Lowe [33] indeed noted that the term was used even to indicate basic instances of industrial symbiosis between single entities, rather than to indicate a planned effort at a common cluster of multiple IS relationships.

While Kalundborg is possibly the largest practical example of a functional IS in terms of scale, other authors such as Mirata [22], and Ristola et al. [19] highlight other

[2] More information on Kalundborg is available at https://en.wikipedia.org/wiki/Kalundborg_Eco-industrial_Park

functioning examples operating on a smaller scale, industries which share resources for the generation of biomass, as well as the common use of RDF and biogas for electrical and thermal generation. Literature such as the latter source is noteworthy as it focuses on energy, rather than solely on material recovery and re-utilisation. With respect to this current study, the potential for this type of IS shall be investigated under the Material Resource thematic, as described further in section 4.4.1.4.

Irrespective of the above, while Kalundborg's IS capacity has never been doubted, Li [7] provided a history of its development and argued that the development in Kalundborg (1972) pre-dated theories in IS and IE (1989) [8], and that its organic growth (at least at first) has been due to a random, fortunate case of personal connections between company executives. Therefore, rather than being a pre-planned system, Kalundborg may have started off as a result of a casual relationship between participants, within which an element of 'trust' was already instilled.

Indeed, Heeres et al. [32] indicated that Kalundborg was not intentionally planned as an EIP, but has gradually evolved organically as one where participants realised the economic benefit of their symbiotic relationship. In this regard, the literature furthered that this could have been the reason why the replication of such phenomenon on other planned EIP's had not yet materialised. Valentine [30], also went as far as calling the Kalundborg phenomenon as "*unique*".

Heeres et al. [32], Gibbs and Deutz [13], and Low et al. [34], further compared the development of symbiotic relationships in other EIP's and noted that many lacked the capacity of Kalundborg. Chen et al. [12] argued that diversity within an eco-industrial cluster is an important characteristic towards the sustainability of an IS network (a position which was also shared with Taddeo [35]), and indicated that many EIP's lacked the necessary organic partnerships which developed strong symbiotic relationships.

This aspect was further corroborated following research by Liwarska and Bizukojc et al. [31] who, in 2013, analysed eighteen European EIP's (or rather, industrial parks claiming to be so), and concluded that only four out of these were likely to develop IS relationships in the future.

Nevertheless, Li [7] extracted a number of lessons which can be learnt from Kalundborg, namely that:

1. Every single IS exchange is valuable towards the development of an IES;
2. Connective relationships between different decision makers is essential to facilitate symbiotic relationships;
3. Industries need to foster a pragmatic environmental culture for IS relationships to develop;
4. IS synergies can only be sustainable if they reap economic benefit to the industry operators.

Li [7] furthered his analysis by noting that the sustainability of an IS practice was dependent on the continuous participation of new partners within an EIS cohort. The potential for IS was thus improved when there:

1. was an established knowledge web (dataset) of different wastes/by-product which are available;
2. was a comprehensive database containing potential participants for IS synergies;
3. were facilitators of IS synergies, i.e., independent elements trained to bypass the first stages of trust-building between potential IS participants;
4. was government support.

Adding to the latter list, an analysis by Lindfors et al. [17], also suggested that strengthening the institutional capacity[3] of potential participants from the onset, was a very efficient way in which fewer resources are required and faster results achieved to encourage IS relationships. In their study, this had manifested in a series of workshops between potential candidates.

[3] Institutional capacity is defined as the capacity of a group of participants to act collectively [17]

Furthermore, Ristola et al. [19] noted that an enduring IS relationship was not only dependent on meeting minimum quality/technical requirements, but was subject to a) a suitable cost saving, and b) the longevity of the relationship, both of which are necessary so as to facilitate a suitable return on investment.

2.6 Barriers to Industrial Symbiosis

Heeres et al. [32], examined the barriers to Industrial Symbiosis, thereby identifying and shortlisting the potential culprits on **technical, informational, organisational and legal/regulatory aspects**. This position was also corroborated by Mirata [3], Azevedo et al. [14], as well as Fracascia et al. [15] (for energy based IS).

2.6.1 Technical Barriers

Chen et al. [12] also noted that the potential for re-use of resources was dependent on the ability to match the **quality specifications** and composition characteristics between the raw virgin resource and the recovered by-product/resource.

More specific to symbiosis for energy resources, Butturi et al. [28] also identified the lack of **technical expertise** within an organisation particularly in Small and Medium Enterprises (SME), as being a major barrier to such developments. In a way, one may argue that such consideration can be extended to include all forms of resources, not only energy.

2.6.2 Informational Barriers

With respect to barriers in data collection and dissemination, the common concern noted in multiple studies [12], [7], [33], [34] was the **method of classification of data,** or rather the lack of a standardised system thereof. As noted earlier, it may not be sufficient to classify a resource (Input/Output) by class alone, but this is best broken down further to include specifics of type, form (composition) and quality.

In this respect, aggregate data may pose a barrier to firms seeking symbiotic relationships whereas, conversely, a more detailed database would facilitate such a process. This is not so straightforward however, as gathering such detailed data may be more complex, and industry may not be willing to provide this level of detail due to legal/regulatory/corporate regulations (refer to the following section).

2.6.3 Organisational Barriers

The initial success of Kalundborg was arguably attributed to the pre-established personal relationship between a cluster of company owners within the same geographic region [7]. These relationships were already standing, and therefore it was not necessary for the business relationship to build inter-business **trust**. While this led to the shorting of a typically time consuming, trust-building stage, it also favourably allowed for a lesser heightened need to retain ‘security of information’ between partners [29].

Furthermore, the authors noted that IS was a process that requires **time** to develop, and therefore the realisation of any symbiotic relationships, cannot be expected to materialise instantaneously, but allowed time to mature [11]. Additionally, however, such an extended incubation period often hindered the possibility to evaluate the success (or otherwise) of newly formed symbiotic relationships [17].

Yeo et al. [9] took a more holistic approach, and argued that industry **engagement** was crucial towards establishing IS relationships. To some extent, locally and particularly in the case of the Ħal Far Industrial Estate, this condition is partially mitigated considering that the various entities are all in contact with the same site administrator, i.e., INDIS Ltd., which takes on the role of park manager.

2.6.4 Legal / Regulatory/ Political aspects

The **legal framework** surrounding the European Waste Framework Directive (WFD), particularly the need to align recovery efforts with limitations imposed by End-of-Waste criteria, were also noted by Li [7].

In such regard, resources which can be made available for IS should not be considered as waste, as otherwise their recovery would be limited by the stringent WFD, thereby limiting the free movement of potential symbiotic resources.

2.7 Collection of Information, Establishing Synergies

To a certain extent, all literature associated with discovering the characteristics for a successful IS and IESs indicated an ‘**opportunity discovery process**’ [23] (sometimes referred to as an ‘Informational Support Phase’ [3]) as their initial stages of the analysis.

This critical stage delves into examining the main resource flows (sourced through a **resource mapping exercise**) within a cluster, with the scope of assessing which flows are more critical, and those which are more abundant, and therefore identify areas displaying major potential. This process, according to Korhonen et al. [16] takes the form of either a) a process-IO (input/output) database, b) a life cycle management, c) an evaluation of the supply chain, or d) a mixture of all.

The methods of data collection listed in different literature sources varied according to the specific area of interest of the relative authors, although these generally took the form of interviews, questionnaires, site visits, as well as focus groups [23].

Once the necessary data on the different process-IO were made available (resource mapping), a second phase related to the discovery of IS relationships commences. Yeo et al. [9] noted that such a process relied on different types of methods, and have distinguished between these methods further, by classifying them in three types, namely:

- **Type 1: Free market mechanism based methods**

As may be deduced, free market mechanisms relied on pure demand and supply forces. This method would explain the existence of any IS relationships already present within an operational industrial park, such as would any pre-established relationship at any current industrial estates in Malta, including the Ħal Far Industrial Estate.

- **Type 2: Process input-output stream based matching**

Unlike the free market method, this process takes on a higher level evaluation, typically performed by an independent body such as an industrial park administrator tasked with cataloguing the various inputs and outputs within a cluster, and therefore establishing relationships by matching them. The output of such exercise would often result in a comprehensive list of both available excess resources (output by-products), as well as resources required for processes (input).

In the case where relationships aren’t immediately available, such a list constitutes a valuable tool for the administrator of an industrial park to target (and attract) potential new participants as part of the IES or EIP, as noted by Low et al. [34].

This type of process is the one which most closely resembles the process undertaken in this study.

- **Type 3: Network design and optimisation**

This type of method relates to the implementation of IS relationships by design, and is therefore a process which is mostly associated with the initial conceptual stages of ‘designing’ of EISs and EIPs, i.e., it is applicable for circumstances where such are being designed from scratch. This method is therefore not in the scope of this study, although the information which shall be gathered can eventually assist in such type of design.

2.8 Tools

With regards to the process-IO matching process, Liwarska et al. [31] developed a simple algorithm to evaluate the potential for IS in an industrial cluster. Initially, the study sectioned participants in three types namely, industrial producers, industrial decomposers[4], and consumers, arguing that an IS relationship cannot exist between industries of the same type.

The authors follow by providing the following process flow chart (Figure 4), which maps the relationship between each element. The flow resulted in a graded outcome of four factors, varying according to the grade of their symbiotic potential.

While this tool gave a reasonable initial indication of IS potential, the authors themselves noted the limitations of this model, specifying that it did not take into account either quantities or composition of the potential symbiotic resource. Such limitations are therefore best accounted for when applying or designing tools for resource mapping (Section 3.2).

It is also interesting to note the development in software aimed at assisting in the creation of symbiotic relationships [23]. A selection (more specifically twenty) of these software packages was analysed in depth in a study by Maqbool et al. [18], therein noting that eight of these were commercially available on the market. The assessment supported a previous study [36] which suggested that the software packages were mostly focused on a similar structure, i.e. that of cataloguing a database of materials, leading Maqbool et al. [18] to question the need for developing more of the same such tools.

[4] In this context, the term “industrial decomposers” is used by Liwarska et al. [31] to define *“Any enterprises, whose main business activity is the treatment or neutralization of any waste streams”*

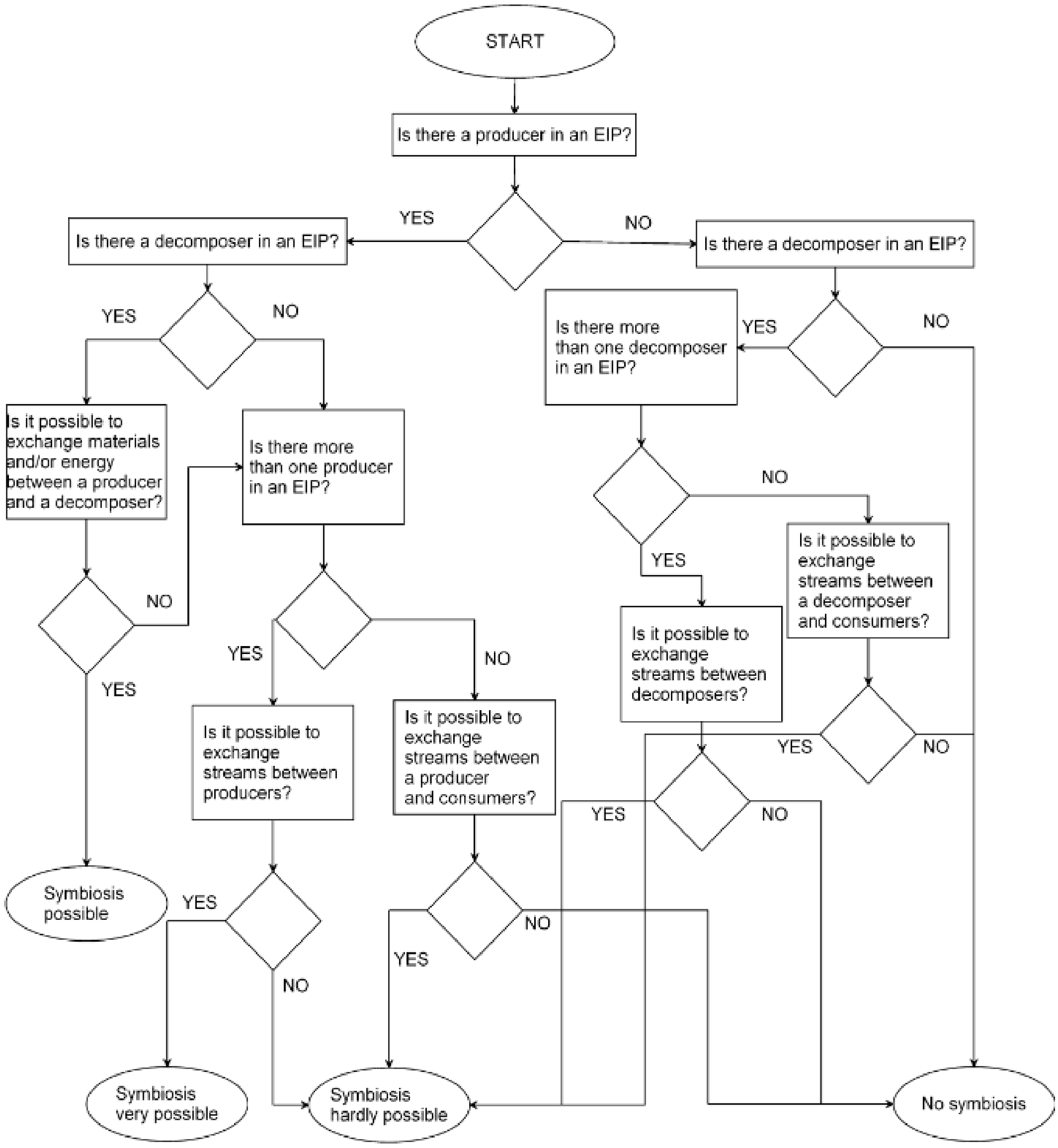


Figure 4 - Algorithm to evaluate the potential for IS - source: [31] *Liwarska et al. (2018)*

This notion was previously sustained by Grant et al. [36] who, while distinguishing between older and newer packages, noted that these improved in terms of user interface (with a preference for administrative users over engineers and technical people), but were otherwise rather unvarying and unchanging in terms of functionality.

A review of available data acquisition platforms and software packages was performed as part of this research, the results of which provided in section 3.2.2.

2.9 Data Structure

In his handbook [33], Lowe indicated a set of strategies aimed at designing and creating an EIP. Some aspects of this handbook relate to the establishing of new EIPs, which function is not within the scope of this study, and therefore, aspects mentioned by the author such as 'Natural Systems' and 'Integration with Host Communities', which are methods designed to better integrate an EIP in a community, may be superfluous and irrelevant to this current research.

On the other hand, the author made considerable emphasis on the inclusion of data relevant to resources other than 'material resources', although covertly including energy and water alongside material flows. With regards to this study, this is considered as being of great relevance.

Chen et al. [12], developed a structured database model to investigate IS potential between industries. The authors mapped a resource IO database for each company, which database was subsequently made available for matching of output by-products with raw material resources (input).

While Chen et al. [12], noted that their area of influence was targeted at the national scale, rather than to individual industries (medio or micro scale), the analysis criteria as proposed by the authors are still considered as suitable to assist in formulating and structuring data to form a resource database for this current study (medio scale).

Such a database was distributed based on the following criteria:

- ***Non-Waste Inputs***

A list of resources (raw materials and other) used in the processes. This therefore corresponds to the raw resources which would eventually be substituted.

- ***Waste Inputs***

A list of by-products which resulted from the industry's operational processes which were currently being re-utilised. If such re-utilisation was internal, it is considered as 'internal-recovery', while if such was being re-utilised by a different industry, this was considered as a pre-established symbiotic relationship.

- ***Waste Outputs***

A list of by-products (excess resources) from donor processes which were being discarded (wasted without recovery).

- ***Product Outputs***

A list of waste outputs which were considered as products (specific to the Taiwanese system (qualified in the following paragraph) as familiar to Chen et al. [12]).

The latter classification referred to provisions within the Taiwanese system, this being the area of influence of the authors [12], which requires classification of a certain type of waste output as products (e.g. concrete aggregate). While this may not be applicable in Malta, it may be opportune to differentiate waste between that which is locally treatable, and waste which has to be exported (with the latter given more prominence due to its extended carbon footprint).

2.10 Summary of Objectives

Besides highlighting the relevant literature on the subject, this chapter also notes the various benefits associated with industrial symbiosis, thereby highlighting the strategic importance an administrator to an industrial park has, with respect to understanding resource flows within it and the importance of creating an ambience which supports industrial symbiosis.

Section 2.6 has delved into the barriers to IS, amongst which the following aspects were identified as being crucial to foster an IS relationship, namely:

1) **The method of classification**, which needs to be compatible between inflows and outflows;
2) The availability of **qualitative data** on the resources which are to be made available, to complement the resource matching exercise;
3) **Technical expertise** of the participants;
4) **Trust,** the ability to collaborate, and the level of engagement between participants.

The above aspects will have a considerable bearing on the methodology of this current study, and therefore their understanding shall also play a crucial role in forming the terms of reference for the **resource mapping** exercise (section 3.2). It is noted that there is currently a lack of data related to the Ħal Far Industrial Estate (as well as to other estates in Malta). The resource mapping exercise is therefore meant to identify the cluster's IO (input/output) and to populate the relevant dataset.

The availability of this dataset shall therefore permit the study to progress to an '**opportunity discovery process**' (Chapter 4), which process shall be based on an input/output stream-based matching exercise, as defined earlier in section 2.7 of this same chapter.

3. Methodology - Resource Mapping Stage

In order to evaluate the potential for industrial symbiosis at the Ħal Far industrial estate, this study will follow a sequential process, a custom flow which has been specifically construed following as part of this work based on the insights gained from the literature review in the previous chapter. This process is graphically illustrated in the flow chart shown in Figure 5:

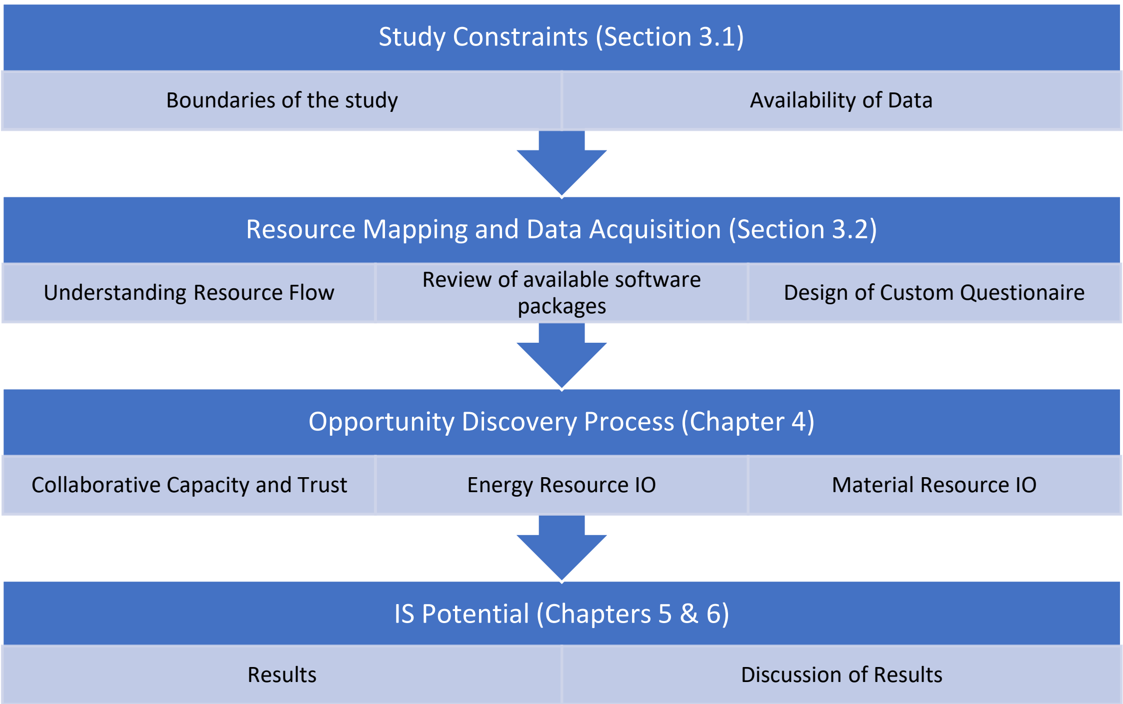


Figure 5 - Methodology Process Chart

The first section of this chapter undertakes a preliminary assessment of constraints, i.e. it provides details on the cluster and the project boundaries. Furthermore, by noting what data are currently available, a gap analysis highlights what data are unavailable and, accordingly, what data needs to be acquired so as to perform such a study.

The second section of this chapter provides a description of the resource flow models which are expected within the industrial estate. Understanding such flows and the relationships between donor and recipient streams are necessary as they help define the terms of reference for the 'resource mapping' exercise which follows.

This section therefore furthers into a review of past and present software and IT packages intended to facilitate IS synergies, and briefly reviews each to establish their relevance to the project.

Finally, this chapter seeks to define the design parameters for a custom data-acquisition questionnaire, which is seen as the more effective option when compared to the available packages, required to reach the project's objectives.

Once the questionnaires' data are processed, the data acquisition process will result in a resource IO database (available in Appendices 2, 3 and 4), which identifies the resources present within the cluster and maps their flows within it. Such a resource mapping database is considered as an essential pre-requisite for the 'opportunity discovery' process meant to expose potential IS synergies within the Ħal Far cluster. The procedure for the opportunity discovery process shall be defined in the subsequent Chapter 4.

3.1 Project Boundaries and Constraints

3.1.1 Boundaries of the Study

This study targets the Ħal Far Industrial Estate, an area which houses a cluster of independent industries, and is administered by INDIS Ltd., a government owned company entrusted with the management of Malta's industrial parks.

This particular industrial estate has been shortlisted due to its specific characteristics, namely that it is the largest, as well as being one of the more modern and more organised industrial estate set-ups in Malta. These characteristics are perceived as being favourable, at least at an earlier stage in this research, towards a wider and a more progressive reach study on its participants with respect to resource sharing.

An array of more modern companies is perceived as being more exposed to the recognition of CSR values, and is therefore already exposed towards the promotion of more resource friendly operations. Such organisations are thus more likely to participate decisively in the study than others which may simply consider such study as a nuisance.

All the companies sited within the named estate that were operational at the time of writing were eligible for this study. The registered companies which were either under construction or, conversely, winding down, insolvent or inactive were omitted.

Companies which, although being registered under an exclusive and distinguishable structure or brand, operated within the premises of their mother/sister company, thereby sharing infrastructural resources, were also omitted from the study. In such unique cases, these companies were considered to be within the mother/sister company umbrella, so as to avoid double counting. In such regard, the total population of this study has been shortlisted to 35 companies.

3.1.2 Ħal Far Industrial Estate in Context

The Ħal Far Industrial Estate is spread over an area of c. 1.1 km^2 and houses 35 independent and operational[5] industries [37]. The site is located at the southwest corner of the main island of Malta in an area which is mostly void of residential housing, as well as being a few kilometres from both the Malta International Airport (4 km) and the Malta Freeport (2 km). Its boundary is delignated in the aerial shot portrayed in Figure 6. For the scope of this analysis, the Ħal Far industrial estate can therefore be considered as a medio-scale cluster of industries.

Figure 6 – Boundary of the Ħal Far Industrial Estate – Source: Google Earth

[5] Industries that are currently not operational (either because of termination or still under construction) have been omitted from the population count.

The proximity to both air and sea freight opportunities has made this estate particularly attractive to a number of industries of different proportions (a mix of large industries as well as SMEs), given that these are the more common distribution nodes for the importation of (most) necessary material resources.

The industrial estate is also very diverse in the range of products being manufactured, with goods ranging from pharmaceuticals to polymers, to steel and iron fabrication, as well as other disciplines. The distribution of industries within the estate which are eligible for this study is demonstrated in Figure 7.

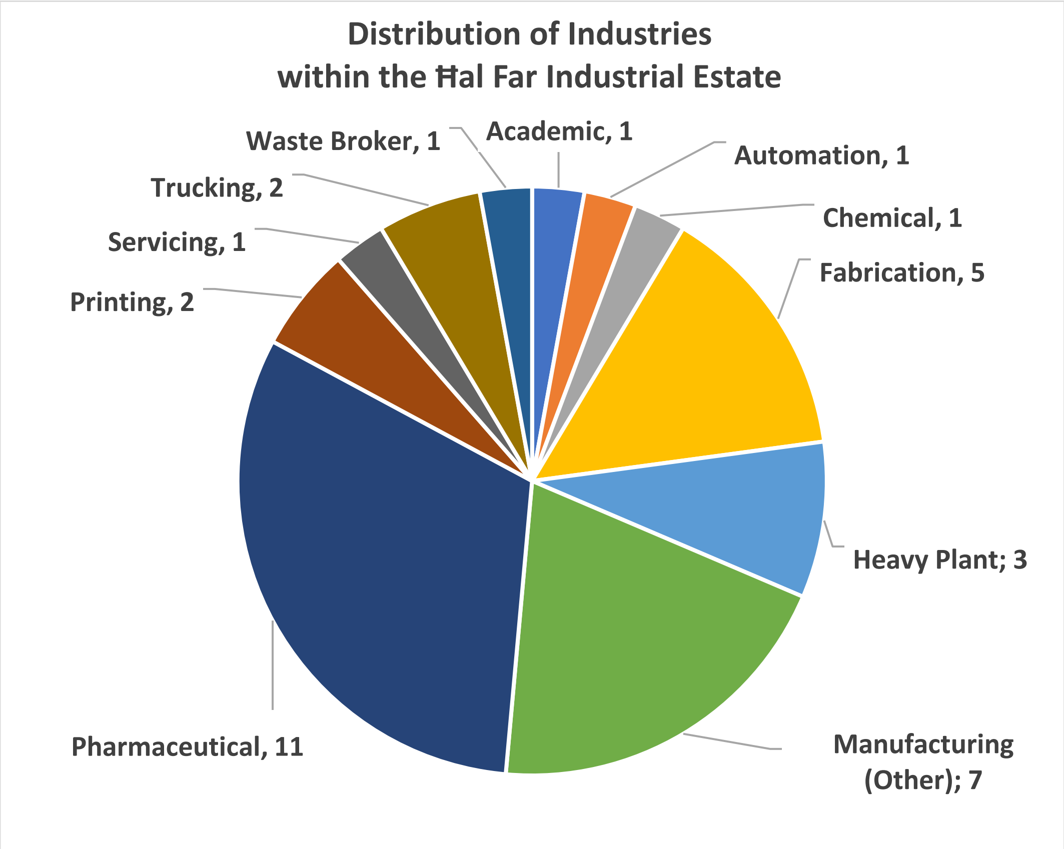


Figure 7 - Distribution of Industries within the Ħal Far Industrial Estate

This diversity in manufacturing, and therefore the corresponding diversity in resource inflows and outflows, is considered to be a positive trait since, as noted by Chen et al. [12], the more varied the trades in a cluster, the greater is the potential to discover shareable resources.

3.1.3 Availability of Data

The data necessary for this project need not only be specific to the cluster in consideration, but also needs to be broken down further to the individual tenants within the Ħal Far Industrial Estate.

Furthermore, evaluating the potential for industrial symbiosis requires a comprehensive dataset comprising all resource flows, therefore not being only limited to material waste flows (material output), but also extending to purchased materials (material input), as well as the energy component counterparts.

The National Statistics Office (NSO) collects energy statistics as regulated by Regulation (EC) No. 1099/2008 of the European Parliament [38]. Material inflow statistics are collected as per Regulations (EC) No. 471/2009 and (EC) No. 638/2004 of the European Parliament, to also include data on fuel imports [39]. Data with respect to waste are collected in accordance with Regulation (EC) No. 2150/2002 of the European Parliament [40].

Unfortunately, the above regulations specify requirements at a national level, and not at a cluster level, thus making them rather incompatible with the resolution levels required by this current study. The lack of such targeted detail therefore makes the segregation of data related to this specific cluster rather challenging, if not impossible.

No other datasets pertaining to the required parameters are known to be available at the time of writing, and therefore it may be concluded that the data required for this study need to be acquired directly by the author from primary sources.

3.2 Resource Mapping and Data Acquisition

Resource mapping is considered as the precursor stage to the 'opportunity discovery process', and therefore deemed essential for the creation of a detailed dataset cataloguing resource IO flow for the individual participants within the selected cluster.

The literature presented in section 2.8 notes a series of tools for this purpose. For this current study, a hybrid model structured between the proposals of Chen et al. [12] and Liwarska et el. [31] is being proposed. This structural distribution of data, shall therefore tabulate (and take the form of an) IO resources mapping dataset for the different participants, which resources shall not only be identified by type, but will be complemented with other quantitative and qualitative characteristics such as condition and form.

Therefore, while keeping a similar IO stream based setup, this current study's model is expected to improve on both the Chen [12] model (which is designed for a larger scale analysis), as well as improve on the limitations of the Liwarska [31] model. The proposed model shall therefore be such as to allow for a clear distinction between the various resource IO flows, and broken down to include qualitative elements.

In this regard, the required data acquisition structure would need to address the following criteria, namely:

a. Distinguish between different classes of resource, principally between material and energy, but secondly also between the various sub-types/sub-fields.
b. Discover, with respect to Input flows:
    - Energy required (in its different forms)
        - Thermal (typically heating);
        - Chemical (e.g. fuels).
    - Material resources required
        - Raw materials;
        - Recovered materials.
    - Any pre-existing IS networks (for both energy and material resources).
c. Discover, with respect to Output flows:
    - Waste energy in all its forms, e.g. thermal (typically cooling), chemical etc.;
    - Output Material
        - Waste;
        - Disposal methods, differentiate between treatment/recovery method (if applicable), and location (locally or exported).
    - Pre-existing IS networks (for both energy and material resources).

Conversely, the following are omitted from the structure due to their irrelevance to the study:

- Electrical energy output, assuming that any excess is already being catered for through a Feed-In-Tariff structure.
- Any resources which are too rare, too specific, or too sensitive to share.
- Fuel used for transportation, given that conversion of vehicles to other fuel types would require considerable economic intervention.

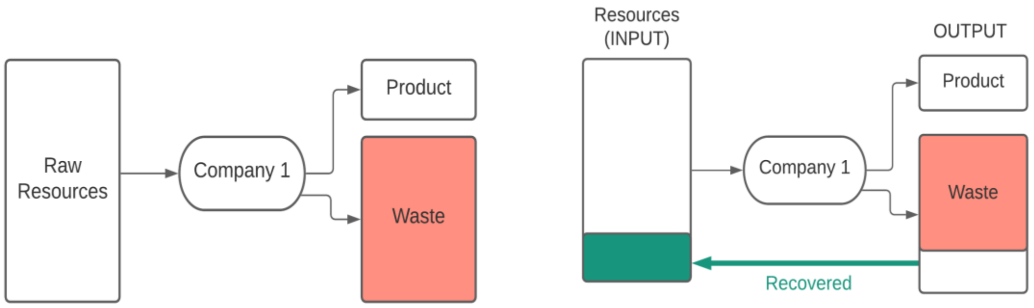
This section will furthermore be examining the different resource flow patterns which are to be expected within the different setups at the Ħal Far Industrial estate, following which, a review of available software and IT packages shall be discussed. This section will also describe why none of the available packages has been deemed as appropriate, and instead, opting for a custom-designed questionnaire as the tool of choice to populate the resource IO flow dataset.

Finally, the chapter will highlight the methodology used when designing the custom questionnaire, and the significance of each section in relation to the above-mentioned design parameters.

3.2.1 Understanding Resource Flow in an Industrial Setup

In a conventional system where a linear economy prevails, understanding the resource flows within it is straightforward. On the input side of a process, an enterprise procures raw resources (energy and material) which it eventually processes to manufacture its desired product.

In this scenario, the target product however is not the only an outward flow, but it is accompanied according to by-product, typically consisting of a resource (material or energy) which is a reject and non-value-adding to the process, therefore destined to be rejected as waste. Such a process is schematically illustrated in Figure 8a.



(a) (b)

Figure 8 - Resource flow schematic in a) Left - a company operating in a linear economy b) Right - a company employing resource recovery measures in a linear economy

A slight improvement to this process is portrayed in Figure 8b, whereby a feedback loop is introduced in a similar enterprise which employs some form of resource recovery measure thereby recovering and adding value to some of this by-product. Whilst still operating in a linear economy, in doing so an enterprise gains a compounded benefit by primarily reducing the pressure on the supply chain for raw resources at the input stage, and secondly by reducing the amount of waste for disposal.

The schematic displays a general representation of the current state of affairs for most industry players. While it is assumed that the majority of operators would undertake a certain degree of resource recovery measures, these are typically driven by economic benefit in an industry that is still heavily reliant on the use of raw resources, as well as still producing significant amounts of waste (a by-product of no added value).

There may however exist instances where the by-product of a company may not be of interest to itself or which, for other reasons, may not be recovered internally. In such instances this resource would need to be discarded. This is particularly true for an industry which is isolated.

The next progression in this sequence is the recovery of resources by establishing industrial symbiotic relationships between independent sources, which process is portrayed in Figure 9.

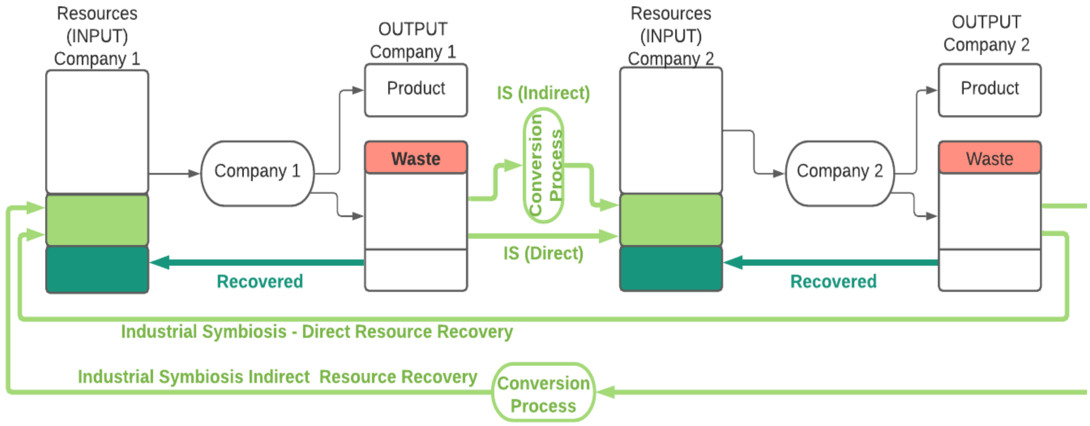


Figure 9 - Resource flow schematic with an Industrial Symbiotic Relationship between enterprises

Within an EIP, i.e. a cluster which embraces Industrial Symbiosis, this by-product would be considered as a resource, given its potential to substitute raw resources for a second company (which is independent from the donor). In economic terms, value is added/recovered to/from a resource which would otherwise be discarded (typically at an added cost).

IS would therefore promote the sharing of resource in either a direct manner, in such cases where the output by-product of a donor matches the exact input specifications of a receiver, or indirectly, in those cases where the by-product of the donor company would require some form of conversion/work done so as to match the input requirements of the receiver. It is expected that the latter instance is more likely to be prevalent within this study, given that by-product streams are generally of lower quality.

It should be noted that a 'conversion process' may involve different disciplines, be they mechanical, chemical, thermal, etc. while it may also require a change in form of the original by-product, such as a) the conversion from one form of energy to another, b) a change in form of a material to another, as well as c) a conversion from a material resource to an energy resource (e.g. as would be the case of an RDF co-generation plant, the conversion of oils to biofuels, etc.).

Beyond the simplistic model presented by the schematic, it is also clear that the larger and more diverse the cluster is, the more probable are the possibilities to realise IS relationships, further substantiating the earlier arguments in favour of a more diverse cluster by Chen et al. [12] and Taddeo et al. [35].

While the schematic in Figure 9 does not portray a perfect circular economic model - in simple terms, a perfect circular economy would be portrayed by an industry whose waste flow (red tab) would be nil, whereas the input would be predominantly catered for from recovered resources (green tab) - it does indicate that Industrial Symbiosis offers a favourable contribution towards the transition from a linear to an idealised circular economic system.

3.2.2 A Concise Review of IT Platforms and Software Packages

The creation of a resource flow database is the first step towards the discovery of IS opportunities, and therefore its formation is essential. Throughout the literature review it has been noted that many authors have either created custom database structures tailored for their requirements, or relied on third party developments.

Following in this chapter is a concise review of some of the software packages available on the market. Evaluation of these packages has been performed by accessing publicly available information where this was available.

The identification of these packages has been achieved by noting the various software references in the works identified in the literature review, with particular attention to the mentions by Grant et al.s' [36] work in 2010, which paper has already been examined (and therefore superseded) by the more recent work by Maqbool et al.[18] published in 2018 (refer to Figure 10 - List of IT Tools examined by Maqbool et al. Source: [18].

The thematic of both these papers was specifically based on the assessment of the effectiveness of information technology (IT) platforms and/or software packages meant to support Industrial Symbiosis.

Table 2. Results of the content analysis of the IT tools.

#	Name	Status	Funding Body and Funding Amount (in Million €)	Target Users	Available Since/From	Synergy Identification	Symbiosis Assessment	Barrier Removal	Implementation	Follow up
1	SymbioGIS	Completed, not operational	Geneva Govt.	Urban planners	2007	3	3	2	1	1
2	Presteo/LGCD	Completed, not operational	Not available	Industry	2010	3	1	1	1	1
3	Nova light	Completed, not operational	Private	Waste producers and users	2010	3	1	1	1	1
4	SMILE Resource Exchange platform	Operational	Public Private	IS facilitators	2013	3	1	2	1	1
5	eSymbiosis	Completed, not operational	EU 0.9, Others 0.9	Industry	2014	3	1	1	1	1
6	iNex platform	Operational	Private	IS facilitators, industry	2014	3	2	1	1	2
7	IT tool by project Locimap	Completed, not operational	EU 1.9, Others 0.6	Park managers	2014	1	3	2	1	2
8	Resource-eXange-Platform (project ZEROWIN)	Completed, not operational	EU 6.1, Others 3.3	General public	2015	2	1	1	1	2
9	Italian Platform for Industrial Symbiosis	Operational	Not available	Facilitators and industry	2015	2	1	2	1	1
10	CIRCULATOR (tool)	Operational	EIT RawMaterials	all users	2017	1	1	3	1	1
11	Symby-Net (project SYMBIOPTIMA)	In development	EU 6, Others 1.3	Industry, park managers	2018	2	3	1	1	1
12	SymbioSyS (tool)	Operational	Not available	General public	2018	3	2	1	1	1
13	EPOS toolbox by EPOS project	In development	EU 5.4, Others 0.5	Industry	2019	3	2	2	1	1
14	Synergie®(project SHAREBOX)	Operational and continuous update	EU 5.4, Other 0.5	Industry	2019	3	2	2	2	2
15	Maestri (Internet of Things) platform (project Maestri)	In development	EU 5.7	Industry	2019	1	3	2	1	1
16	IT tool by FISSAC project	In development	Not available	Cluster managers, industry	2020	2	3	1	1	1
17	BISEPS-tool (part of BISEPS project)	In development	EU	Park managers	2020	3	2	2	1	1
18	Industrial Symbiosis DATA repository	Operational	Not available	Researcher, IT developers	On going	1	1	2	1	2
19	Symbiosis 3.0 (project SYMBIOSE BE)	Operational	Public	General public	2016	3	1	2	1	1
20	ERMAT web tool	In development	EIT RawMaterials	General public	2018	3	1	1	1	1

Figure 10 - List of IT Tools examined by Maqbool et al. Source: [18]

Although the literature is comparatively recent (2018), an internet-based search was also utilised for a general search so as to identify any available packages which may have been developed more recently than those referenced within the aforementioned papers.

The packages have therefore been reviewed based on their current:

a) **Status:** Is the software Operational, Updated and/or Retrievable?
b) **Level of Relevance:** How relevant is the software to this current study?

Aspects of 'Relevance', in turn, have been evaluated based on any of the following sub-criteria as applicable, namely:

- **Versatility:** allowing for versatility and options to include resource flows in various forms.
- **Energy:** The software needs to cater for energy resources in its various forms, alongside material resources.
- **Qualitative:** Data collection shall not be limited to quantitative data, but should provide sufficient qualitative information to allow for a thorough analysis. This should include fields such as 'Type' and 'Form', as well as allow users to specify resource 'Cleanliness' (where applicable).
- **Sharable:** Easily distributable to various entities who may utilise different IT platforms.
- **Licensing:** The software needs to be provided with an open-source license, or as a minimum requirement to provide a demo version prior to actual purchasing/licensing.

The following Table 1 summarises the twenty IT platforms or software packages which were reviewed in this current work.

Table 1 - IT Platforms and Software Package Review

Name	Status	Relevance	Notes
SMILE [6] - Resource exchange platform	Not Operational		Since Dec 2018
eSymbiosis [7]	Not Operational		Former Life+ Project. Developers contacted by email and referred to new generation software DigiCirc (see below)
INEX Platform [8]	Operational	No - Operates in France. Requires Licensing	Private set-up. Provides for an interesting platform for French companies to search for synergies.
ENEA [9] (Italian Platform for IS)	Operational	No - Operates in Italy. Requires Licensing and Registration	Government set-up. Provides for an interesting platform for Italian companies to search for synergies.
Circulator [10]	Operational	No - Provides data on examples of IS in the EU, but not database related	Supported by the EU EIT body.
SYmBIOPTIMA [11]	Not Operational		Former Horizon 2020 project. It developed an integrated Energy and Resource Management System for internal company use.
SymbioSYS [12]	Not Operational	No - waste streams are restricted to 14 specific streams. Platform unavailable until early 2022	Academic project which structure is similar to what is required, however platform is being re-hashed and won't be available until early 2022. Details of the validation strategy for the project is available by Alvarez et al. [41]

[6] https://www.facebook.com/smileexchange/
[7] https://www.youtube.com/watch?v=EQpzQjrEgCo
[8] https://www.inex-circular.com/eng/1/home
[9] https://risorse.sostenibilita.enea.it/projects
[10] https://www.circulator.eu/
[11] https://cordis.europa.eu/project/id/680426
[12] https://symbiosys.unican.es/

Name	Status	Relevance	Notes
EPOS ToolBox / Spire2030 [13]	In Development	No - no resources are accessible	Horizon 2020 - Spire Project
Synergie / Sharebox [14]	In Development	No - no database building resources or platform	Horizon 2020 - Spire Project - Website provides access to interesting informational resources, other than database building
Maestri Project [15]	In Development	No - no database building resources or platform	Website provides access to interesting informational resources, other than database building
FISSAC Project [16]	Terminated	No - access to platform by registration, but registration is inaccessible	Horizon 2020 Project
BISEPS [17]	Operational	No - focuses solely on energy. Creates IS by networking not database of resources	Interreg Project
IS Data [18]	Operational	No	A repository of Data related to waste, but not a database creation tool or an IS networking tool
SYMBI [19]	Operational	No - Information Dissemination only	
DigiCirc [20]	Operational	No - Low penetration and too broad a scope	Horizon 2020 Project - a Repository of Data related to anything having a connection to the environment

[13] https://www.spire2030.eu/epos
[14] http://sharebox-project.eu
[15] https://maestri-spire.eu/
[16] http://fissacproject.eu/
[17] http://www.biseps.eu/
[18] http://isdata.org/
[19] https://www.interregeurope.eu/symbi/
[20] https://digicirc.eu/tools/

Name	Status	Relevance	Notes
SynerGie 4.0 [21]	Terminated		Private set-up, having a large database for multiple countries but not Malta. Replaced by similar CircLean software
CircLean [22]	In Development	No - related to setting up of EIP's	
Scaler Project [23]	Operational	No - Not a tool to create database of resources	Provides interesting reports on guidelines towards Industrial Symbiosis
#CEstakeholderEU [24]	Operational	No - Not a tool to create database of resources	Provides a repository of databases for anything related to circular economy across EU member states
ZeroWin	Not Operational		Former Life+ Project ended in 2014

As may be observed form the above listing, interest in the development of such packages has been incentivised with institutionalised funding (for eight packages out of twenty), through funding programs such as Interreg, Horizon 2020 and Life+. However, it is typically noted that the operational lifetime of such packages does not make it past the funding/project period.

At best, the information gathered and the conclusions/goals achieved during such projects is documented. However, any functional IT platforms or associated software developments, which may have been created as part of such funding programs seems to be no longer supported, if at all available.

Whilst such a result is disheartening, this situation was somewhat predictable as it mirrors the same outcome experienced previously by Maqbool et al. when performing a similar exercise on the packages mentioned in Grant et al. In turn, this was also

[21] www.international-synergies.com
[22] https://www.international-synergies.com/ourprojects/europe-circlean-european-commission-dg-grow-2019-ongoing/
[23] https://www.scalerproject.eu/
[24] https://circulareconomy.europa.eu/platform/en/dialogue/existing-eu-platforms/

experienced by the same Grant et al., when they also indicated that only four out of thirteen tools discovered were operational [18].

Whilst acknowledging that a wealth of data related to the theoretical aspects of IS can be sourced from the above reviewed packages[25], the analysis also notes that there seems to be no one package which can be considered as suitable or sufficiently relevant to address the demands for this particular study.

Considering this, it has therefore been concluded that the best approach towards establishing the IS potential at the Ħal Far industrial estate is to create a custom database, thereby retaining full control and flexibility of the query fields. The design characteristics for such a questionnaire are defined in greater detail in the following section 3.2.3.

3.2.3 Designing a Custom Questionnaire

A custom questionnaire was deemed to be the most effective measure to populate the necessary dataset leading to an 'opportunity discovery process', due to the inability to source a pre-available tool which could cater for such requirements. The data to be sourced from such a questionnaire would therefore investigate those aspects associated with the potential to form IS relationships within the designated cluster. A copy of this questionnaire is being provided in Appendix 1 of this study.

A custom-built questionnaire will not only provide sufficient flexibility to cater for a wide spectrum of resources as potentially identified at the Ħal Far Industrial Estate at the required resolution levels, but may also be tailored to assess other qualitative data which are not directly related to resource IOs; particularly for queries related to the readiness of participants for IS.

[25] The data has been safeguarded as a consequence of documentation and publishing obligations typical of such funding programmes.

The questionnaire therefore addresses the need to:

a) Establish a uniform **method of classification**, which is simple to understand, yet includes sufficient detail to enable matching of resources.
b) Provide **qualitative data** on the resources which are to be made available, to complement the resource matching exercise. In this regard, qualitative data is given precedence over quantitative data. Furthermore, the resolution of the quantitative data need not be high for the purposes of an ‘opportunity discovery’ exercise. A lower resolution is also thought to allow for a quicker and less-threatening compilation of the data.
c) Gauge the participants’ readiness for IS, particularly their ability to share data on resource and collaborate (**trust**).

Given that the exercise required to gather the data could be perceived by some participants as complex and time consuming, it may be more opportune to segregate the questionnaire by resource type, i.e. distinguishing between energy and material resources as well as their respective input and output streams. This segregation should aid in the compilation of data particularly for those organisations where energy and material resources would classically fall under the responsibility of different departments (say EHS, technical, purchasing, etc.).

A section which investigates the non-resource related queries should also be included separately.

Assuming that a further introductory section should be reserved to informing participants of the scope of the study, the guidelines on filling in the questionnaire, and other matters related to General Data Protection Regulations (GDPR), it is being suggested that the questionnaire should be divided into six (6) sections. A conceptual data flow model would therefore suggest the following structure as shown in Figure 11:

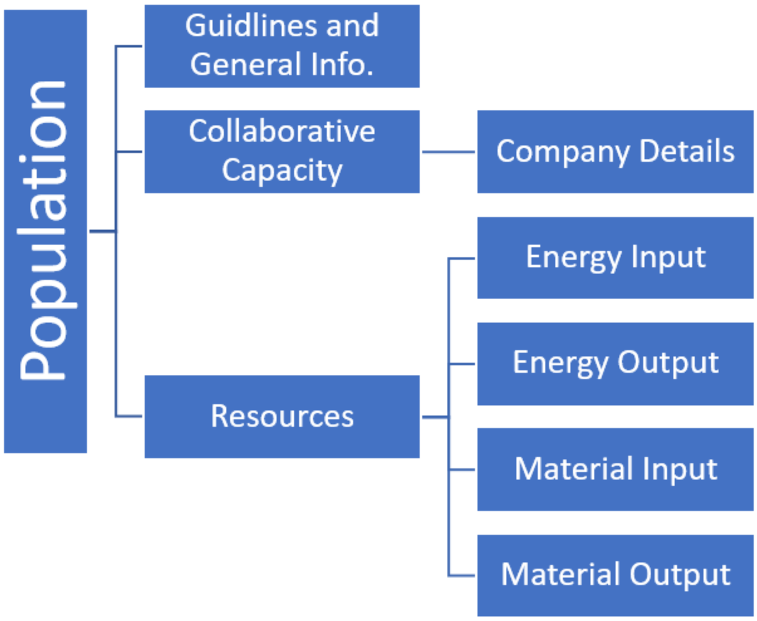


Figure 11 - Conceptual data model for the custom questionnaire

For the sake of coherence, and in order to provide a structured document (method of classification) while also limiting inconvenience to the participants (hence improving on the response rate), the questionnaire was designed to provide standard pre-set options, presented in a sequence of intuitive drop-down menus.

Furthermore, in order not to limit the capturing of data to such pre-sets only, thus also allowing for some additional flexibility, fields were provided allowing for custom entries to participants. The individual 'Tabs' are explained in the forthcoming sections and are made available in Appendix 1 of this document.

3.2.3.1 Tab 1 - Description of research project and instructions to the survey

The first section is purely administrative, and provides details regarding the scope of the research, thereby not only complying with GDPR requirements by specifying why such data is being requested, but was also informing participants of what data and level of detail (resolution) was required.

The resolution level requested was based on a 'ball-park' estimate. As noted earlier, data with high resolution would be cumbersome and time consuming to compile, thereby potentially acting as a deterrent to participation levels (lower response). This was not expected to be of major concern to the quality of this study, as high-level estimates should suffice to allow for the discovery of potential IS relationships.

The questionnaire was presented as a means of cataloguing resources which were 'being wasted', and a lessor emphasis was made on the term 'Industrial Symbiosis' throughout, so as not to distract or prejudice the participants, while also implicitly incentivising participation.

Given that IS relationships were more likely to come to fruition if they were economically viable, participation was more likely possible if participants were presented with an opportunity to supplement economic value, and valorise resources which they were currently discarding (wasting).

3.2.3.2 Tab 2 - GDPR and company organisational details relevant to the study

The second section starts off by querying basic contact information details of the participating entity, besides other GDPR considerations relevant to such information. This section also noted two important indicators of a company's readiness to collaborate.

The first query field (Figure 12) relates to the technical capacity of the entity in terms of its environmental and resource-efficiency support. It is being posited that entities which do employ personnel specifically for such tasks would be more favourable to actively participate in the research (refer to section 4.2.1.4).

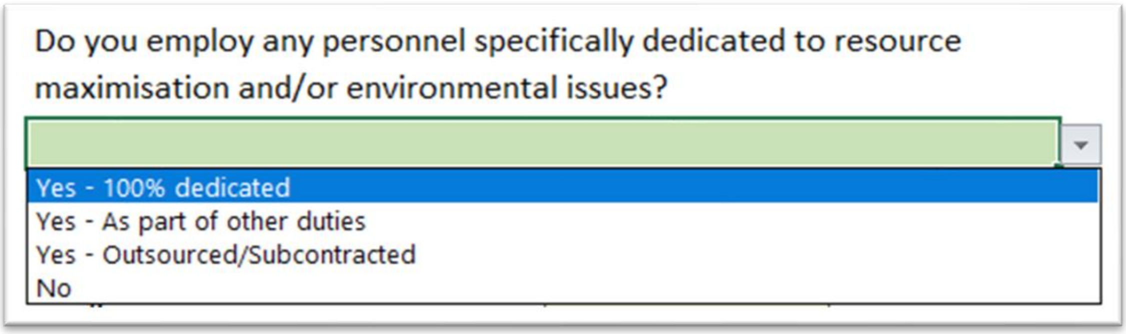


Figure 12 - Internal Expertise Query Field

The second query field (Figure 13) relates to the secrecy of operation of an entity, i.e. an insight into the sensitivity the participants' operations and their ability to provide details of their resources for the scope of this research, beyond the legal and/or corporate obligations (refer to section 4.2.1.2). Industries providing sensitive services, or operating in highly competitive markets, may not be willing to neither share their waste resources, nor provide relevant data for it.

This is considered as highly relevant to this research, given the importance of 'ability' when forming IS networks. Entities operating in highly sensitive sectors are therefore unlikely to participate in such projects, therefore hindering their IS capacity.

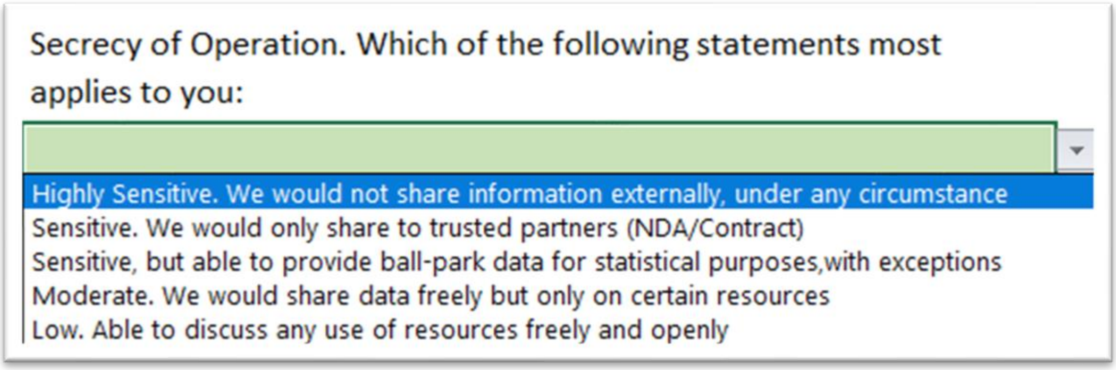


Figure 13 - Secrecy of Operation Query Field

As an incentive to overcome participants' possible apprehension from releasing sensitive data, the questionnaire has emphasised (in both Tab 1 and Tab 2) that the data need not be accurate, and that a lesser resolution (ball-park estimate or range) would suffice for this scope.

3.2.3.3 Tab 3 - Energy Inflow (Part A - Fuel; Part B - Thermal)

This and the forthcoming tabs now focus on resource inflows and outflows, starting off with energy inflow. As noted earlier, this section omits electrical energy given that the re-sale of electrical energy is heavily regulated, but relates to other forms of energy namely chemical and thermal (with options to highlight other in custom entries, if such options are at all available).

Section A of this tab therefore enquires on the use of fuels used by the entity (refer to Figure 14). The goal of this query is to take stock of what fuels are used at the time of participation, and therefore possibly find direct or indirect substitutes for them.

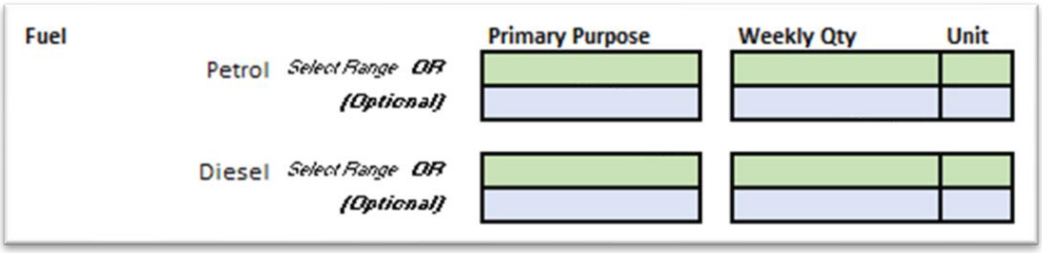


Figure 14 - Fuel Inflow Query Fields

Fuels for the scope of mobility (classically Diesel and Petrol) were excluded, primarily so as not to over-shadow the use of fuel for other industrial processes (given the predominant use of fuels for mobility), and secondly due to the difficulty in converting vehicles from one fuel type to another, which is typically a delicate and cost sensitive intervention.

Section B of the questionnaire takes a more direct approach towards the heating requirements of the participating entities, not only gauging the requirements for applications such as ambient heating, but also extending to industrial heating demands (Figure 15). such as furnaces, oil baths etc., which appliances are generally presumed to be more energy intensive than ambient heating

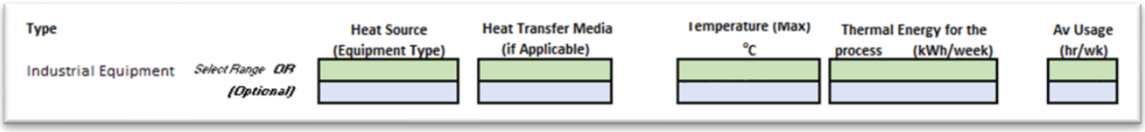


Figure 15 - Thermal Energy Inflow Query Fields

In such case where the participant may not have had the technical capacity or ability to quantify these fields, an alternate approach (see Figure 16) was offered whereby the participant was invited to provide details of the equipment. Reasonable estimates would be eventually computed upon the return of the survey.

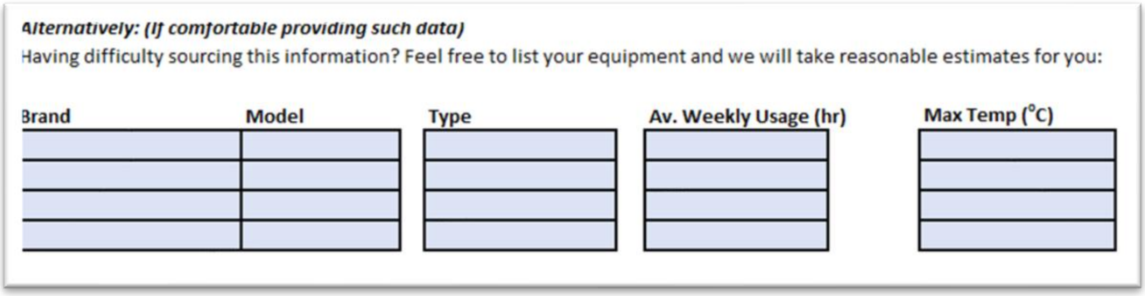


Figure 16 - Custom Entry Query Fields for Details related to Equipment for the Generation of Thermal Energy

The significant information in this section was not only the query field regarding the source of such thermal energy (e.g. solar/heat pump/boiler etc.), but also the information related to the delivery parameters of such energy particularly the choice of heat transferring media as well as the operating temperature.

Such parameters would therefore not only relate to a 'quantifiable' measure of energy, but were considered as critical operational parameters necessary to establish whether or not potential symbiotic relationships existed (section 4.3).

3.2.3.4 Tab 4 - Energy Outflow (Part C - Thermal/Cooling)

This section relates to the participating entities' energy outflows particularly for ambient climate cooling, industrial equipment cooling, and for other purposes as may be the case.

Consistent with the requirements of Tab 3 presented earlier, the focus is not on the actual source which is generating/rejecting energy, (i.e. such as the manufacturing equipment benefitting from such cooling), but rather on the method of delivery employed to transfer this excess heat from the source and expel it to ambient.

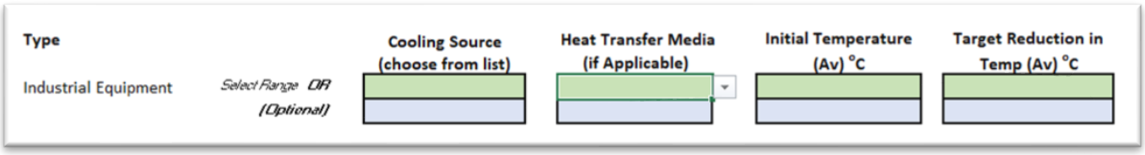


Figure 17 - Energy Outflow Query Fields

Similarly, to the Energy Inflow section, the data fields of greater significance were the qualitative parameters which, depending on their nature, would either enable or limit potential resource sharing initiatives (Figure 17).

These parameters would therefore indicate the possibility for IS for energy in the form of an energy cascade (section 2.4 and section 4.3), if such potential exists.

Notably absent in this section was the outflow of chemical energy (fuels). This field was not included in this energy-related section (contrary to its inflow counterpart in Part 3), but was instead nested within the 'Material Waste' topic in the subsequent Part 5. While the classification may be considered as incorrect, this was done intentionally, based on the reasoning explained further on in the next section.

3.2.3.5 Tab 5 - Material Outflow (Part D - Material Waste)

This section relates to Material Resource Outflow, more commonly associated with waste. In keeping with the method of this questionnaire, while a quantitative element was always present, the data fields of greater significance were the qualitative fields (refer to snippets in Figure 18 and Figure 19), which in this case segregated the various expected waste streams by:

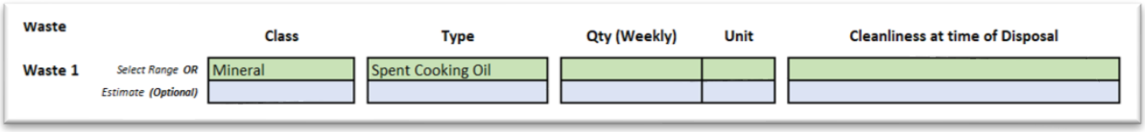


Figure 18 - Material Outflow Query Fields (Part 1)

- **Class** - refers to the family category namely, Chemical, Mineral, Food-waste/Organic, Metals, Polymers etc.
- **Type** - to further differentiate the ‘Class’ by its type. This field varies according to what ‘Class’ category is chosen (e.g. ‘Metals’ may be subdivided in ‘Ferrous’ and ‘Non-Ferrous’, etc.)
- **Cleanliness** - specifies the level of cleanliness of the stream at point of disposal

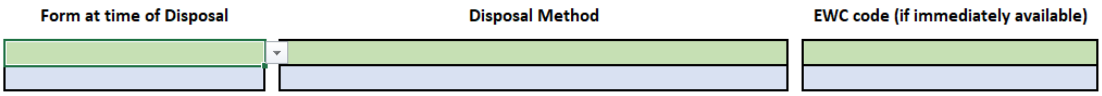


Figure 19 - Material Outflow Query Fields (Part 2)

- **Form** - Specifies the form of the resource stream at time of disposal
- **Disposal Method** - Identifies the method of disposal of the particular stream, and differentiates between ‘Landfilling’, ‘Recycling-Local’, ‘Recycled-Foreign’, ‘Reused Internally’ or ‘Reused Externally’. It is interesting to note that both ‘Reused’ fields may indicate pre-existing symbiotic relationships, and were therefore very significant to this study (refer to section 4.4.1.3).
- **EWC-Code** - Which field requests the participant to indicate the EWC code for that particular stream. It is acknowledged that this information may be particularly complex to obtain, particularly for participants who may lack the technical capacity or waste expertise. In order not to alienate such participants, this field was marked as an ‘optional’.

As noted earlier, within the ‘Class’ fields one finds the ‘Fuels and Oils’ class, which was nested in this Tab, rather than in the more categorically-correct ‘Energy Outflow’ section in Tab 4 above. This deliberate inaccuracy is being justified due to the way in which fuels and oils are typically disposed of in industry.

Waste fuels are stored in bulk containers until reaching a specific capacity (volume) which is considered to be economically viable to dispose of. In such instances, such waste is eventually brokered away in similar fashion to other material waste streams. In this respect, fuel is not treated as a form energy, but is rather considered as a material resource.

It is therefore unlikely that participants would recognise the potential that spent oils/solvents/chemicals may have in terms of energy content. Therefore, in order to facilitate compilation of this questionnaire, it was considered that such data would be best collected through an association with material waste resources, rather than with energy.

3.2.3.6 Tab 6 - Material Inflow (Part E - Material Inflow)

The last Tab in the questionnaire relates to material inflows. This section has been left for last out of consideration to the potentially sensitivity nature (commercial or otherwise) of this information. Requesting such data at an early stage of the compilation process would have risked alienating potential participants thereby affecting response.

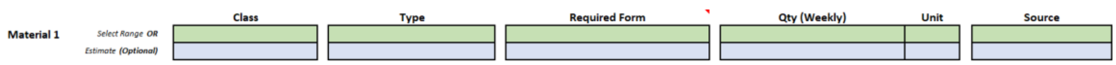


Figure 20 - Material Inflow Query Fields

The format of this section (shown above in Figure 20) mirrors closely that of the corresponding ‘Material Outflow - Tab 5’ above, particularly in the ‘Class’ and ‘Type’ fields, with the main differences being as follows:

- **Required Form** - substitutes the ‘Cleanliness’ field and provides options for the participant to further differentiate the stream in the various forms that particular ‘Class’ of resource may be required in.
- **Source** - specifies whether the resource originates from virgin sources (brand new) or from alternative sources (e.g. internal bi-products, recovered, etc.). The latter may indicate pre-existing symbiotic relationships, and were therefore very significant to the study.

4. Opportunity Discovery Stage (Procedure)

The completion of the 'resource mapping' exercise described earlier provided the fundamental data required to perform the 'opportunity discovery process', which process is described as "*the initiator for further development of IS*" [9].

As expressed in section 2.7, Yeo et al. [9] noted that there are different forms of mechanisms aimed at classifying an opportunity discovery process, which mechanism depends on the particular characteristics of a cluster. It has been concluded that the mechanism which was most applicable to this current case study is the "*Process input/output stream-based matching mechanism".*

This mechanism relies on matching the characteristics of output resources with the input resource requirements, thereby identifying potential 'donors' and potential 'recipients'. While this process may be driven by the free-market alone, (i.e. participants voluntarily and independently placing output resources for sale), it is unlikely to occur organically, and would be best coordinated by a central entity.

This type of mechanism is also preferred in those instances where an opportunity/relationship may exist indirectly, thereby further requiring the identification of an intermediary process (typically offered by a third party) to upgrade an output resource to reach the appropriate specifications for the recipient's input requirements.

It should be noted that this current study is limited to the discovery of such an opportunity by matching the input and output streams, without going into the merits of the financial or economic feasibility to actually render the substitution possible (where such is required).

As some of these opportunities may require extensive infrastructural upgrades/investment, they may also require a more in-depth technical feasibility study to ascertain their viability. This current study is therefore limited to describing a methodical approach by which such opportunities can be discovered, and thereby establish a ball-park benchmark of the potential benefits of IS within the Ħal Far Industrial Estate cluster.

The following sections defines the different thematics and the objectives for this current study, and provides the methodology used to establish the IS potential within the cluster.

4.1 Structuring the Resource IO Database

Further to the dissemination and eventual receipt of the questionnaire, the first process within the opportunity discovery stage was to prepare the resource IO database, i.e. a structured recipient of the data which allowed for a methodical analytical process.

Given the varying depth of the objectives of this study and the different characteristics of the resources under examination, this database was divided into three sections representing the following thematics, namely:

- Collaborative Capacity within the cluster,
- Energy Resource Thematic,
- Material Resource Thematic.

Once equipped with a holistic resource IO database, the stream-based matching process was initiated. The database fields shall reflect the data received from the participants as relevant to the specific thematic.

Essentially, the objectives of this exercise for each thematic were as identified in Figure 21 below, and are described in greater detail in the following respective sections:

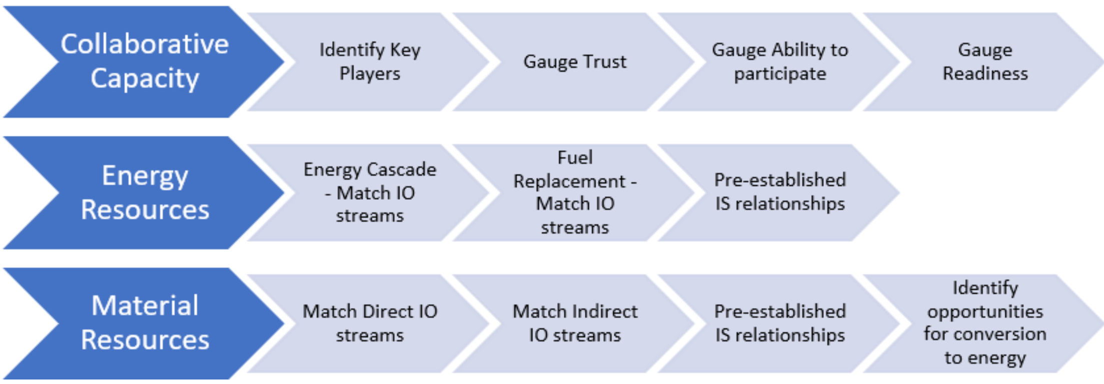


Figure 21 - Opportunity Discovery Process Targets

4.2 Thematic: Collaborative Capacity

This first thematic does not relate directly to resources, but focuses on gauging the connective relationships and organisational barriers (Section 2.6.3) within the cluster, essentially providing a qualitative method to measure the readiness of the cluster for IS.

The source of the information related to this thematic was nested in Tab 2 of the questionnaire. The collated data relevant to this thematic is provided in Section 5.1 of this document.

4.2.1 Thematic Objectives

The objectives of this thematic were to:

a) Identify key players and drivers within the cluster;
b) Gauge the trust of an entity to collaborate with neighbours;
c) Gauge the ability of the participants to collaborate;
d) Gauge the readiness of an organisation for potential IS relationships.

4.2.1.1 Objective 1A: Key Players and Drivers

This objective is likely to be the most subjective of all, given that there is no direct measure to determine a ranking. In this regard, each participant would be assigned a score based on the level of enthusiasm which they showed towards the current research and on the quality of the submission.

This objective shall thus be measured based on the following three factors, namely:

a) Acceptance to receive feedback

Within Tab 2, the participants were invited to provide their details and asked whether they wished to receive feedback on findings which are relevant to their organisation (Figure 22). Clearly, those participants who do not provide such details were unlikely to be drivers to IS, and would be excluded from such a ranking.

Figure 22 - The 'Feedback permission' toggle

b) Response time

In accordance to GDPR obligations, it was agreed that participant details would be omitted, with their individual designations rebranded with an anonymous label in the form of 'Participant X', with 'X' being a sequential number assigned upon submission of the questionnaire. Therefore, such a number would rank participants by submission response time.

A score, up to a maximum of 100 points was assigned proportionally to the respondents in accordance to their ranking, with 100 assigned to the quickest respondent and the remaining points distributed evenly between the remaining participants. Non-respondents, or respondents failing to indicate interest in being contacted (see 'a' above), were excluded from this measure.

c) Level of detail in filling the questionnaire

Participants were assigned a score from 0 - 100 based on the level of detail that they provide in the questionnaire. As this metric is highly subjective, the following guidance displayed in Table 2 shall be used when assigning such scoring.

Table 2 - Guidance Scores for Level of Detail

Score Range	Level of Detail
80 - 100	Very detailed submission, with data provided for all tabs, multiple streams provided, all qualitative fields completed.
60 - 80	Detailed submission, with data provided for all tabs, some streams provided, most qualitative fields completed.
40 - 60	Average submission, with data provided for most tabs, some streams provided, some qualitative fields completed.
20 - 40	Poor submission, with data provided for some tabs, few streams provided, some qualitative fields completed.
0 - 20	Scantly detailed submission, data provided for only one (or few) tabs, few streams provided, mostly missing qualitative data.

It may be argued that a very detailed response will take longer to submit, and therefore the response-time score would be lower. Given that the detail-score is a far more important indicator of quality than the response-score, a weighting in favour of detail-score was arbitrarily applied.

Enthusiasm was therefore ranked by summing both the above-mentioned scores with a respective weighting as follows:

Enthusiasm Score (out of 100) = 15% (Response time score) + 85% (Detail score)

The participants were ranked according to this final score, with the key players and drivers identified by considering the top 33% entries. It should be noted that this ranking is purely arbitrary and subject to the interpretation of the researcher. It is therefore a measure meant to assist with the interpretation of the results, and narrow the focal point for IS facilitators in distinguishing the key players within a cluster, but not meant to exclude any potential participants.

4.2.1.2 Objective 1B: Gauging Trust Levels (Response Rate)

Trust, has been mentioned throughout the reviewed literature as having a major influence within successful IS relationships. It relates to the ability of an entity to form a connective relationship with a third-party industry, and is therefore considered as a main factor towards the sustainability of any IS relationship.

Industries within the same cluster may in some instances be competitors, and therefore the dissemination of potentially sensitive information on resource flows may be perceived as a risk to competition. This is undeniably a barrier towards resource mapping, with the inevitable consequence of missing out on the creation of IS relationships. With emphasis on this exercise, participants who may not trust others would be unlikely to participate in the questionnaire given that participation was completely voluntary.

In such respect, a correlation between level of trust within the cluster, and the questionnaire’s response rate was created. While participation to the survey was highly encouraged, the non-response to the questionnaire was, in itself a significant indicator.

In such circumstances, this factor would highlight the lack of trust between neighbouring industries within the cluster, especially in cases where such organisations were neither internal nor affiliated. This lack of trust would therefore inhibit both the creation, as well as an organic evolution of IS relationships.

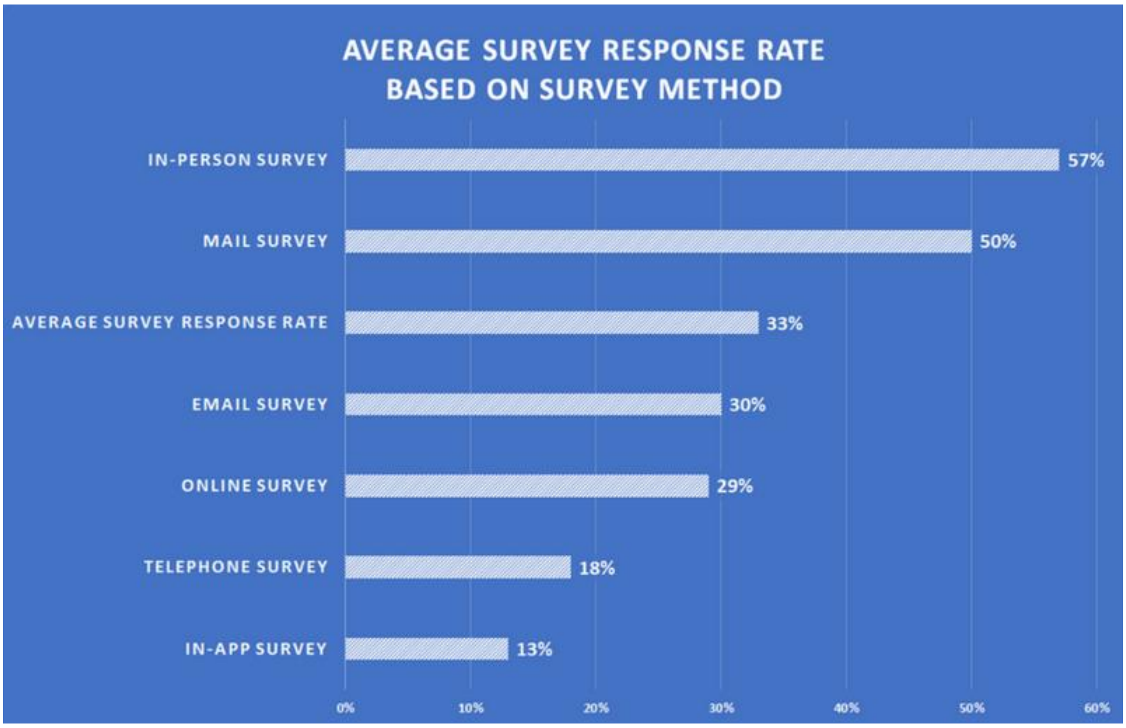


Figure 23 - Average Survey Response Rate by survey method. Image and data source [42]

It is considered that the average survey response rate is of 33%, reducing this number to 30% for surveys sent by email [41], as was the case of this current work's questionnaire. While this metric is rather subjective, a 20 - 30% average response rate for email surveys has also been corroborated in other literature [42][43], and shall therefore be taken as a baseline for this current study. Figure 23 above provides for the average survey response rate by various forms of survey methods.

Considering the above, a response rate within the 30 - 40% bracket shall be considered as the target response rate, and therefore indicative of a good level of trust between participants.

Response greater than 40% may be considered to be exceptionally good, while a response in the 20 - 30% bracket may be considered low. Response rates lower than 20% are to be considered as very poor. These ranges are summarised in Table 3.

Table 3 - Correlation of Response Rate with Trust

Response Rate Range	Quality	Trust bearing
> 40%	Exceptional (above Average)	the cluster enjoys exceptional trust between participants, suggesting that relationships are already present or can be easily established
30% - 40%	Good (Above average)	The level of trust is good and at par with expectations. There is suitable potential to form relationships.
20% - < 30%	Low (Average)	There may be some elements of concern which may hinder relationships, but there is still potential
< 20%	Poor (considerably below average)	Trust is extremely poor and building relationships may be more challenging.

4.2.1.3 Objective 1C: Gauging the Ability to participate

Independently of both ‘trust’ and ‘readiness’ levels, is the ‘ability’ of a company to participate in such a resource mapping exercise. This objective acknowledges that a company may operate within a rigid regulatory/legal/corporate framework which limits its ability to disseminate information on resource flow, and/or to provide the necessary data for resource mapping.

Also derived from a straightforward query, this objective finds its information within the second enquiry of the questionnaire nested in Tab 2 (refer to Figure 13 - Secrecy of Operation Query Field) which allows for different levels of freedom.

The ‘ability’ of a company operating in a highly sensitive/regulated environment to participate in IS activities is severely jeopardised, and therefore it is unlikely to establish IS relationships.

Nevertheless, it may be premature to exclude a company operating in a highly sensitive environment from the onset, given that such restrictions may only apply to specific streams, whilst a more liberal approach may be taken on others, e.g. an industry may be unable to provide details of its use of, say, gold leaf, but may be at liberty to provide data regarding their packaging waste, or their heating capacity. An option to cater for such instances was therefore included within the query field.

4.2.1.4 Objective 1D: Gauge Readiness (Internal Expertise)

The readiness of a company with respect to its potential to collaborate on IS relationships is associated with its ability to understand its own internal flows, as well as on its level of commitment towards dedicating internal resources to environmental-related disciplines (such as waste, energy resources, material resource).

The most straightforward of objectives therefore finds its information within the first enquiry of the questionnaire (nested in Tab 2 as presented in Figure 24) which suggested different levels of commitment/investment in expertise.

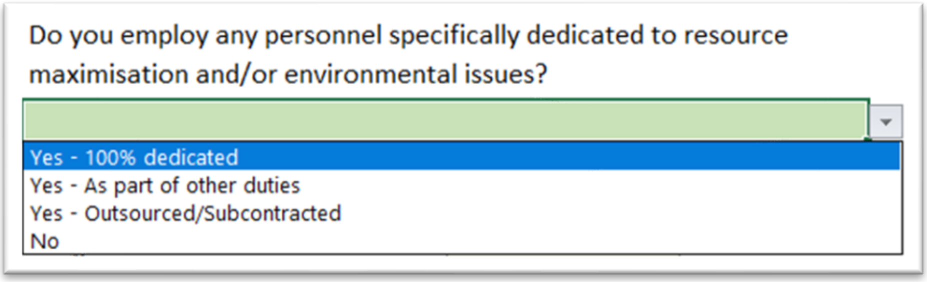


Figure 24 - The 'Internal Expertise' Query Field

Measuring the level of commitment in internal expertise within a company is therefore a strong indicator of the company's commitment towards the environmental thematic, i.e. its potential readiness to participate in IS relationships.

It is being posited that entities which employ personnel specifically for such tasks will not only be more willing to actively participate in this current research, but will also be more receptive towards outreach for potential IS relationships.

4.3 Thematic: Energy Resource IO

The source of information related to this thematic is nested in Tab 3 (Energy Inflow), where 'Fuels' and 'Heating' have been separated in two different sections, and Tab 4 (Energy Outflow) of the questionnaire. Details of waste fuels were not included as part of Tab 4, but were instead been included in Tab 5 (Material Outflow) (this reasoning is explained in detail in section 3.2.3.4).

As noted in section 2.4, energy themed IS may occur in three modes, namely, as bioenergy production (from waste materials), as fuel replacement, and as an energy cascade (Fraccascia et al. [15]). ‘Energy from waste’ is closely related to material resources, and is therefore dealt with as part of objective 3D (Section 4.4.1.4).

‘Fuel replacement’ takes place in instances when waste fuels can be used to substitute fossil fuels (e.g. for use in gas/HFO/coal-fired boilers). In this case a relationship is rather straightforward, and can be either direct or indirect (requiring some conversion process).

An ‘energy cascade’ occurs when the output energy from one industry is of sufficiently high quality to substitute (in whole or in part) the energy demand of another (the receiver). This particular mode is expected to be the predominant driver within this thematic.

4.3.1 Thematic Objectives

The objectives of this thematic are:

a) Energy Cascade - Matching of energy IO streams;
b) Fuel Replacement - Matching of fuel IO streams;
c) Establish the existence of pre-established IS relationships.

4.3.1.1 Objective 2A: Energy Cascade - Matching of energy IO streams

This objective seeks to identify energy-focused IS relationships within the participating cluster through an energy cascade model. These relationships can also be direct as well as indirect. However, the likelihood of such being direct is rather low, suggesting that some form of conversion may be necessary as an intermediate step.

Conversion is a generic term which is being floated to describe any mechanical, chemical, or other type of process employed to change the qualitative characteristics of the output stream, thereby upgrading the output stream characteristics to match those of the input streams.

A practical example of such would be the inclusion of a heat exchanger between a donor stream operating with one type of heat transfer medium, and a recipient stream operating with a different heat transfer medium.

Considering that the identification of viable energy cascade streams is dependent on multiple parameters this process may pose a complex task. In this regard, the IO resource database for energy necessitates structuring the data in a way that facilitates the matching process, so as to simplify the identification of donors and recipients.

The following database fields have been recognised as being the critical parameters, and the database was designed in such a way as to allow for the structured handling of this data. The fields are as follows:

- **Entry number** - a unique identifier for every IO entry;
- **Heating/Cooling -** to identify an entry as a heating (energy inflow) or a cooling (energy outflow) requirement;
- **Type - Ambient/Ind. Equip.** - to distinguish between flows required for the heating or cooling of industrial equipment, and flows required for the heating or cooling of ambient surroundings. Ambient cooling/heating is considered as seasonal, whereas Industrial heating/cooling is less variable with season.
- **Participant ID -** to distinguish the owner of the flow;
- **Source -** To identify the type of equipment used to achieve the energy flow. For a relationship to be successful, the equipment used needs to allow for heat transfer beyond the intended scope.
- **Media -** To identify the heat transfer media employed by the equipment. For a relationship to be successful, the media of the donors need to be compatible/relatable with that of the recipients.
- **Op. Temp** - The operating temperature of the media. Target temperature for heating applications, initial temperature and change in temperature (dT) for cooling applications.
- **Thermal Energy -** Thermal energy transferred in kWh/Wk
- **Av. Usage -** The average time (hr/Wk) during which the heat transfer is active.

The data received from the individual questionnaires was therefore extracted and compiled in accordance with the above fields. The compiled list relevant to the energy thematic is being provided in Appendix 2 of this document.

Once the data had been compiled, the following process was undertaken to simplify the discovery of potential relationships in an energy cascade. Starting off with discovering **heating load energy cascades**, the process was as follows:

➢ ***Step 1: Sort by Operating Temperature***

The database was sorted in descending order of magnitude of operating temperature, i.e. starting from the highest temperature first.

➢ ***Step 2: Identify Potential Donors***

Each entry was analysed sequentially (starting from the highest order of magnitude of temperature). Donor entries were identified as those entries originating from:

- Energy outflows (Cooling) - This represents the energy which a participant is using to **reject** heat from his operation. It is therefore that energy which is in excess to the requirements of a participant. Consequently, such a participant is classified as a 'donor', providing a reject (by-product) that can potentially substitute the heating energy requirement of a receiving participant. The recovered energy is thus not the energy which is being rejected by the donor, but that energy which would have had to be sourced by the receiver.
- Industrial Equipment **OR** Ambient type of applications. Both applicable, but to note that industrial outflows are considered as being less susceptible to seasonal variations, and therefore more stable (less disruptive to the receiver).
- A suitable source - Not all cooling equipment can transfer heat beyond its intended scope. Split unit HVAC units for example, are excluded from this selection. However, chiller units (open or closed loop), chimney stacks, and other such equipment may offer such a possibility.

➢ ***Step 3: Identify Potential Receiver(s)***

Once the potential donors were identified, the list was revisited so as to identify potential receivers. The operating temperature of a receiving entry must be of a lower grade to that of a donor entry (cascading), and therefore the original sorting of the list should be retained. Receiving entries were therefore identified by examining the following fields in sequence.

- Energy inflows (Heating) - This represents the energy which the receiver may potentially accept from the donor, which energy may substitute his heating process, and therefore recover energy.
- Industrial Equipment **OR** Ambient type of applications - similarly, industrial inflows are considered as less susceptible to seasonal variations, and therefore less disruptive to the donor. Ambient heating however typically requires lower grade heating than industrial equipment, and could be a viable substitute for lower grade recipients.
- A suitable source - Not all heating equipment can transfer heat beyond their intended scope without requiring major modifications. In terms of industrial heating, this therefore excludes that equipment which uses electrical filaments to heat the equipment directly (such as injection moulding machines). Common split unit heat pumps, would also be excluded. On the contrary, heating applications using fuel-driven boilers or closed loop heat-pump systems would potentially be suitable receivers.
- Compatible Media - Associated with the above, the compatibility of the heat transfer media is also an important consideration. A relationship could be established by means of an intermediary application, such as a heat exchanger on the return line of a heating system. However, the heat transfer media need to operate at relatable temperatures.
- Comparable Type - While an Ambient cooling system could contribute to an Industrial Heating system, it is ‘off-phase’ with an ambient heating system, and thus a less than likely match.
- Energy demand - Ideally, the energy demand of the receiver is comparable (or greater) than that of the donor, so as to maximise the efficiency of the substitution. Whilst a donor reject can be split between more receivers, it is unlikely that such relationship would be feasible.
- Comparable Average Usage - This parameter should be comparable between donor and receiver. Whilst a relationship could still function, a

discrepancy between a donor and receiver would render the relationship less feasible.

- ***Step 4: The physical distance between Donor and Receiver***

After shortlisting the number of potential receivers, a final determining factor should be considered to determine the more efficient fit. This factor relates to the physical distance between the donor and the receiver, which parameter has a significant impact on both the cost of infrastructure as well as on the thermal efficiency of the system.

The larger the distance the greater is the heat transfer loss. In the case where multiple shortlisted potential receivers are available, with all other determining parameter being equal, the receiver which is geographically closer to the donor is therefore the preferred option.

4.3.1.2 Objective 2B: Fuel Replacement - Matching of fuel IO streams

Given that the qualitative characteristics of fuels and thermal energy differ, IS opportunities by 'fuel replacement' are being distinguished as a separate objective from 'energy cascade'.

Fuel replacement can either be direct or indirect. Direct matches for fuel resource would be rather straightforward and follow the 'fuel replacement' model. However, direct fuel replacement would only occur if the outflow fuel's characteristic of 'cleanliness' (as identifiable in Tab 5) matches the inflow's form (which is intrinsically assumed to be pure/clean) (Tab 3). It follows that such matches are considered as unlikely since fuel 'waste' of this quality would be more likely reused in-house, rather than being disposed of. Nevertheless, the questionnaire allowed sufficient flexibility for a participant to indicate such possible entries, if such were at all present.

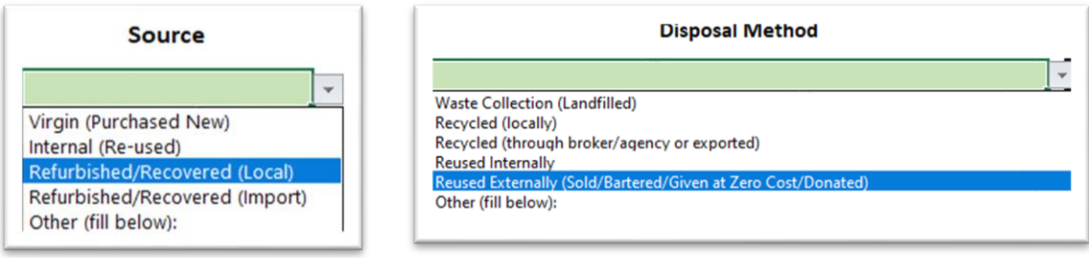
Similarly, the qualitative measures dedicated to indirect relationships are similar to those for direct ones (Tab 5 'Type: Fuel as donor, Tab 3 'Fuel' section as receiver), with the difference that while some quality fields describing the donating stream may indeed be relatable, these would not be able to realise an exact (direct) match. This would therefore indicate that there could be a potential relationship through an intermediate conversion process/intervention.

A practical example of such a conversion would, say, see that a donor fuel may not be of sufficient purity to act as a direct substitute, but would therefore require a cleaning/filtering stage (conversion) to improve its quality up to the receiver's point of entry standard.

4.3.1.3 Objective 2C: Pre-Established IS Relationships (Energy Resources)

The questionnaire allows for the identification of pre-exiting IS relationships by providing pre-set options for both fuels and thermal energy, as well as allowing for custom entry fields as may be required.

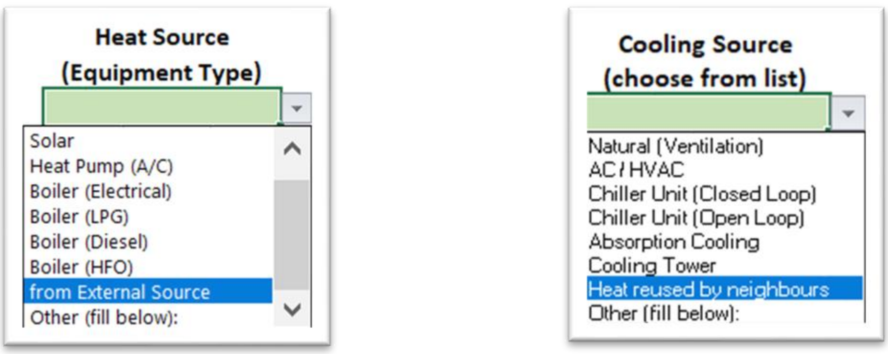
As illustrated in Figure 25, details related to fuel input and output data are available in Tab 3 under the 'Source' field and in Tab 5 under the 'Disposal Method' field. A participant selecting one of these toggles will thus indicate the existence of a pre-established IS relationship for fuel.



(a) *(b)*

Figure 25 - Fuel IO Mapping a) Left - Tab 3 Energy Inflow b) Right - Tab 5 Material Outflow

Similarly, as illustrated in Figure 26, details related to thermal energy IO are available in Tab 3 under the 'Heat Source' toggle, and in Tab 4 under the 'Cooling source' toggle.



(a) *(b)*

Figure 26 - Thermal Energy IO Mapping a) Left Tab 3 Energy Inflow b) Tab 4 - Energy Outflow

4.4 Thematic: Material Resource IO

The source for this information was nested in Tab 5 (Material Outflow) and Tab 6 (Material Inflow) of the questionnaire. The IO resource database for materials was structured as a summary of the different inflow and outflow streams received through the questionnaire.

The fields are as follows:

- **Entry number** - a unique identifier for every IO entry.
- **Inflow/Outflow -** to identify an entry as material inflow or as material outflow (waste)**.**
- **Participant ID -** to distinguish the owner of the flow.
- **Class, Type, Quantity (QTY), Form, Disposal Method and Source** - retains the same definition as adopted for the questionnaire (refer to section 3.2.3.5).
- **Condition -** Substitutes/unifies the fields for 'Cleanliness at time of disposal' for the outflow streams and 'Required Cleanliness Level' for the inflow stream.

The matching process for material resources is less complex than that for energy resources, which process is also common for the first two objectives (matching of IO streams) under this thematic. The process is as follows:

➢ ***Step 1 - Sort data by Class and Type***

Once the data was compiled, it was firstly sorted by **Class** and subsequently by **Type**.

➢ ***Step 2 - Analyse the Form field***

An exercise was undertaken whereby the Form field of the Inflow, was compared to that of the outflow. If the inflow requirement were equal or similar to that of the outflow, then the entry was highlighted as a possible match.

➢ ***Step 3 - Analyse the Condition field***

An exercise was undertaken whereby the condition field of the entries highlighted in Step 2 were compared. If the inflow requirement were equal or inferior to that of the outflow, then the entry was noted as a certain match, potentially being a direct match.

In such case where the condition was not satisfied, further analyses were undertaken to establish the possibility of an indirect match.

This process was repeated for all available 'Class' and 'Type' combinations.

4.4.1 Thematic Objectives

The objectives of this thematic were:

a) Matching direct material IO streams,
b) Matching indirect material IO streams,
c) Establishing the existence of resource recovery measure or pre-established IS relationships,
d) Identifying opportunities for conversion to energy.

4.4.1.1 Objective 3A: Matching of direct material IO streams

The pre-established qualitative measures for material resources vary according to the 'Class' of the stream. In both outflow and inflow tabs, this qualification was further drilled down to 'Type', which is a sub-class field meant to define further the class of materials.

In the Outflow tab, the participants were requested to indicate the form of the resource at time of disposal (in the selection toggle bearing the analogous name), and which inflow counterpart was tabled as 'Required Form'. 'Cleanliness' establishes the degree of purity of such material at time of disposal, with its inflow counterpart tabled as 'Required Cleanliness Level'.

In this case, the distinction between direct and indirect streams for material resource was somewhat more straightforward. For a stream to be qualified as a direct relationship, the quality fields between input and output stream should match perfectly. On the contrary, if 'Class' and 'Form' match, but other quality fields are non-identical, an indirect relationship may exist.

4.4.1.2 Objective 3B: Matching indirect material IO streams

The qualitative measures dedicated to this objective are similar to the above, with the difference being the quality fields may be relatable, but not match exactly. Similarly to indirect matching of energy related IO streams, this would therefore indicate that there could be a potential relationship through some form of conversion process/intervention.

Conversion is a generic term which is used to describe any type of process employed to change the qualitative characteristics of the output stream to match those of the input streams. Such a conversion process requires an additional resource input, (i.e. of energy and/or material), which would therefore result in a larger ecological footprint.

In such regard, a direct match is preferred over an indirect one, yet whilst precedence should be given to directly matched streams, these are less probable to occur, and it is expected that indirect streams would comprise the larger category of the results.

4.4.1.3 Objective 3C: Pre-Established IS Relationships (Material Resources)

The information related to this objective is sourced from two areas. Primarily, Tab 5 - Material Outflow which provides for a 'Disposal Method' field (Figure 27), and allows for two options for reuse. The 'Reused Internally' option indicates the existence of resource recovery measures (internally within the company), while the 'Reused Externally' field suggests the existence of pre-established IS relationships.

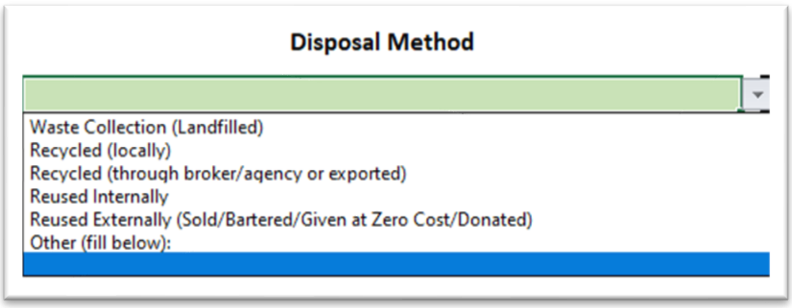


Figure 27 - The 'Disposal Method' Query Field

With respect to its Inflow counterpart, Tab 6 provided for a 'Source' field (Figure 28) which, amongst other options, included two criteria, namely; 'Internal (re-used)' and 'Recovered (local/import)'. The former option indicates the presence of resource recovery measures within the same company, while the latter suggests the existence of pre-established IS relationships, either locally or imported, given that such relationship could exist with members which are external to the cluster.

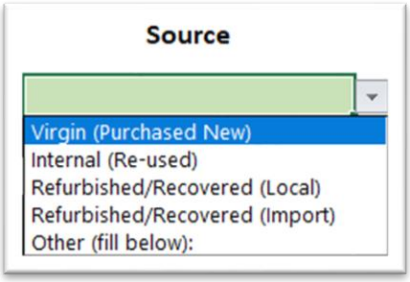


Figure 28 - The 'Source Query' Field

4.4.1.4 Objective 3D: Conversion to Energy

While data (acquired throughout the questionnaire) was collected at participant level, this objective relates to the collective effort of the whole cluster, and therefore sought to identify those resources which were common across the cluster which, when combined together could provide justification for investment in a conversion plant (from material to an energy resource). This objective is tied to the energy thematic, and follows the third classification for energy based IS, as reported by Fraccascia et al.[15], and as noted in section 2.4.

Material resources eligible to classify under this objective are those output streams (Tab 5), which satisfy the following criteria:

a) Flows which were not suitable for inclusion in either Objective 3A, 3B or 3C, so as to prioritise re-use of materials over recovery (in respect of the waste hierarchy).
b) Considered as:
    i. Organic Material, OR
    ii. Spent Oil and Fuel suitable for Biofuel production, OR
    iii. Combustible material providing an average calorific value which is comparable (or higher) to a conventional fuel (e.g. RDF c. 15 MJ/kg).
c) Be available in sufficient quantity (as a total within the cluster) to justify (economically) conversion from a material to an energy resource).

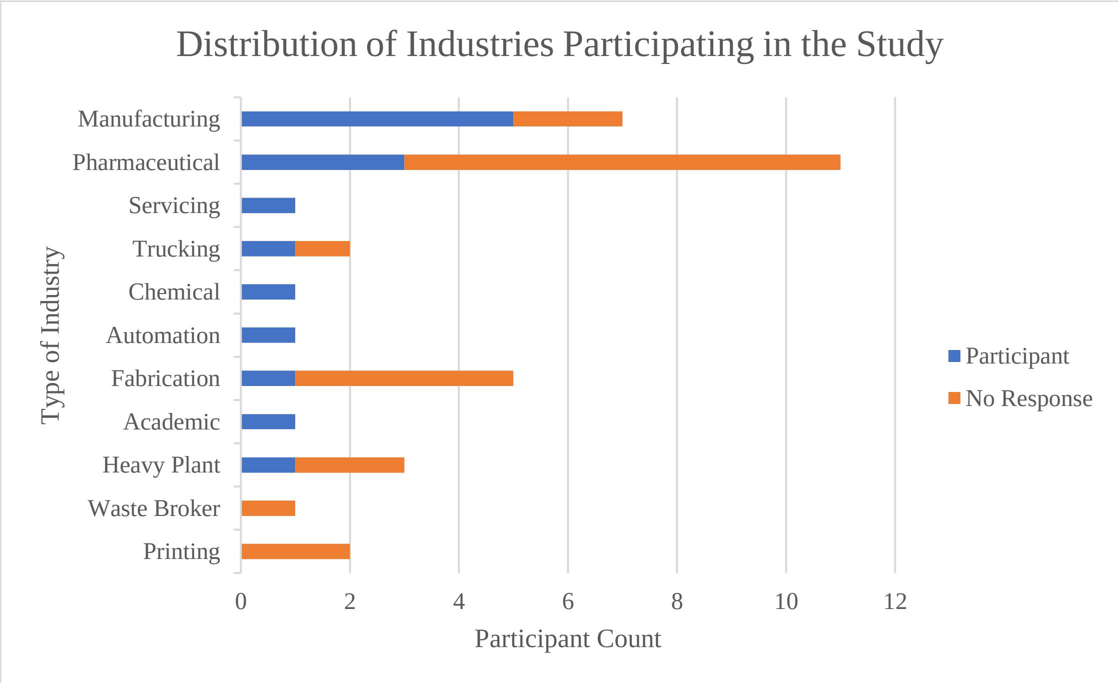
This may include outflow streams in multiple classes, these being 'Chemicals' (as may be applicable), 'Food waste', 'Fuels and Oils', 'Paper Based', 'Polymers', and 'Wood'.

5. Results and Discussions

The following section presents the results of the study undertaken as part of the resource mapping and opportunity discovery stages as described in Chapters 3 and 4.

The number of responses has been noted as **15 entries** (out of a global population of 35 companies), thereby reaching **c. 43%** of the available population. It is interesting to note that while the pharmaceutical industries are predominant on the Ħal Far industrial estate (accounting for 32% of the estate's complement), a better response was received from the manufacturing industries (the second largest block accounting for 20% of the estate). The distribution of the entries received per industry type is presented in Table 4 below.

Table 4 - Distribution of Industries Participating in the current study



The feedback from the different participants varies considerably between entries. The individual questionnaire entries are being pictorially represented by means of a mind map which display the various inflows and outflows within each industry. It should be noted that the thicknesses of the lines representing the flows do not represent the magnitude of the flow (unlike, say, in the case of a Sankey diagram). A sample of a typical entry is being represented in Figure 29, while the rest of the entries are being provided in Appendix 4.

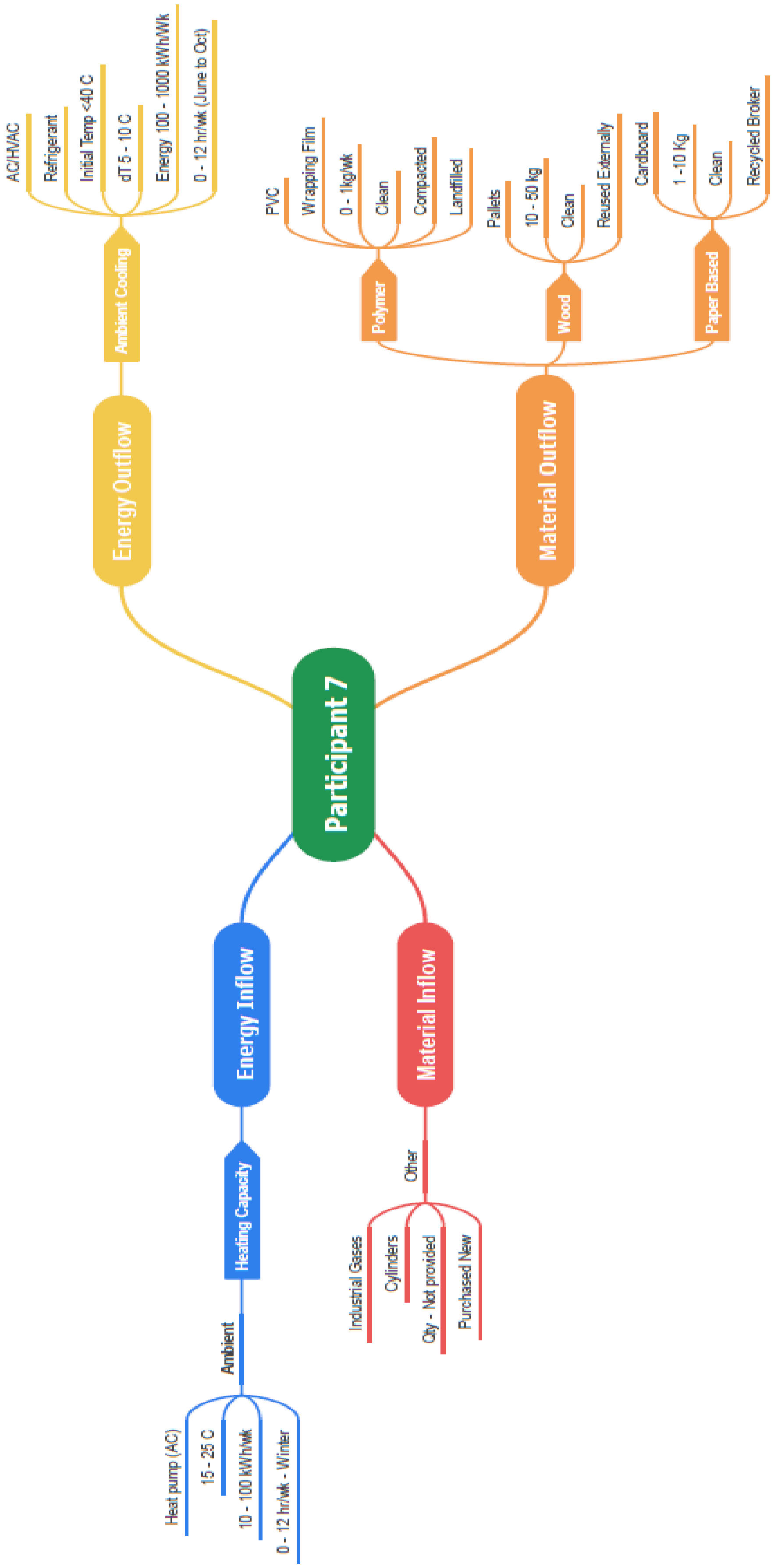


Figure 29 - Resource flow map for Participant 7

The different resource IO streams were extracted from each of the participants' entries. These streams were listed sequentially in three separate datasets corresponding to the respective objectives' IO resource database, in preparation for the data analysis process as described earlier in the "Opportunity Discovery Stage" in Chapter 4. The comprehensive datasets listing the "Collaborative Capacity" parameters, the "Energy Resource IO Flows" and "Material Resource IO Flows" are presented in Appendices 2, 3 and 4 respectively.

The results specifically relating to the individual objectives were processed further and are being presented in the following sections 5.1, 5.2 and 5.3 respectively.

5.1 Results relating to the Collaborative Capacity

5.1.1 Objective 1A: Key Players and Drivers

Table 5 lists the qualitative metrics by which 'enthusiasm' of a participant was gauged. Whilst such attributes are highly subjective, the score for each entry was assigned based on the parameters set forth in section 4.2.1.1 described earlier.

It may be observed that only one out of the fifteen entries did not indicate approval to be contacted with any feedback resulting from this study. This respondent (Participant 2) was therefore omitted from such ranking.

The top 35% of the participants (out of a total of 35 eligible entries) represent a ranking from 1 to 6, i.e. noted as Participants 3, 6, 14, 4, 5 and 11 respectively. These entries represent participants from the manufacturing, fabrication, pharmaceutical, and servicing industries.

Table 5 - Key Players and Drivers

Key Players and Drivers		OK to contact	Response Time Score	Level of Detail Score	Total Weighted Score	Ranking
	Count	14				
Participant ID.	*Weighting*		**15%**	**85%**		
Participant 1		Y	100	60	51	13
Participant 2		N	0	0	0	15
Participant 3		Y	93	95	95	1
Participant 4		Y	86	85	85	4
Participant 5		Y	79	80	80	5
Participant 6		Y	71	90	87	2
Participant 7		Y	64	70	69	8
Participant 8		Y	57	65	64	9
Participant 9		Y	50	60	58	10
Participant 10		Y	43	80	74	7
Participant 11		Y	36	85	78	6
Participant 12		Y	29	40	38	14
Participant 13		Y	21	60	54	12
Participant 14		Y	14	100	87	3
Participant 15		Y	7	65	56	11

5.1.2 Objective 1B: Gauging Trust (Response Rate)

The number of responses has been noted as **15 entries** (out of an eligible population of 35 potential respondents), thereby reaching **c. 43%** of the available companies. Overall, this result exceeds the 30 to 40% target bracket, a result which suggests that the cluster enjoys **exceptional trust** between participants.

As posited earlier, this further suggests that some form of relationships were already present (or can be easily established), a premise which has been corroborated from the feedback received. This is further aided by the close proximity between the cluster units, the existence of collaborative forums such as a ‘Tenant’s Association’, as well as a common administrator, namely INDIS Ltd.

It is also interesting to note the disparity in the response rate between the two major industry types within the cluster, (i.e. the pharmaceutical vs manufacturing industries presented in Table 4), with the latter taking the lead and therefore enjoying a greater level of trust.

5.1.3 Objective 1C: Gauging the Ability to participate

Table 6 summarises the entries of each participant in relation to their respective secrecy of operation. As immediately evident from the results, the majority of the participating entities falls within the lower scales of secrecy, thereby suggesting that most industries are not inhibited from providing information which can lead to the discovery of IS relationships within the cluster.

Table 6 - Secrecy of Operation (Summary of Responses)

Secrecy of Operation		Highly Sensitive	Sensitive - with NDA	Sensitive - with exceptions	Moderate	Low
	count	1	1	5	6	2
Participant ID.		**6.7%**	**6.7%**	**33.3%**	**40.0%**	**13.3%**
Participant 1				✓		
Participant 2		✓				
Participant 3				✓		
Participant 4				✓		
Participant 5					✓	
Participant 6					✓	
Participant 7				✓		
Participant 8						✓
Participant 9					✓	
Participant 10					✓	
Participant 11					✓	
Participant 12					✓	
Participant 13				✓		
Participant 14			✓			
Participant 15						✓

It is also pertinent to examine the entry indicating a higher level of secrecy. Participant 2, noted in its response that the questionnaire was not applicable to its operation, further failing to indicate that it wished to be contacted with any feedback. In such case, the entry was considered as extremely poor and was awarded the lowest possible score (refer to section 5.1.1).

On the other hand, while Participant 14 noted a 'Sensitive - with NDA' level of secrecy (therefore typically requiring a Non-Disclosure Agreement (NDA)), the information that was provided for this research was been provided relatively free from any obligation, bar for requiring a (verbal) reassurance that anonymity would to be respected (as committed per GDPR). This particular entry turned out to be the most comprehensive of all respondents.

In general therefore, it may be deduced that such data acquisition method and format for requesting resource flow information has been considered as acceptable to the eligible participants within the cluster.

5.1.4 Objective 1D: Gauging Readiness Level (Internal Expertise)

The summary of responses related to the readiness query is provided in Table 7 below. This table reflects the individual participants' responses in relation to the technical capacity that they employ with a specific focus on environmental and resource maximisation issues.

The results indicate that 66.6% of all respondents do not dedicate personnel specifically for addressing such issues, a result which seems to suggest that the technical capacity necessary to facilitate IS may be lacking.

In section 4.2.1.4 it was further posited that entities which employ personnel specifically for such tasks would be more willing to actively participate in this research, as well as being more receptive towards potential IS relationships.

As demonstrated by the responses, this premise conflicts with the results obtained for Objective 1A above - Key players and drivers, i.e. in terms of the quality and timeliness of the response, and therefore suggests that such a hypothesis may not hold.

Table 7 - Participant's Readiness (Summary of Responses)

Do you employ personnel specifically dedicated to resource maximisation and/or environmental issues?		Yes - 100% dedicated	Yes - As part of other duties	Yes - Outsourced/Subcontracted	No
	count	1	4	0	10
Participant ID.		**6.7%**	**26.7%**	**0.0%**	**66.7%**
Participant 1					✓
Participant 2					✓
Participant 3		✓			
Participant 4			✓		
Participant 5					✓
Participant 6					✓
Participant 7			✓		
Participant 8					✓
Participant 9					✓
Participant 10			✓		
Participant 11					✓
Participant 12					✓
Participant 13			✓		
Participant 14					✓
Participant 15					✓

5.1.5 Summary of Thematic 1 Results (Collaborative Capacity)

While this current study has received a good response rate of **43%,** it has not managed to gather the whole population. This figure has been associated with objective 1B, as an indication of the readiness of a participant to share information, i.e. an indication of trust between participants, which has been noted as being exceptionally good.

Should the potential IS relationships within the cluster mature, and participants start realising the benefits of IS (Section 2.2), it would also be expected that interest within the sceptic, non-participating population would also grow, potentially enticing new participants.

In such regard, it is therefore best to primarily target the key players and drivers within the population who would take the lead for IS related projects as identified in Objective 1A.

This objective noted these key players as Participants 3, 6, 14, 4, 5 and 11, which participants hail from the manufacturing, fabrication, pharmaceutical, and servicing industries. Each to their own degree, these key drivers have all featured in this research as both donors as well as receivers, thereby confirming their support (openness) to the concepts of resource sharing.

The research also notes that the majority of the cluster is also able to provide information relevant to the requirements for IS. Objective 1C notes that only 6.7% of the entries have indicated their operations as highly sensitive, and only a further 6.7% requiring strict NDA for discussions. This leaves the rest of the population of 86.6% relatively unencumbered.

Table 8 - Summary of Objective 1C results - Ability to Participate

Highly Sensitive	Sensitive - with NDA	Sensitive - with exceptions	Moderate	Low
1	1	5	6	2
6.7%	**6.7%**	**33.3%**	**40.0%**	**13.3%**

Table 9 - Summary of Objective 1D results - Readiness

Do you employ personnel specifically dedicated to resource maximisation and/or environmental issues?		Yes - 100% dedicated	Yes - As part of other duties	Yes - Outsourced/Subcontracted	No
	count	1	4	0	10
Participant ID.		**6.7%**	**26.7%**	**0.0%**	**66.7%**

What does require some attention however is the result of Objective 1D - Readiness (Refer to Table 9), which indicates that only a 33.4% of the cluster has (or sees the need for) access to technical personnel dedicated to the maximisation of resources. (Refer to Table 8).

Such a result therefore highlights the need to augment the technical capacity on sustainability issues within the cluster, which responsibility should either be shouldered by each of the individual participants, or be provided as a centralised service by the estate's administrator (in collaboration with the individual participants).

5.2 Results Relating to Energy Resources

The following section focuses on the results obtained for energy IO resource flows, which dataset is provided in its entirety in Appendix 2 of this study.

The graph below (Figure 30) sums the total thermal energy requirements between participants of the cluster, indicating the total heating and cooling demand, segmented by energy required for control of ambient conditions and energy required for the thermal demands for industrial equipment.

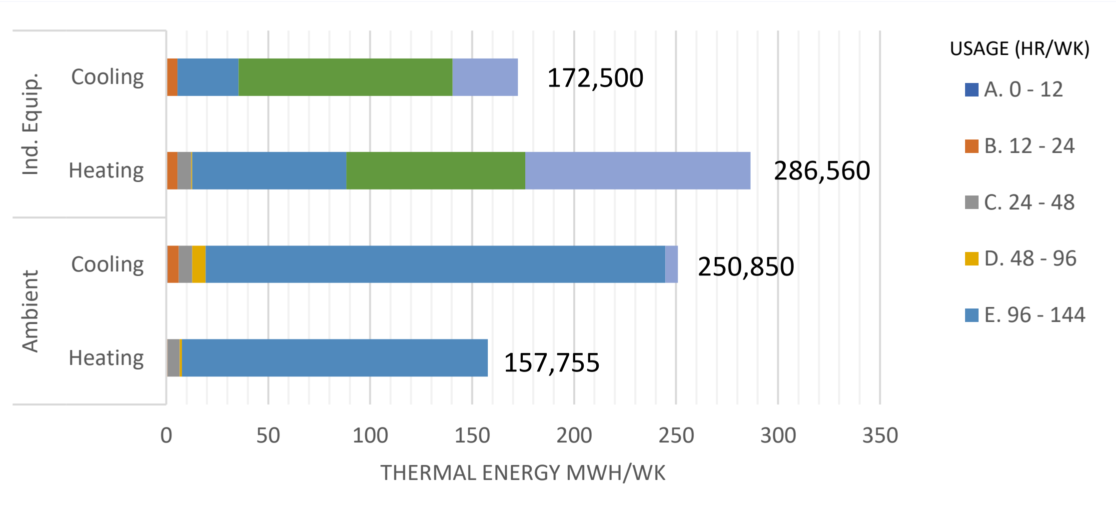


Figure 30 - Thermal Energy in MWh/Wk by type and by Usage

Industrial heating is shown as the dominant energy consumer (c. 287 MWh/Wk) which is followed closely by ambient cooling (c. 251 MWh/Wk), yet the two offer very distinct consumption patterns (Figure 31 and Figure 32).

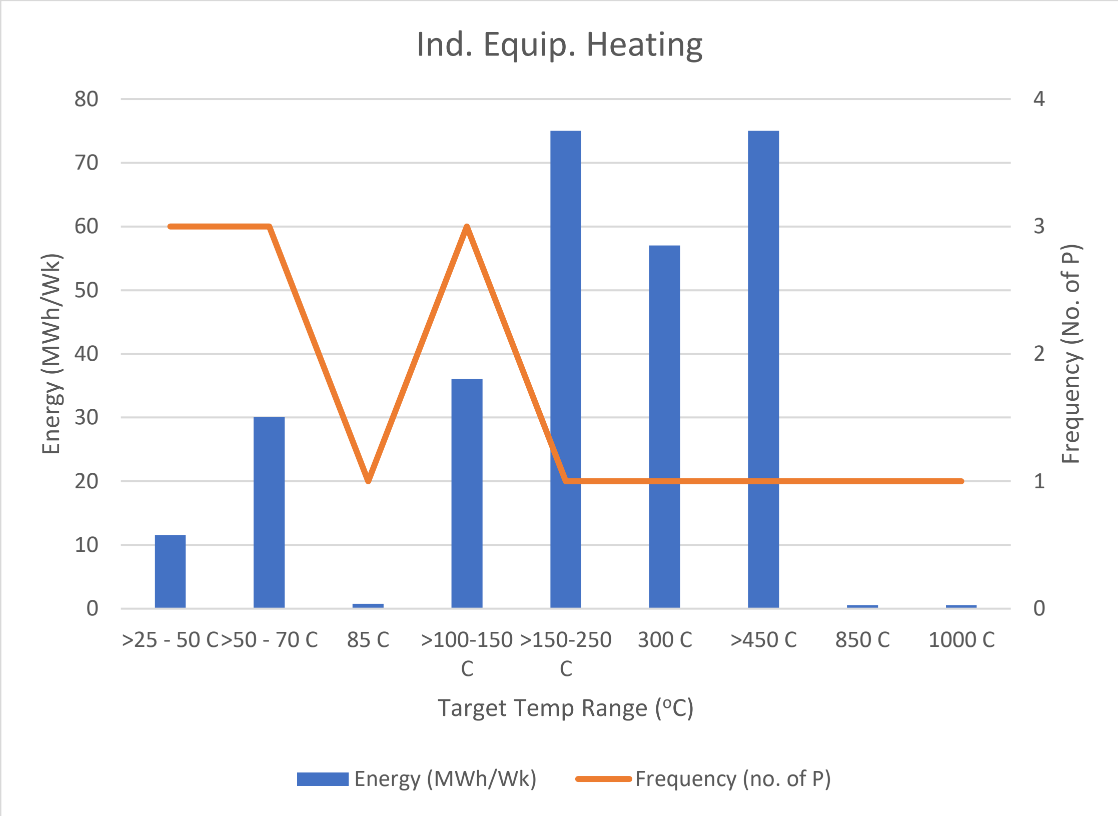
The majority of industrial heating (as well as industrial cooling) falls within the 144 - 168 hr/Wk and 24/7 brackets, which indicates that the demand is present during extended periods, beyond 3-shift (typically for a 6-day working week) up to being uninterrupted. Such behaviour is characteristic of the type of industry (predominantly manufacturing and pharmaceutical) present within the cluster. The major players in this area are P3, P6, P13 and P14.

On its part, the graph highlights how ambient control dominates the energy demand within the 96 - 144 hour bracket (typically 3-shift). This demand (both ambient cooling and heating), is dominated by two participants, P3 and P14, both entities featuring extensive shopfloor areas.

Given that the storage of thermal energy is more complex than other forms, any potential symbiotic relationship is only likely to occur if the usage pattern of the donor is synced with that of the receiver. In such respect, the patterns as described above are good news.

Nevertheless, “usage” pattern is not the only parameter of importance to enable potential relationships, with “operating temperature” playing a determining role, particularly for the scope of energy cascading.

The tables which follow provide an indication of the energy intensity within the specific temperature ranges, as well as the number of participants owning energy flow streams within these ranges.



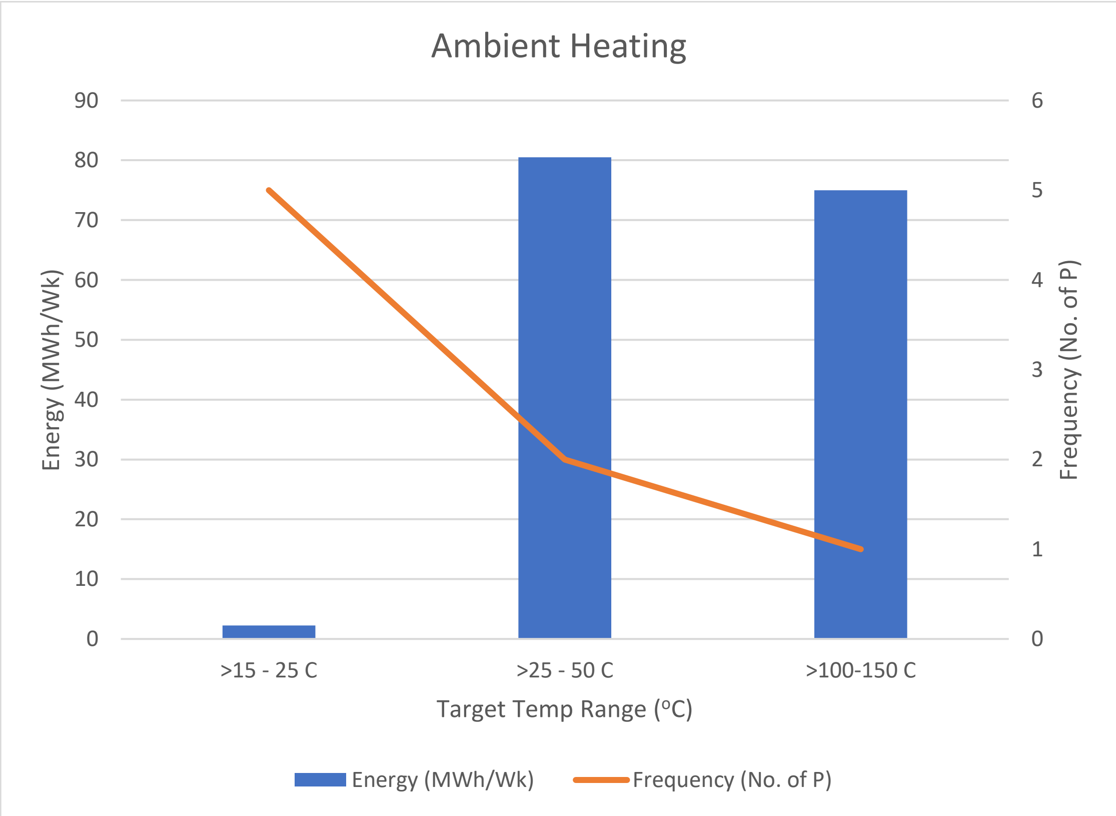
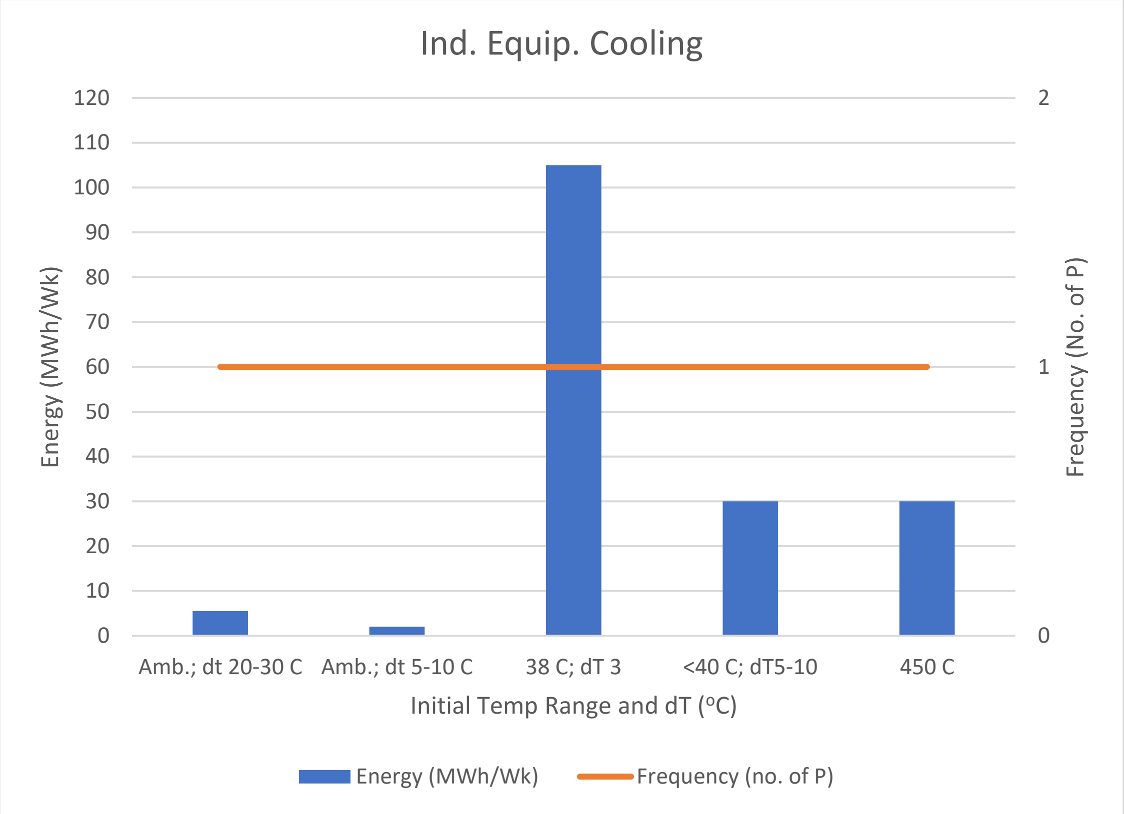


Figure 31 - Plot of Energy and Frequency per Temperature Range (upper - Industrial Heating; lower - Ambient Heating)



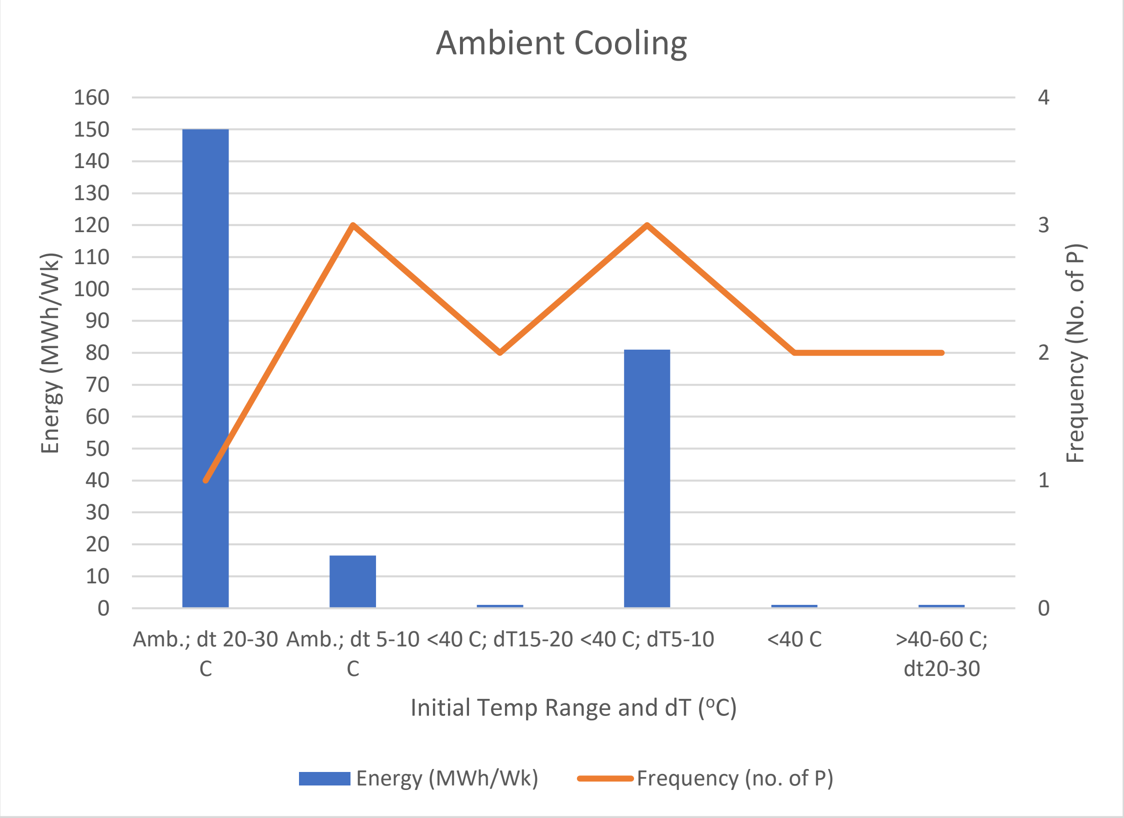


Figure 32 - Plot of Energy and Frequency per Temperature Range (upper - Industrial Cooling; lower - Ambient Cooling)

5.2.1 Objective 2A: Energy Cascade - Matching energy IO streams

The energy resource IO dataset (available in Appendix 2) has been further organised following the method described in section 4.3.1.1. This process has identified the presence of 7 potential donors, as well as 6 potential recipients. Furthermore, the following assumptions have been taken while sorting the data, namely:

- ***Range***

  It should be noted that some data have been provided in ranges, rather than as a specific number. For the purpose of comparison, computation and analysis of data, when such is necessary, the mean value of that particular range has been considered as the significant value. (e.g. a range of 10,000 - 50,000 kWh/Wk is assumed as indicating 30,000 kWh/Wk).

- ***Load fluctuation (and seasonality)***

  While all thermal loads are expected to fluctuate in accordance to the season, industrial loads are considered as being more stable throughout the year, and for the scope of this exercise are considered as constant throughout the year. On the other hand, ambient loads (heating or cooling) are assumed to provide a constant base load throughout the year, but increase substantially during the applicable season.

- ***Temperature***

  Temperatures have been measured in degrees Celsius (^oC). The term 'Ambient' or 'Amb.' Refers to the daily mean ambient temperature in Malta. Considering that a number of loads are seasonal, ambient cooling loads are assumed to be mostly employed during April to September, at an average of 24^oC, whereas ambient heating loads are assumed to be mostly employed during October to March, at an average of 16^oC [43].

- ***Terminology***

  'Operating temperature' or 'Op. Temp' for cooling loads is considered as the set-point temperature for the outlet line of a chiller unit, while *dT* (change in temperature) indicates the difference in temperature at the return line of the same unit.

Table 10 below summarises these results. The table is sorted by decreasing operating temperature, and thus the higher entries indicate a higher grade of energy. The entries highlighted in orange, and noted with an abbreviation 'D' represent the donor entries, whereas the entries highlighted in light green represent the potential recipient entries.

Table 10 - Energy Cascade Results

Entry No.	Inflow (Heating) / Outflow (Cooling)	Type (Industrial /Ambient)	Participant	Source	Heat Transfer Media	Op Temp (ºC)	Thermal Energy (kWh/Wk)	Av Usage (hr/Wk)	Match with entry no:
15	Cooling	I	P6	Stack	Exhaust	450	10,000 - 50,000	G. 24/7	D
28	Heating	I	P13	Boiler - LPG	Steam	>100-150	10,000 - 50,000	G. 24/7	15
33	Heating	A	P14	Boiler - Diesel	Steam	>100-150	50,000 - 100,000	E. 96 - 144	15
12	Heating	I	P6	Boiler - LPG	Water	>50 - 70	10,000 - 50,000	F. 144 - 168	15
36	Cooling	I	P14	Chiller (CL)	Water	Amb.; dt 20-30	1,000-10,000	B. 12 - 24	D
37	Cooling	A	P14	Chiller (CL)	Water	Amb.; dt 20-30	100,000 - 200,000	E. 96 - 144	D
4	Cooling	I	P3	Chiller (CL)	Water	38; dT 3	105,000	F. 144 - 168	D
5	Cooling	A	P3	Chiller (CL)	Water	<40; dT5-10	50,000 - 100,000	E. 96 - 144	D
10	Cooling	I	P4	Chiller (CL)	Water	<40; dT5-10	10,000 - 50,000	E. 96 - 144	D
8	Heating	A	P3	Heat Pump (Chiller)	Water	>25 - 50	50,000-100,000	E. 96 - 144	15, 4, 10
30	Cooling	I	P13	Chiller (CL)	Water	Amb; dt 5-10	2,000	G. 24/7	D
18	Heating	A	P8	Heat Pump (Chiller)	Water	>15 - 25	100 - 1,000	B. 12 - 24	30, 36

As noted, not all donor entries could be matched with a potential recipient, while not all potential recipients would necessarily be assigned a donor, if a better fit was established for such a donor. Breaking down this table by donor, while indicating the potential recipients, the analysis highlights the following opportunities:

- *Opportunity 1: Donor Entry 15, Participant 6*

Table 11 - Energy Cascade Opportunity 1

Entry No.	Cooling / Heating	Type (Industrial /Ambient)	Participant	Source	Heat Transfer Media	Op Temp (ºC)	Thermal Energy (kWh/Wk)	Av Usage (hr/Wk)	Distance from Donor (km)
15	C	I	P6	Stack	Exhaust	450	10,000 - 50,000	G. 24/7	N/A
28	H	I	P13	Boiler - LPG	Steam	>100-150	10,000 - 50,000	G. 24/7	0.19
33	H	A	P14	Boiler - Diesel	Steam	>100-150	50,000 - 100,000	E. 96 - 144	0.6
12	H	I	P6	Boiler - LPG	Water	>50 - 70	10,000 - 50,000	F. 144 - 168	0

Entry 15 corresponds to a stream by Participant 6, consisting of an exhaust system (cooling industrial equipment) for an LPG fuelled furnace. This stream consists of a flue gas exhaust line, whose exhaust temperature (close to source) was estimated at 450ºC, given that the furnace's operating setpoint is meant to be greater than 450ºC, running continuously 24/7.

By analysing the resource IO database, this donor stream was matched with 3 potential receiver streams, namely entries 28, 33 and 12 (Table 11). Given that none of the heat transfer media matched, all of the potential options resulted in indirect matches, i.e. requiring an intermediary conversion process, which process should be technically possible given the large temperature gradient between donating and receiving streams.

In terms of matching demand, all 3 potential receiving streams have a heating demand which was either within the same range, or greater, therefore ensuring that all available thermal energy (estimated at 30,000 kWh/Wk) can be recovered (less conversion and transfer losses). The weekly usage of all three potential recipients was also comparable, being equal or lower than that of the donor.

In terms of transfer losses, the distance between donor (P6) and potential recipients was estimated at 0.19 km (P13) ,0.6 km (P14) and 0 km (P6). The analysis further notes that one of the potential receivers was a stream belonging to the same participant, which therefore has an opportunity of energy recovery within the same premises. The schematic representing entry 15 (P6) and entry 12 (P6) at the time of writing is shown in Figure 33.

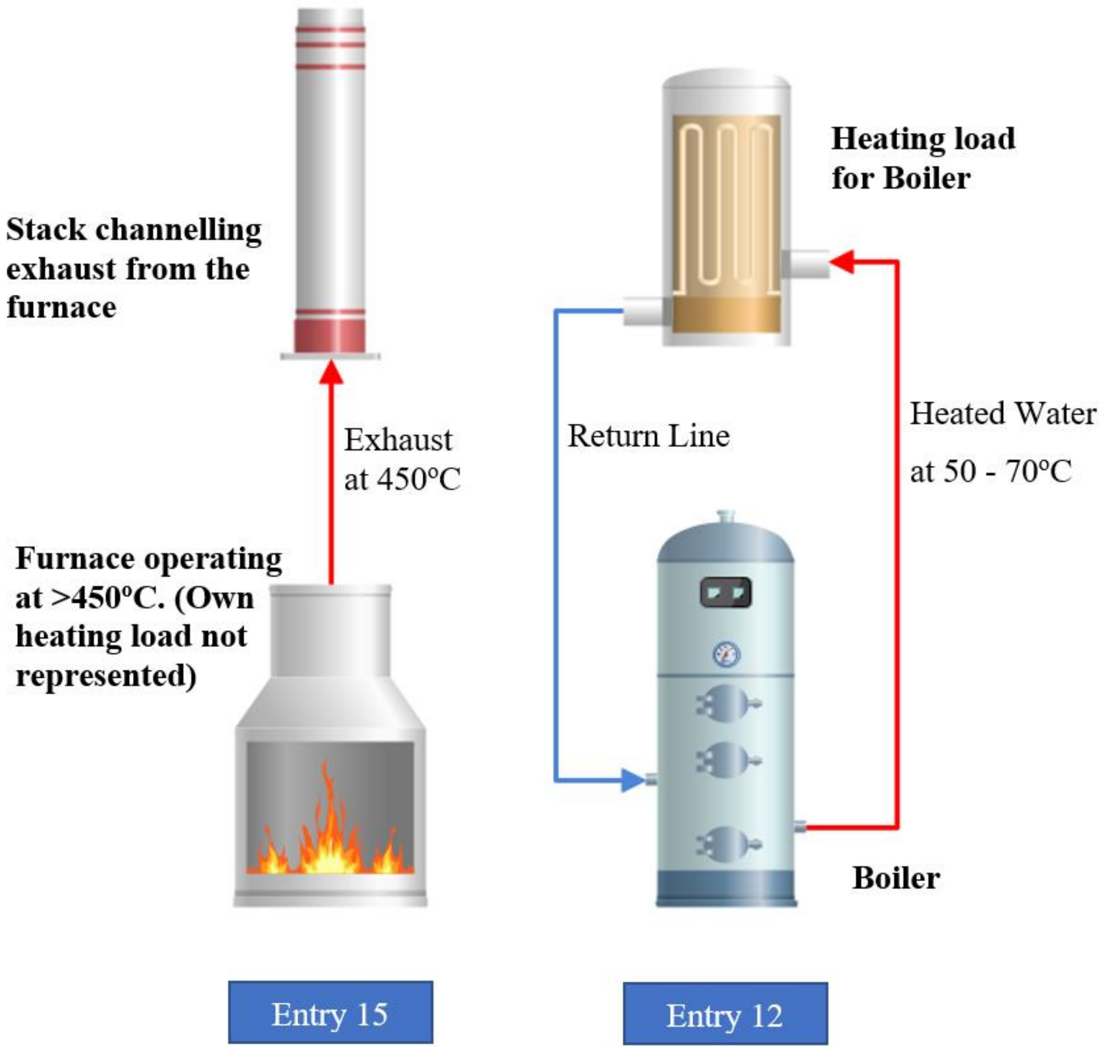


Figure 33 - Current state for Entries 15 and 12 both by P6

Given that Entry 33 was the furthest, and had a seasonal (ambient) demand, it was the least preferable of options. The demand from the remaining entries was comparable, and therefore, the opportunity for self-consumption (Entry 12) was preferred over the remaining opportunity (i.e. Entry 28). The schematic representing the proposed potential match is provided in Figure 34.

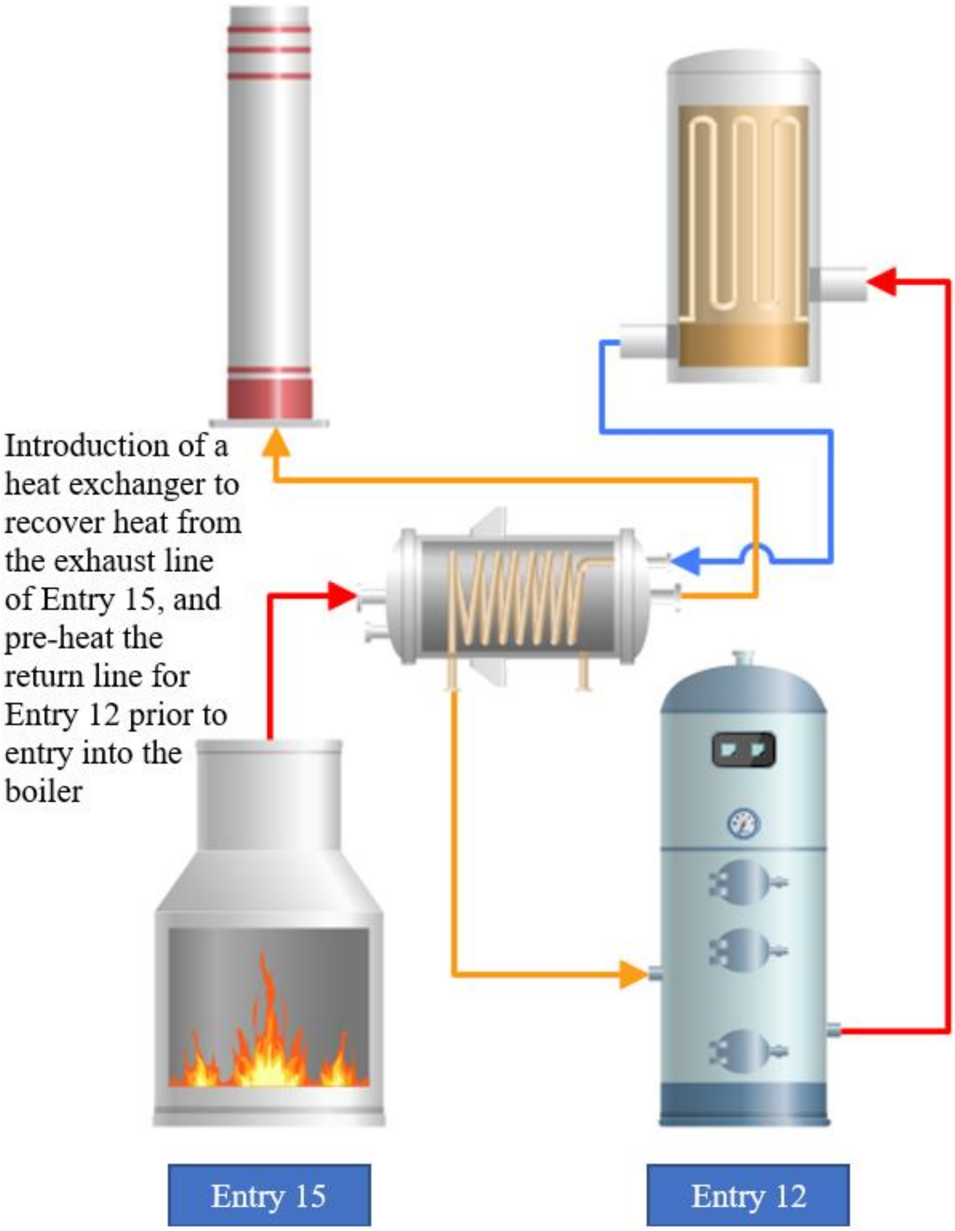


Figure 34 - Potential match representation for Entries 15 and 12 both by P6

In essence, this symbiotic relationship between processes offers an estimated thermal energy recovery potential of **30,000 kWh/Wk**.

- *Opportunity 2: Donor Entry 36, Participant 14*

Table 12 - Energy Cascade Opportunity 2

Entry No.	Cooling / Heating	Type (Industrial /Ambient)	Participant	Source	Heat Transfer Media	Op Temp (°C)	Thermal Energy (kWh/Wk)	Av Usage (hr/Wk)	Distance from Donor (km)
36	C	I	P14	Chiller (CL)	Water	Amb.; dt 20-30	1,000-10,000	B. 12 - 24	N/A
18	H	A	P8	Heat Pump (Chiller)	Water	>15 - 25	100 - 1,000	B. 12 - 24	1.16

Entry 36 corresponds to a stream by Participant 14, consisting of a cooling system for industrial equipment. The chiller unit, whose set-point was at ambient temperature, had a return line with a *dT* 20 - 30°C, uses water as heat transfer medium, and operates between 12 to 24 hours per week.

As shown in Table 12 a potential recipient stream was identified in Entry 18 (P8), a stream which was also identified as being a potential recipient from another donor (Entry 30 below). While the entry is seasonal (ambient heating) it uses the same heat transfer media, and could therefore be a direct relationship. Furthermore, this receiving stream operates at temperatures in the range of 15 - 25°C, which is below the estimated return temperature of the donor stream.

The demand for energy from this receiving stream is estimated at 550 kWh/Wk, which is lower than the available energy at the donor (in turn estimated at 5500 kWh/Wk).

This donor stream did not operate continuously, but followed a similar pattern to the receiving stream, i.e. in operation for 12 - 24 hrs/Wk, which receiving stream was however also seasonal (unlike the donor). Whilst not an ideal scenario, no other potential recipients were identified for this donor.

This recipient was identified as a potential candidate by another donor (refer to opportunity 7 below). Of the two donors courting this recipient, Entry 18 (opportunity 2) was at a shorter distance to the donor in Entry 30 (1.59 km), and would therefore be preferable in terms of transfer losses. Nevertheless, both donors were at a considerable distance from the recipient, signalling a potential red flag for the technical and economic feasibility of this relationship due to heat transfer losses in the distribution lines.

If realised however, this symbiotic relationship between processes could offer an estimated energy recovery potential of **550 kWh/Wk**, by means of substitution from Entry 18 (P8).

A schematic for a similar system is provided in Figure 35 (Opportunity 4) below.

- *Opportunity 3: Donor Entry 37, Participant 14*

Table 13 - Energy Cascade Opportunity 3

Entry No.	Cooling / Heating	Type (Industrial /Ambient)	Participant	Source	Heat Transfer Media	Op Temp (ºC)	Thermal Energy (kWh/Wk)	Av Usage (hr/Wk)	Distance from Donor (km)
37	C	A	P14	Chiller (CL)	Water	Amb.; dt 20-30	100,000 - 200,000	E. 96 - 144	N/A

Entry 37 corresponds to a stream by Participant 14, consisting of a seasonal ambient cooling chiller unit of considerable capacity, whose set-point was at ambient temperature and which had a return line at *dT* 20 - 30ºC. The heat transfer medium used within the system was water. While the supply was seasonal, it operated between 96 - 144 hr/Wk (3-shift).

This donor stream offers a substantial energy saving potential estimated at **150,000 kWh/Wk**, which potential cannot be realised since no receiver stream could be identified (Table 13).

- *Opportunity 4: Donor Entry 4, Participant 3*

Table 14 - Energy Cascade Opportunity 4

Entry No.	Cooling / Heating	Type (Industrial /Ambient)	Participant	Source	Heat Transfer Media	Op Temp (°C)	Thermal Energy (kWh/Wk)	Av Usage (hr/Wk)	Distance from Donor (km)
4	C	I	P3	Chiller (CL)	Water	38; dT 3	105,000	F. 144 - 168	N/A
8	H	A	P3	Heat Pump (Chiller)	Water	>25 - 50	50,000-100,000	E. 96 - 144	0 (self)

Entry 4 corresponds to a stream by Participant 3, consisting of a cooling system for industrial equipment. The chiller unit, whose operating temp was at 38°C, returns warmer water (its heat transfer medium) at a *dT* of 3 degrees, and operated between 96 - 144 hr/Wk (3-shift). Its main function is to extract heat from industrial equipment (moulding machines) to an estimated thermal energy order of 105,000 kWh/Wk. The schematic representing Entry 4 and Entry 8 in their current state at the time of writing is shown in Figure 35.

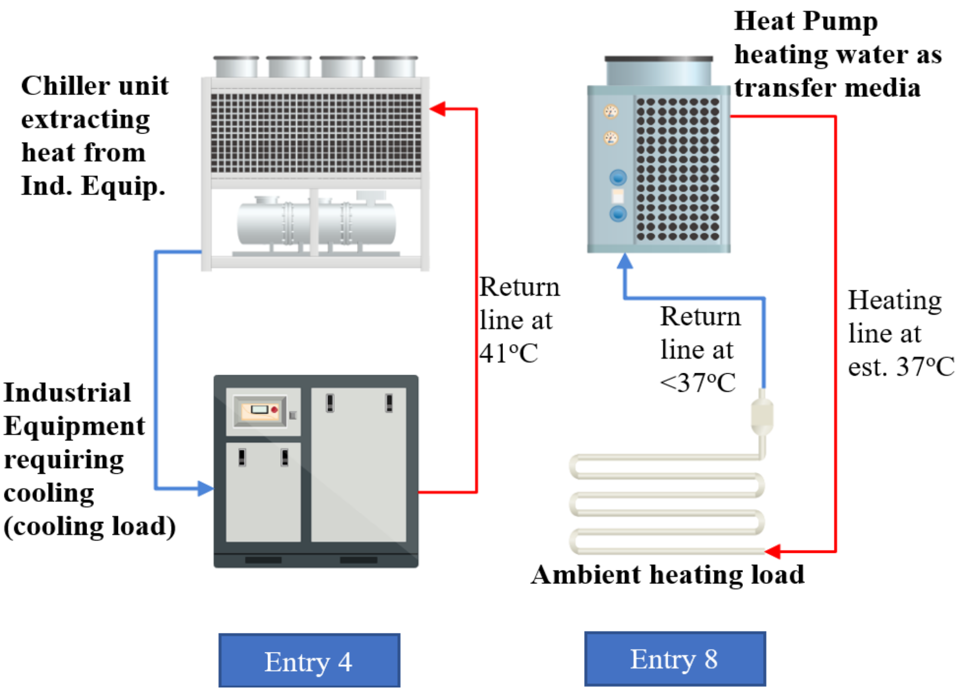


Figure 35 - Current state for Entries 4 and 8 both by P3

Table 14 shows how a potential recipient stream was identified for this donor, namely Entry 8 (a self-energy recovery opportunity for P3). This potential recipient was also considered as a potential match for donor Entry 10 (referred to later). Entry 8 provides an opportunity for a direct relationship, given that the heat transfer media are identical.

It is further noted that the usage pattern was similar (slightly lower) than that of the donor (a condition which is acceptable), although it was a seasonal demand (unlike the donor's which was continuous). In this case, it is also noted that the energy available from the donor (105,000 kWh/Wk) was considerably higher than that of the potential recipient which was estimated at 75,000 kWh/Wk. While this is not an ideal scenario, given that not all of the donor's energy can be recovered, it is equally an attractive match. The schematic representing the potential proposed match is provided in Figure 36.

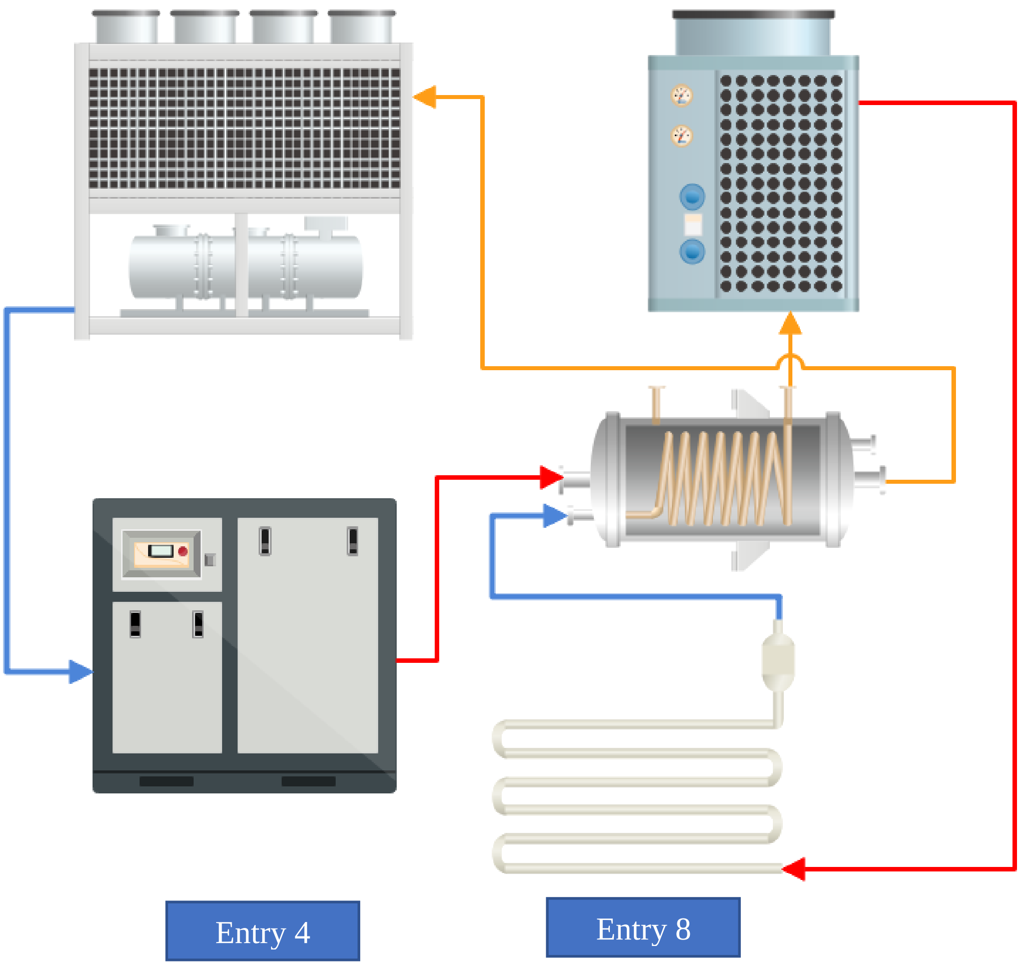


Figure 36 - Potential match representation for Entries 4 and 8 both by P3

The relationship involves the introduction of a heat exchanger to recover heat from the return line of Entry 4, and pre-heat the return line for Entry 8 prior to entry into the boiler. Given the right conditions, the heat exchanger could be eliminated in lieu of a direct connection.

While most parameters suggest that a good fit exists, further examination needs to be undertaken to determine the heat transfer capability between the return temperature of the donor and the recipient stream (the return line of the donor needs to be at a higher temperature than that of the recipient for heat transfer to occur).

Given that the ranges provided for selection in the questionnaire may have been too wide (and overlapping), further analysis would be necessary. This situation is encountered for other potential relationships identified hereunder, and a relationship made more challenging particularly when donors and recipients are geographically distant, due to the increased transfer losses.

Assuming that such a condition is satisfied, this relationship could see to an estimated thermal energy recovery from Entry 4 (P3) of **75,000 kWh/Wk**, (less conversion and transfer losses) through means of substitution, from Entry 8 (P3).

- *Opportunity 5: Donor Entry 5, Participant 3*

Table 15 - Energy Cascade Opportunity 5

Entry No.	**Cooling** / Heating	**Type (Industrial /Ambient)**	**Participant**	**Source**	Heat Transfer **Media**	**Op Temp** (°C)	**Thermal Energy** (kWh/Wk)	**Av Usage** (hr/Wk)	**Distance from Donor (km)**
5	C	A	P3	Chiller (CL)	Water	<40; dT5-10	50,000 - 100,000	E. 96 - 144	N/A

Entry 5 corresponds to a stream by Participant 3, consisting of a seasonal ambient cooling chiller unit, whose operating temperature was set at <40^{o}C (but higher than ambient temperature), and its return line at a *dT* within the 5-10 degree range. The heat transfer medium used within the system was water. While the supply was seasonal, it operated between 96 - 144 hr/Wk (3-shift).

This donor stream offered an estimated thermal energy availability of **75,000 kWh/Wk**, which potential cannot be realised since no receiver stream was identified (Table 15).

- *Opportunity 6: Donor Entry 10, Participant 4*

Table 16 - Energy Cascade Opportunity 6

Entry No.	**Cooling / Heating**	**Type (Industrial /Ambient)**	**Participant**	**Source**	**Heat Transfer Media**	**Op Temp (ºC)**	**Thermal Energy (kWh/Wk)**	**Av Usage (hr/Wk)**	**Distance from Donor (km)**
10	C	I	P4	Chiller (CL)	Water	<40; dT5-10	10,000 - 50,000	E. 96 - 144	N/A
8	H	A	P3	Heat Pump (Chiller)	Water	>25 - 50	50,000-100,000	E. 96 - 144	0.48

Entry 10 corresponds to a stream by Participant 4, consisting of a cooling system for industrial equipment. The chiller unit, whose operating temp is at < 40ºC (but higher than ambient temperature), used water as heat transfer medium, and operates between 96 - 144 hr/Wk (3-shift). Its main function is to extract heat from industrial equipment (rubber forming machines) to an estimated thermal energy order of 30,000 kWh/Wk.

Table 16 shows how a potential recipient stream has been identified for this donor, namely Entry 8 (P3). Entry 8 provides an opportunity for a direct relationship, given that the heat transfer media are identical. The schematics for this relationship are similar to those provided in Figure 35 and Figure 36.

It is noted that the usage pattern was similar to the donor's although it was seasonal (unlike the donor's which was continuous). It is also noted that the energy demand for the recipient was substantially higher for the recipient (est. 75,000 kWh/Wk), ensuring that all the available donor energy can be recovered.

While most parameters suggest a good fit, further examination needs to be undertaken to determine compatibility between the operating temperatures of the donor and recipient streams (the return line of the donor needs to be at a higher temperature than that of the recipient), given that the ranges as provided are too wide and overlapping.

Assuming that such a condition is satisfied, this relationship could see to an estimated thermal energy recovery from Entry 10 (P4) of **30,000 kWh/Wk**, (less conversion and transfer losses) through means of substitution from Entry 8 (P3).

- *Opportunity 7: Donor Entry 30, Participant 13*

Table 17 - Energy Cascade Opportunity 7

Entry No.	Cooling / Heating	Type (Industrial /Ambient)	Participant	Source	Heat Transfer Media	Op Temp (°C)	Thermal Energy (kWh/Wk)	Av Usage (hr/Wk)	Distance from Donor (km)
30	C	I	P13	Chiller (CL)	Water	Amb.; dt 5-10	2,000	G. 24/7	N/A
18	H	A	P8	Heat Pump (Chiller)	Water	>15 - 25	100 - 1,000	B. 12 - 24	1.59

Entry 30 corresponds to a stream by Participant 13, consisting of a cooling system for industrial equipment. The chiller unit, whose operating temperature was set at ambient, had a return line with a *dT* of 5 - 10 degrees higher, uses water as heat transfer medium, and operates between 24/7.

Table 17 shows how a potential recipient streams was identified in Entry 18 (P8), which entry was also identified as a potential recipient for donor Entry 36 above. While the entry was seasonal (ambient heating) it used the same heat transfer medium, and could therefore offer a direct relationship. Furthermore, this receiving stream operated at temperatures in the range of 15 - 25°C, which was below the return temperature of the donor stream.

The demand for energy from this receiving stream was estimated at 550 kWh/Wk, which is lower than the available energy at the donor (in turn indicated as 2,000 kWh/Wk), suggesting that not all available energy may be recovered.

While the donor stream was operated continuously, the receiving stream operated for only 12-24 hrs/Wk, and was also seasonal. Whilst not an ideal scenario, no other potential recipients were identified for this donor.

A potential red flag to this relationship is the physical distance between donor and recipient, estimated at 1.59 km, which *a prima facie,* would suggest that both technical and economic feasibility could be endangered.

If realised however, this symbiotic relationship between processes thus offers an estimated thermal energy recovery potential of **550 kWh/Wk**, by substitution from Entry 18 (P8).

5.2.2 Objective 2B: Fuel Replacement - Matching fuel IO streams

With respect to fuels, this study found that there is no potential for either a direct or an indirect fuel replacement relationship between participants of the cluster. The study however noted the potential to convert material resources (such as spent oil) to fuel/energy, which streams are being reviewed in section 5.3.4.

5.2.3 Objective 2C: Pre-Established IS Relationships (Energy Resources)

The study identified that as far as energy resources are concerned, there were **no pre-existing external relationships** formed between participants at the time of writing.

5.2.4 Summary of Thematic 2 Results (Energy Resources)

Table 18 - Summary of Objective 2A results - Energy Cascade

Opportunity	Donor / Entry no.	Donor Available Energy (kWh/Wk)	Recipient / Entry no.	Recipient Demand (kWh/Wk)	Realisable Energy Recovery (kWh/Wk)
1	P6/15	30,000	P6/12	30,000	30,000
2	P14/36	5,500	P8/18	550	550
3	P14/37	150,000	None	N/A	0
4	P3/4	105,000	P3/8	75,000	75,000
5	P3/5	75,000	None	N/A	0
6	P4/10	30,000	P3/8	75,000	0 [26]
7	P13/30	2,000	P8/18	550	550
TOTAL		**397,500**		**181,100**	**106,100**

The total heat outflow from the cluster has been noted in Figure 30 as 423,350 kWh/Wk, composed of 172,500 kWh/Wk from industrial sources and 250,850 kWh/Wk from ambient sources.

As can be observed in Table 18, the total available donor energy was estimated at 397,500 kWh/Wk, which is less than the reported total heat outflow (i.e. of c. 94%). This discrepancy relates to that outflow energy whose characteristics (such as the heat transfer medium) hinder its availability for establishing IS relationships. This has been explained in detail in section 4.3.1.1.

Table 18 also indicates the losses arising from the matching process. Indeed, not all available donor energy could be matched with a recipient, and not all potential recipients could be assigned to a donor. As noted, out of the available 397,500 kWh/Wk, only the potential recovery of 106,100 kWh/Wk **(26.7%)** could be realised.

[26] Opportunity 4 has been chosen as the preferred recovery opportunity for recipient P3/Entry 8. To avoid double counting, the recovery potential described in opportunity 6 has been counted as zero.

This figure therefore also represents c. **23.9%** of the heating energy demand (of 444,315 kWh/Wk for ambient and industrial heating) within the cluster. It should be noted that this value does not take into account any transfer and conversion losses, and is therefore, in practice, an over estimate. Notwithstanding this, the potential recoverable energy constitutes a significant portion of the demand within the cluster.

It is also noted that none of the above-mentioned relationships have, at time of writing, been realised. Indeed, Objective 2C noted that no pre-established energy resource relationships have been identified. As shall be discussed later, this contrasts with the availability of pre-established material resource relationships.

Finally, in terms of fuel demand, the research also noted that no fuel replacement opportunities were identified (Objective 2B).

5.3 Results Relating to Material Resources

The following section focuses on the results obtained for material IO resource flows, which dataset is provided in its entirety in Appendix 3 of this dissertation. Summarised in Table 19 below is the distribution of flows (by weight) for inflow and outflow, which figures are also graphically illustrated in Figure 37.

Table 19 - Distribution of Material Resources by Flow and Class

Class	Inflow (kg/Wk)	Outflow (kg/Wk)
Chemicals	75,250	321
Food	-	230
Fuel and Oils	-	87
Glass	-	-
Metal	550,105	43,934
Mineral	5,500	5,500
Other	-	372
Paper	693	358
Polymer	35,675	9,470
Wood	786	2,577
Total	**668,009**	**62,848**

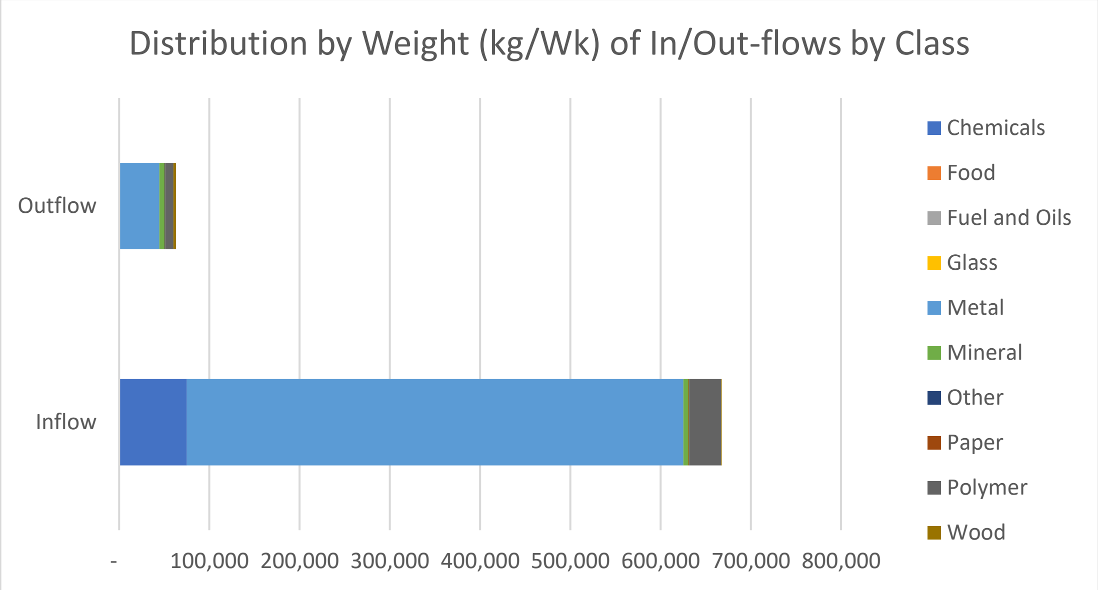


Figure 37 - Distribution (by weight in kg/wk) of flows

The above figures note that the reported outflows (c. 63 t/Wk) equated to c. 9.4% (by weight) of the inflows (c. 668 t/Wk). This distribution is however not even across all classes of materials, which difference is more evident in the Figure 38 below.

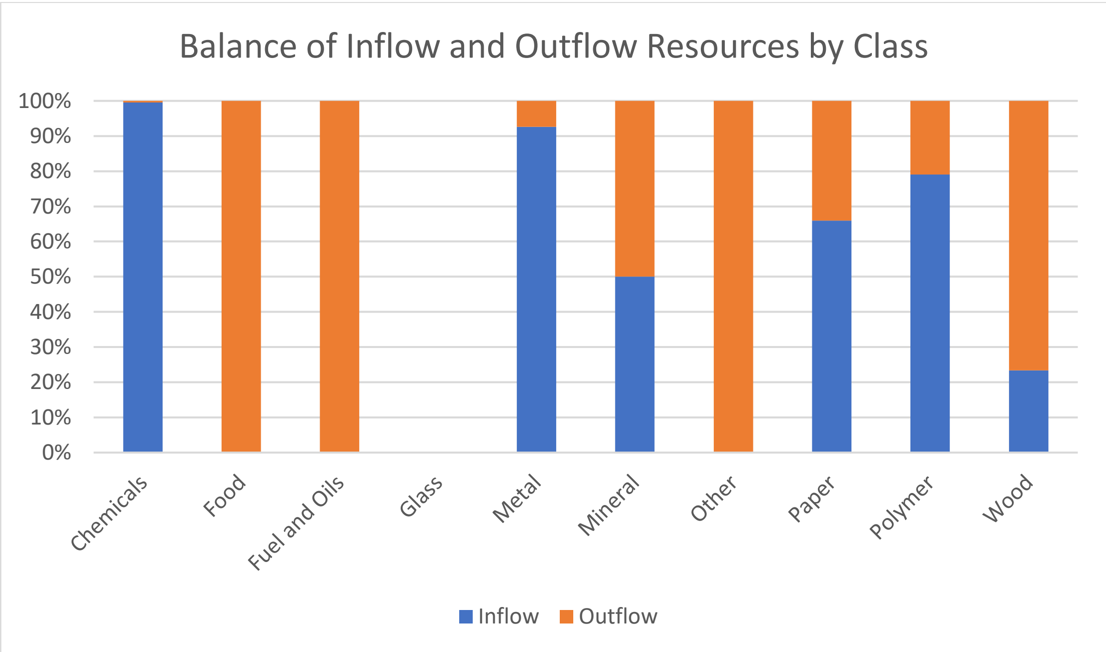


Figure 38 - Balance of flows by Class (by weight in kg/wk)

The data indicated that the ‘Chemicals’ class was predominant in the inflow streams, while ‘Metal’ class was predominant in both, with the ‘Polymer’ class following in closely. For ease of comparison, the dominating fields (i.e. ‘Chemicals’ and ‘Metal’) have been eliminated form Figure 37, which was further represented in Figure 39.

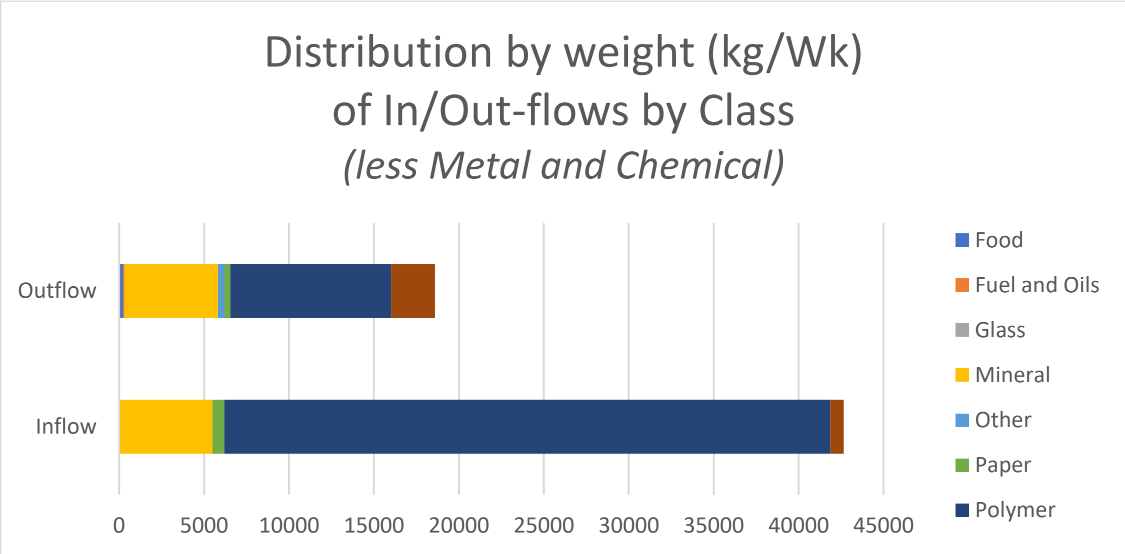


Figure 39 - Distribution of flows by Class (with Chemicals and Metals Class removed)

These data were further organised following the method described in section 4.4., which process identifies the potential for a number of relationships as explained in further detail in the coming sections.

Throughout the exercise, the following assumptions were taken, namely:

➢ ***Multiple receivers for one donor (and vice-versa)***

Throughout the energy thematic a situation whereby only one recipient was shortlisted for every donor was preferred, particularly due to a consideration for efficiency and economies. In the case of material resource, this consideration was still preferred, but had a lesser impact on both efficiencies and economies if a donor material was shared between recipients (or a recipient received from multiple donors).

➢ ***Carbon footprint***

The study attempted to assign a carbon footprint for each of the potentially recoverable materials. This characteristic is highly variable and dependent on a multitude of factors, such as origin, type of fabrication process, origin of raw materials, design, transportation of the goods, opportunities for disposal etc. The values provided in this study attempted to reflect the most accurate estimation from referenced life cycle analysis studies as well as other available literature.

➢ ***Calorific Value (CV)***

Calorific Value (CV) refers to the heat energy potential which is intrinsic in a material, which energy is released during a combustion process. When a material is dry and combustion is complete, the energy release is at its peak, and the CV is referred to as the higher heating value (HHV).

Nevertheless, in practice, some of this heat energy is lost from the wet (humid) fractions within the material, in the form of latent heat of vaporisation of the water. This adjustment to the HHV is referred to as the lower heating Value (LHV), and reflects the typical value used for estimating waste-to-energy throughput [44].

Conversion between HHV and LHV is not straightforward as it is largely dependent on the condition of the waste. This study assumed that the waste was being provided with no water content and unless otherwise stated (and if available), this study refers to the HHV of a material. This therefore suggests that estimation of energy yields in respect to WTE would be **higher than actual figures**.

For reference purposes HHV is also referred to as HCV (Higher Calorific Value) or GCV (Gross Calorific Value) [45].

➢ ***The Variability of the 'Form' Field***

The field for 'Form' assumes a number of standard forms (shapes and sizes), which model is rather simplistic considering that in practice, these options may be infinite. Any conclusions in this section are presented so as to shortlist possibilities, but which would require a more detailed understanding of the actual 'Form' of both donor and recipient streams.

- ***The Variability of the 'Range' Field***

It should be noted that some data was provided in ranges, rather than in terms of a specific number. For the purpose of comparison, computation and analysis of data, when such is necessary, the mean value of a particular range of values was considered as the significant value. (e.g. a range of 100 - 500 kWh/Wk assumed as a significant mid-range value of 300 kWh/Wk).

5.3.1 Objective 3A: Match direct material IO streams

The resource mapping exercise revealed a number of direct material matches, which matches were however **pre-established** and were therefore listed in the appropriate section (refer to section 5.3.3 - Pre-established relationships, below). **No new direct material match opportunities** were discovered.

5.3.2 Objective 3B: Match indirect material IO streams

While a direct match is preferable since it is considered as being less energy and/or resource intensive than an indirect relationship (due to the requirement for a conversion process), the possibility of an indirect material match is more likely to occur.

This is indeed the case with the Ħal Far cluster, whereby a number of indirect matches (both new as well as pre-established) were noted. These are being listed hereunder by 'Class' and 'Type' in their sorting order.

- *Opportunity 1 - Paper/Carboard*

The first relationship relates to the Paper-Class Resource, more specifically Cardboard-Type. The study noted the following (Table 20):

Table 20 - Summary of Indirect Paper/Carboard IO Streams

Entry no.	In/Out	Participant	Qty (unit/Wk)	Condition	Form	Disposal Method (or) …	… Source
8	O	P3	47 kg	Clean	Sheets	Recycled Locally	N/A
29	O	P7	1 - 10 kg	Clean	Various	Recycled broker	N/A
41	O	P10	100 - 250 kg	Clean	Sheets	Recycled Locally	N/A
45	O	P11	10 - 50 kg	Clean	Sheets	Recycled Locally	N/A
62	O	P14	38 kg	Clean	Packaging	Recycled Locally	N/A
73	O	P15	30 kg	Clean	Sheets	Recycled Broker	N/A
43	I	P10	100 - 250 kg	Pristine	Standard forms	N/A	Purchased New
49	I	P11	250 - 500 kg	Pristine	Standard forms	N/A	Purchased New

Participants 3, 7, 10, 11, 14 and 15 disposed (either by recycling locally or exporting through a broker) of c. 325 kg/Wk of Cardboard. These output streams came in various forms, but mainly as sheets or as packaging waste, and were generally in a clean state.

On the other hand, Participants 10 and 11 collectively purchased c. 550 kg/Wk of cardboard in pristine condition, in Standard Form (typically as boxes and sheets).

While this study indicated a potential match in both Class and Type of a material resource, there is a clear mismatch in Form. Such mismatching was further accentuated by the fact that both P10 and P11 demonstrated input and output streams which were not self-consuming. This therefore immediately suggests that the Form of their own output stream may differ from the required form at the input stream.

These streams are therefore considered as an indirect match requiring an intermediary conversion process to enable substitution. Should this be financially and economically feasible, this relationship would therefore potentially see a saving of c. **325 kg/Wk of carboard** which has a calorific content of **4,791 MJ/Wk (1,330 kWh/Wk)** and a carbon footprint of **1,288 kg of CO2/Wk** [27]**.**

- *Opportunity 2 - Chemicals/Solvents*

The second relationship relates to the Chemicals-Class Resource, more specifically Solvents-Type. This study noted the following (Table 21):

Table 21 - Summary of Indirect Chemicals/Solvent IO Streams

Entry no.	In/Out	Participant	Qty (unit/Wk)	Condition	Form	Disposal Method …. (or) …	… Source
40	O	P10	1 - 10 kg	Cont. Similar	Liquid	Recycled broker	N/A
58	O	P13	31 kg	Cont. Similar	Liquid	Incinerated	N/A
59	O	P14	250 kg	Cont. Similar	Liquid	Recovered	N/A
71	I	P14	250 L	Pristine (ACS Grade)	Liquid	N/A	Purchased New

Participant 14 disposed of 250 kg/Wk of solvent (typically organic, non-halogenated compounds such as Acetone/Ethanol/Methanol), which stream was contaminated with a similar material, typically water. As part of the study, P14 noted that a portion of this stream is recovered (internally) by means of a cleansing system (also refer to objective 3C hereunder).

On their part, Participant 10 and Participant 13 also disposed of a stream with similar characteristics, i.e. the same type of solvent with same type of contamination level, to the combined order of 36.5 kg/Wk. This stream was currently being exported by means of a broker.

[27] Based on an HCV of 14,740 kJ/kg [49] and an estimated 3.963 kg of CO2/kg of Cardboard [52]

An opportunity therefore exists for P10 and P13 to provide this output stream to P14, which conversion process was already established within the operations of the same participant. This relationship could therefore potentially see to saving an estimated **36.5 kg/Wk of solvent**.

Subject to the above considerations therefore this relationship would result in an equivalent saving of solvent with a calorific content of **1,084 MJ/Wk (301 kWh/Wk)** and a carbon footprint of **47.4 kg of CO2/Wk.** [28]

5.3.3 Objective 3C: Pre-Established IS Relationships (Material Resources)

This current study revealed a series of pre-established relationships, i.e. relationships which were already in place and functional. This objective includes those streams which were either reused/recovered internally, as well as those which were reused/recovered externally to the company. An external relationship in this case may indicate a relationship with an entity which was not necessarily within the cluster of this case study. The streams are noted as follows:

- *Pre-Established Relationship 1 - Chemicals/Solvents*

Table 22 - Pre-Established Chemicals/Solvent streams

Entry no.	In/Out	Participant	Qty (unit/Wk)	Condition	Form	Disposal Method
59	O	P14	250 kg	Cont. Similar	Liquid	Recovered

Participant 14 noted an output stream of 250 kg of Solvent (Table 22), which was ‘recovered internally’ by means of a treatment process. This recovery operation substitutes the requirement for pristine solvent to the order of **150 kg** (assuming a 60% recovery process efficiency), and therefore results in the recovery of solvent with a calorific content of **4,455 MJ/Wk (1,238 kWh/Wk)** and a carbon footprint of **19.5kg of CO2/Wk** [28].

[28] Based on an HCV of 29,700 kJ/kg [45] and 1.3 kg of CO2/kg (production) for Ethanol [49]

- *Pre-Established Relationship 2 - Fuel/Spent Oils*

Table 23 - Pre-Established Fuel/Spent Oil streams

Entry no.	In/Out	Participant	Qty (unit/Wk)	Condition	Form	Disposal Method
72	O	P15	10 - 50 L	Cont. Similar	Liquid	Reused Externally

Participant 15 noted an output stream of 10 - 50L of Spent oils (Table 23), which was provided to an external company as a direct substitute for bitumen in asphalt. This operation substituted the requirement for c. **30 L (27 kg)** [29] of tar sands, and therefore results in the substitution of Tar sands (recovery of oil) with a calorific content of **972 MJ/Wk (270 kWh/Wk)** and a carbon footprint of **105 kg of CO_2/Wk** [29]

- *Pre-Established Relationship 3 - Metal/ Non-Ferrous*

Table 24 - Pre-Established Metal/Non-Ferrous streams

Entry no.	In/Out	Participant	Qty (unit/Wk)	Condition	Form	Disposal Method
22	O	P6	250 - 500 kg	Cont. Similar	Zinc ash	Reused Externally
23	O	P6	250 - 500 kg	Cont. Similar	Zinc dross	Reused Externally
67	O	P14	19 kg	Clean	Blister Packs Shredding	Reused Externally

Participant 6 notes an output stream of 250 -500 kg/Wk of Zinc Ash (Table 24), which material is treated externally through a process which mechanically separates the Zinc metal (60-85%) from the ash (at a very high recovery rate of 99%) [46]. This recovery operation substitutes the requirement for pristine Zinc Metal to the order of c. **233**

[29] Based on an HCV of 36,000 kJ/kg [45] and 108 g of CO_2/MJ (Well to Wheel) for Tar sand [53]

kg/Wk and therefore results in an equivalent saving from the recovery of Zinc (carbon footprint) of **838 kg of CO_2/Wk**. [30]

Also, as part of the same operations, Participant 6 also notes an output stream of 250 - 500 kg of Zinc Dross, a material resource which is composed of c. 95 - 98% of Zinc metal. Similarly, to Zinc Ash, the material is treated externally through a process which separates the Zinc metal (at a very high recovery rate of 99%) [46]. This recovery operation substitutes the requirement for pristine Zinc Metal to the order of c. **310 kg/Wk** and therefore results in an equivalent saving from the recovery of Zinc (carbon footprint) of **1,116 kg of CO_2/Wk**. [30]

Separately and independently, Participant 14 notes an output stream of 19 kg of blister pack shredding used in the pharmaceutical industry, which consists of a compound of Aluminium and plastic (generally PVC). P14 notes that this stream was reused as farm bedding (by an external entity)[31]. This stream therefore directly substitutes the requirement for pristine bedding (wood chips) to the order of c. **19 kg/Wk** and therefore results in the substitution of wood chip with a calorific content of **358 MJ/Wk (99 kWh/Wk)** and a carbon footprint of **0.6 kg of CO_2/Wk**. [32]

- *Pre-Established Relationship 4 - Paper/Carboard*

Table 25 - Pre-Established Paper/Cardboard streams

Entry no.	In/Out	Participant	Class	Type	Qty (unit/Wk)	Condition	Form	Source
20	I	P5	Paper	Cardboard	10 - 50 kg	Any	Standard forms	Internal (re-used)

[30] Based on 3.6 kg of CO_2/kg of Zinc [54].Calorific Value of a metal is not taken into consideration.
[31] This current research has reported the findings without going into the merit of whether such activity was covered (or otherwise) by the necessary veterinary permits for such process.
[32] Based on an HCV of 18,825 kJ/kg [49] and 6.1kg of CO_2/MWh [55] for Wood Chip.

Participant 5 noted an input stream of c. 30 kg/Wk (10 - 50 kg range) of Cardboard used for packaging (Table 25), which source was noted as being internal, i.e. re-used from otherwise waste material resources. This stream therefore indicates a direct substitution for the need for pristine cardboard to the order of c. **30 kg/Wk** which has a calorific content of **442 MJ/Wk (123 kWh/Wk)** and a carbon footprint of **119 kg of CO_2/Wk** [33]**.**

- *Pre-Established Relationship 5 - Polymer/PP (Polypropylene)*

Table 26 - Pre-Established Polymer streams

Entry no.	In/Out	Participant	Class	Type	Qty (unit/Wk)	Condition	Form	Disposal Method
12	O	P3	Polymer	PP	495 kg	Cont. Other	Jumbo bags	Reused Internally

Participant 3 noted an input stream of c. 495 kg/Wk of Polypropylene in the form of Jumbo Bags, which resource was reused internally (Table 26). This stream therefore directly substitutes the requirement for pristine Jumbo Bags and therefore results in an equivalent saving of Polypropylene of 495 kg/Wk which has a calorific content of **23,315 MJ/Wk (6,476 kWh/Wk)** and a carbon footprint of **782 kg of CO_2/Wk** [34]**.**

[33] Based on an HCV of 14,740 kJ/kg [49] and an estimated 3.963 kg of CO_2/kg of Cardboard [52]

[34] Based on an HCV of 47,100 kJ/kg [44] and an estimated 1.58 kg of CO_2/kg of PP [56]

- *Pre-Established Relationship 6 - Wood/Pallets*

Table 27 - Pre-Established Wood streams

Entry no.	In/Out	Participant	Class	Type	Qty (unit/Wk)	Condition	Form	Disposal Method (or) …	… Source
2	O	P1	Wood	Pallets	1 - 10 kg	Clean	N/A	Reused Externally	N/A
4	O	P3	Wood	Pallets	2,200 kg	Clean	N/A	Reused Externally	N/A
21	I	P5	Wood	Pallets	1 - 10 kg	Any	Standard forms	N/A	Refurbished /Recovered
28	O	P7	Wood	Pallets	10 - 50 kg	Clean	Undisclosed	Reused Externally	N/A
36	O	P9	Wood	Pallets	1 - 10 kg	Cont. Similar	N/A	Reused Externally	N/A
38	I	P9	Wood	Pallets	10 - 50 kg	Clean	Any	N/A	Internal (re-used)
52	I	P11	Wood	Pallets	500 - 1000 kg	V.Clean	Pallets	N/A	Refurbished /Recovered
53	O	P12	Wood	Pallets	10 - 50 kg	Cont. Similar	N/A	Reused Externally	N/A

Pallets (wood) constitute the largest presence of symbiotic relationships within (as well as beyond) the cluster (Table 27). As input streams, Participants 5, 9 and 11 procure their resource from recovered/refurbished sources, with P9 indicating their source as being internal. The order of these streams is of c. 785 kg of pallets (wood).

Similarly, Participants 1, 3, 7, 9 and 12 noted that their output stream is re-used by external entities. The order of these streams was of c. 2270 kg of Pallets (wood).

This class therefore directly substitutes the requirement for pristine wood pallets to the order of c. **3055 kg/Wk** (c.122 pieces/Wk) and therefore results in the substitution of wood pallets (typically pine wood) with a calorific content of **61,100 MJ/Wk (16,972 kWh/Wk)** and a carbon footprint **of 211 kg of CO_2/Wk**[35].

[35] Based on an HCV of 20,000 kJ/kg [44] for pine and 1.73 kg of CO_2/unit pallet [57] (each assumed at 25kg).

5.3.4 Objective 3D: Conversion to Energy

This objective collected those material resources which typically present a high calorific value, i.e. have a potential for conversion to an energy resource, but excluded those resources which were identified as valuable for either of objectives 3A, 3B, 3C.

- *Organic Fraction*

The table below summarises details of organic waste within the cluster.

Table 28 - Organic Fraction Streams

Entry no.	In/Out	Participant	Class	Type	Qty (unit/Wk)	Condition	Form	Disposal Method
58	O	P13	Organic	Non-Halogenated	1600 kg	Cont. Similar	Mixed	Landfilled
69	O	P14	Food	Organic	230 kg	Clean	Mixed	Landfilled

Collectively Participants 13 and 14 dispose of c. 1830 kg/Wk of Organic Waste (in different forms) (Table 28).

While this amount of waste may be too small to justify a dedicated digestion plant (microscale digestion plants may be too delicate for such a heterogeneous feed), a consideration should be made to direct such waste to an existing Anaerobic Digestion plant.

While the specific output of such waste is highly dependent on multiple parameters, including the actual composition of the waste, the specifics of the AD plant, and the ambient conditions, a general rule of thumb is that every 10 kg of wet (organic) waste produces 1 m^3 of biogas, which contains c. 21.6 MJ of energy [47]. Considering this approximation, the potential energy recovery from this process equates to an estimated **3,953 MJ/Wk (1098 kWh/Wk).**

- *Fuel/Spent Oils*

The table below summarises details of the spent oils and lubricant streams discovered within the cluster.

Table 29 - Fuel and Spent Oil Streams

Entry no.	In/Out	Participant	Class	Type	Qty (unit/Wk)	Condition	Form	Disposal Method
3	O	P1	Fuel and Oils	Spent Oils/Lubricants	50 - 100 L [36]	Cont. Similar	Sludges	Recycled Locally
19	O	P5	Fuel and Oils	Spent Oils/Lubricants	10 - 50 kg	Cont. Similar	Liquid	Recycled broker
72 [37]	O	P15	Fuel and Oils	Spent Oils/Lubricants	10 - 50 L[35]	Cont. Similar	Liquid	Reused Externally

Collectively Participants 1, 5 and 15 dispose of c. 124 kg/Wk of spent oil and lubricants (Table 29), which stream was contaminated with similar materials (different grades of spent oils). A conversion to Biofuel would result in a yield of c. 75kg of Biodiesel (60% yield [48]), which would substitute the use of regular diesel, with an equivalent calorific content of **3,420 MJ/Wk (950 kWh/Wk)** and a carbon footprint of **57.1 kg of CO2/Wk**[38].

- *Residual Fraction*

Any remaining material flows, not mentioned anywhere in the previous categories, but which are intrinsically rich in their energy content (i.e. possess an energy content which may be (partially) recovered, may collectively offer potential value for energy recovery, should such streams be directed to a Waste-to-Energy (WTE) plant. These streams of the residual fraction are listed in the following Table 30 and Table 31:

[36] The density for spent oil is assumed as 887 kg/m^3, hence the range for P3 is equivalent to c. 44 to 89 kg/Wk, and the range of P4 is equivalent to c. 9 to 45 kg/Wk.
[37] To note that Entry 72 has also featured as a 'pre-established IS relationship'
[38] Based on an HCV of 45,600 kJ/kg [45] and 16.7 g of CO_2/MJ [58] (well to tank) for diesel

Table 30 - Residual Fraction Streams

Entry no.	In/Out	Participant	Class	Type	Qty (unit/Wk)	Condition	Form	Disposal Method
5	O	P3	Wood	Pallets	300 kg	Clean	Broken	Recycled Locally
9	O	P3	Polymer	HDPE	15 kg	Cont. Other	Bottles and Jerry Cans	Recycled Locally
10	O	P3	Polymer	PE	63 kg	Cont. Other	Bags	Recycled Locally
11	O	P3	Polymer	PP	32 kg	Cont. Other	Jumbo Bags	Recycled Locally
13	O	P4	Polymer	Rubber	1 - 10 t	Clean	Various	Recycled broker
27	O	P7	Polymer	PVC	0 - 1 kg	Clean	Compacted - wrapping film	Landfilled
32	O	P8	Paper	Printing Material	2-5 kg	Clean	Sheets	Landfilled
42	O	P10	Polymer	PVC	100 - 250 kg	Cont. Similar	Compacted	Landfilled
46	O	P11	Polymer	PE (Plastic Wrapping) [39]	1 - 10 m^3 (c. 3168 kg)	Cont. Similar	Various	Recycled Locally
56	O	P13	Chemical	Toxic	10 kg	Hazardous (ICS)	Solid	Incinerate d
57	O	P13	Polymer	PVC	2 kg	Hazardous (ICS)	Various	Recycled broker
58	O	P13	Organic	Non-Halogenated	31 kg	Cont. Similar	Mixed	Landfilled
60	O	P14	Other	Pharma Waste - Hazardous	115 kg	Hazardous	In bags	Incinerate d
63	O	P14	Polymer	PE	19 kg	Clean	Solid - HDPE Drums	Recycled Locally
65	O	P14	Other	PPE and Filters	38 kg	Hazardous (ICS)	Solid	Incinerated
66	O	P14	Paper	Paper	19 kg	Clean	Shredded/ Chip	Recycled Locally

[39] Density of PE taken as 9.6 g/cm3 [59] - packing factor assumed at 60%.

Entry no.	In/Out	Participant	Class	Type	Qty (unit/Wk)	Condition	Form	Disposal Method
68	O	P14	Paper	Paper	10 kg	Clean	Sheets	Recycled Locally
76	O	P15	Wood	Strips of Wood	1 - 10 kg	Clean	Strips of Wood	Recycled Locally

Summarising the above table by type, and listing the CV for each type:

Table 31 - Summary of Residual Fractions Streams with details of the HCV for each

Class	Type	Qty (kg/Wk)	Calorific Value (HCV) MJ/kg	Actual CV (MJ/Wk)	Reference
Wood	Wood	305	20	6,100	[44]
Polymer	PE/HDPE	3265	47.1	153,781	[44]
Polymer	PP (inc. PPE waste)	70	47.1	3297	[44]
Polymer	Rubber	5500	45.0	247,500	[44]
Polymer	PVC	177.5	22.7	4,029.3	[44]
Paper	Paper	32.5	14.740	479	[49]
Chemical [40]	Toxic	10	19.1 (LCV)	191	[50]
Other [39]	Pharma Waste - Hazardous	115	19.1 (LCV)	2,196.5	[50]

[40] Both entries are listed by their user as "EWC 07 05 13 - solid wastes containing hazardous substances". Both streams originate from the pharmaceutical industry, which waste is generally composed of a mix of chemicals, such as leftover/expired powder and tablets as well as analytical/lab waste as well as packaging waste which was in contact with such chemicals. The chemical-rich waste is varied and the composition generally unknown, typically requiring characterisation prior to incineration. Experimental results demonstrate that the LCV of waste varied considerably in the range of 8.5 to 41.2 MJ/kg [50].

As quantifiable from Table 31, the total available higher calorific value (HCV) of this mix can be estimated at **417,574 MJ/Wk or 115,993 kWh/Wk**.

The recovery efficiency of a typical WTE plant varies according to type and feed (characteristics of waste such as its LCV [41]), but would typically have an electrical efficiency of 17-23%, and an overall efficiency (for plants combining heat and power - CHP) of 82 to 86% [51].

This therefore results in a potential energy recovery of **97,434 kWh/Wk, of which, 23,199 kWh/Wk** could be electrical.

5.3.5 Summary of Thematic 3 Results (Material Resources)

The first objective of this thematic (3A) discovered no new instances of direct IO relationships between entries. While this result may be interpreted as disappointing when seen in isolation, it is best interpreted alongside the more populous objective 3C, which exposed a series of pre-existing relationships, most of which of a direct nature.

Indeed, the summary provided in Table 32 below indicates that the Ħal Far cluster was already enjoying a series of pre-established IS relationships, which relationships were probably driven by free-market economies. While this method of formation of IS relationships was considered as less probable, this result is considered as a positive observation.

These relationships amounted to a collective 4,319 kg/Wk of by-products (consisting of 6.9% of the total outflow), materials which have thus been re-circulated in the economy rather than being disposed of. This effort resulted in an estimated collective carbon footprint saving of 25,745 kg of CO_2(eq), thereby recovering materials to an estimated collective calorific value of 2,625 kWh/Wk.

[41] Refer to the assumptions noted in section 5.3.

Table 32 - Summary of Objective 3C Results - Pre-Established Relationships

Opportunity	Class/Type	Weight (kg/Wk)	kg of CO2eq / Wk	CV kWh/Wk
1	Chemical/Solvent	150	19.5	1238
2	Fuel/Spent Oils	27	105	270
3a	Metal/Non-Ferrous	233	838	N/A - Metal
3b	Metal/Non-Ferrous	310	1116	N/A - Metal
3c	Metal/Non-Ferrous	19	99	0.6
4	Paper/Cardboard	30	119	123
5	Polymer/PP	495	6476	782
6	Wood/Pallets	3055	16972	211
TOTAL		**4,319**	**25,745**	**2,625**

This result was further positively supplemented by the discovery of a number of potential indirect relationships (Objective 3B) which are summarised in Table 33.

Table 33 - Summary of Objective 3B Results - Potential Indirect Relationships

Opportunity	Class/Type	Weight (kg/Wk)	kg of CO2eq / Wk	CV kWh/Wk
1	Paper/Cardboard	325	1288	1330
2	Chemical/Solvent	36.5	47.4	301
TOTAL		**362**	**1,335**	**1,601**

Should it be established that such relationships are financially and economically feasible, they could potentially see to the recovery of c. 362 kg/Wk of by-products which are currently being disposed of. The combined calorific content of these resources was estimated at 1,601 kWh/Wk, which materials had a combined carbon footprint of c. 1,335 kg of CO_2/Wk.

Notwithstanding these efforts, which equate to c. **7.5%** of the reported outflow, the research showed that the remaining fraction of material resources going to waste stood at a further 58 tonnes. As identified under objective 3D, while not all had the potential to be re-used (re-circulated), a further **19.6%** of these (i.e. 11,429 kg, with a combined CV of **99,482 kWh/Wk,** etc.) could be directed to a conversion process to extract their energy.

As noted in Table 34, three forms of conversion were identified. The potential energy recovery from each is also noted in the same table.

Table 34 - Summary of Objective 3D - Conversion to Energy

Opportunity	Class/Type	Weight (kg/Wk)	Energy kWh/Wk
1	Organic Fraction	1830	1,098
2	Fuel/Spent Oils	124	950
3	Residual Fraction	9475	97,434 (of which 23,199 electrical)
TOTAL		**11,429**	**99,482**

The above figures noted that the combined IS potential from material resources within the industrial cluster equated to the recovery of **16,110 kg/Wk of materials**, which consist of **c. 27.1%** of the total outflow streams (of which 6.9% is already realised). The combined energy content of these materials was estimated at **103,708 kWh/Wk**.

6. Conclusions

The study set out to establish the potential for IS within the Ħal Far Industrial Estate with the understanding that industrial symbiotic relationships could be the catalyst within industry promoting the transition from a linear to a circular economy. Industrial symbiotic relationships would therefore substitute the demand for raw resource with recovered resources of equivalent characteristics. In so doing, such relationships would contribute towards the sustainability of industry by reducing the burden on the supply of resources, including all aspects of the supply chain, and on the environment (as well as availing of other favourable economic and social benefits).

The research methodology was divided into two stages. The first stage consisted of a 'Resource Mapping Exercise' with a focus on exposing the various resource IO's within the cluster. This stage saw to the creation of a custom questionnaire based on a hybrid model between those suggested by Chen et al.[12] and Liwarska et al.[31], which data formed the necessary resource IO database of the study.

Armed with such database, the second stage was focused on an 'Opportunity Discover Process', thereby distributing the research into three thematics, namely: 1) Collaborative Capacity Thematic, 2) Energy Thematic, and 3) Material Resource Thematic.

The analyses has discovered a series of pre-established IS relationships for the material resources stream (Objective 3C). While none of these could be identified as being relationships within this cluster, the result was equally satisfactory, as this resulted in the recovery of various resources to the tune of 4,319 kg per week; materials with an estimated carbon footprint of 25,745 t of $CO_{2(eq)}$/Wk, and an estimated CV of 2,625 kWh per week. This result was somewhat unexpected, although it is likely that it is being driven organically by free-market forces rather than by other mechanisms. It therefore supports the notion put forward by Li [7] who noted that IS synergies can only be sustainable if they reap economic benefits to the industry operators.

The result indeed contrasts with the discovery of pre-existing energy relationships (Objective 2C), given that no relationship was identified within this latter objective. It was unlikely that such a discrepancy was caused by lack of opportunity, given that this research established a potential for realisable energy IS relationships to the tune of 106,100 kWh per week (Objective 2A).

The potential cause for such lack of pre-established energy IS relationship was likely exposed when delving into the collaborative capacity thematic. While three of the four objectives under this thematic noted encouraging results (industry drivers, trust and ability; Objectives 1A,1B and 1C respectively), the technical capacity within the cluster for personnel dedicated to resource recovery was generally lacking, consequently affecting the readiness for IS (Objective 1D).

The need to strengthen the technical capacity within the participants has also been exposed when observing that the vast majority of the potential Energy Resource IS opportunities identified in the study can happen within the same organisation (as potential energy saving measures).

This research therefore highlighted the need to substantiate the technical capacity of the participants, or better still, the need to centralise such service at a common base through dedicated bodies within the site administrator's remit. Such centralisation would allow for a holistic analysis of the cluster and would therefore facilitate the formation of IS relationships. This supports the theoretical concept discussed earlier, i.e. that connective relationships between different decision makers is essential to facilitate symbiotic relationships.

Industries and related players need to foster a pragmatic environmental culture for IS relationships to develop. Thus, besides exploring and developing the potential energy relationships mentioned earlier, such a body could also facilitate the formation of the unrealised material resource IS relationships. According to this current study, these resources were estimated as having a combined weight of 362 kg/Wk, i.e. materials with an estimated carbon footprint of 1,335 t of $CO_{2(eq)}$ per week, and an estimated CV of 1,601 kWh per week.

Collectively, the symbiotic material relationships (summing the existing ones together with the potential relationships), have the possibility of recovering (by means of a circular substitution of resources) c. **7.5%** of the material resources indicated as entering the cluster.

Similarly, if realised, the potential benefit of energy resource IS relationships provides for a larger contribution, with the potential recovery (also by means of a circular substitution of resources) of c. **23.9%** of the reported heating demand within the cluster.

The above findings suggest that while the majority of material resource IS relationships are indeed already established, much greater focus should be placed on the energy thematic, which offers greater opportunity **and** benefit.

The research has also established how a portion of the residual material resources (not recoverable under either of Objectives 3A, 3B and 3C), can also have their energy recovered through different processes (such as WTE, AD, and conversion to Bio-fuels). This was established under Objective 3D, which recognises an energy recovery potential from the residual fraction of the reported outflow materials to the tune of 99,482 kW/Wk (from the c. 11,429 kg/Wk worth of materials which would otherwise be landfilled).

It is therefore noticed how IS within the cluster would primarily see to recovering material and energy resources by means of a substitution (in a manner which is compatible with a circular economy), and in the absence of such opportunity therefore a subsequent secondary stage, recovering energy from the residual fractions. Such a-process flow is also considered as being compatible with the waste hierarchy, thereby promoting sustainability within industry, and promoting the transition towards a circular economy.

7. Suggestions for Future Work

The scope of this study was to evaluate the potential of IS within an industrial cluster in Malta, which study has therefore been constrained by a number of limitations as explained in section 3.1, amongst which was economic feasibility. The natural progression of this work would therefore involve a deeper economic and technical analysis of the potential relationships highlighted in the various sections of the results chapter. Such a process would therefore take the form of a Cost Benefit Analysis, quantifying all impacts on environment, organisational, social and economic domains.

The conclusions of this research provide for a series of results which expose the magnitude of the resource recovery potential through industrial symbiosis within the Ħal Far Industrial Estate. Given that such estate is merely one cluster among a number of similar clusters within the country, such results can provide a benchmark position, should such research be extended to the national scale.

In such circumstance therefore, it is likely that a similar methodology as presented in this research would provide for an effective tool in exposing potential IS relationships at a national level. The methodology as presented can assist future IS studies on similar clusters to build their own databases. In such case, the following improvements to the methodology would be recommended:

- Range and Resolution

The concept of including ranges within the questionnaire has been favourably welcomed by the same participants. This method has been perceived as being less threatening to the secrecy of the participants' operations, as well as having facilitated the compilation of data.

While such a wider set of ranges have been suitable for some non-critical fields (such as 'Quantity', 'Form', 'Usage' etc., the resolution of other parameters is best increased (a tighter range). This is particularly so for data fields which are more critical to the opportunity discovery stage, with particular mention to fields such as 'Operating temperature' and '*dT* - change in temperature'. During the opportunity discovery stage, the range used for these parameters was considered as being too broad (low resolution), requiring a more in-depth analysis during the course of this study.

- Frequency of collection

With the exception of ambient heating/cooling, this study assumes a uniform and linear resource flow model, and does not take into account, the variability of the market, be it seasonal or otherwise.

The data collected for this research are indeed a snapshot of the period in which they were collected, and do not provide a stable insight of long-term operations within the cluster. This variability may only be mitigated by increasing the frequency of the data collection exercise to cover multiple periods, and thus attain a better statistical representation. Such process is of course very time consuming, which may however be mitigated by centralising the data collection sequence.

- Water

Given the nature of the resource it may be more beneficial to emphasis/segregate 'Water' resource IO streams from the other Materials Tab categories. A similar reasoning has been established for 'Fuels' which have been specifically distinguished in the Energy Tab of the questionnaire. This segregation would encourage participants to provide the necessary detail for this class of resource, which would otherwise be overlooked (as was the case in this research).

- Centralisation

This recommendation should not only result in the creation of a central IO database of resources, but highlights the benefits of forming a central body (possibly within INDIS) with the scope of overseeing IS formation. This body would therefore regulate the collection of data by coordinating data collection efforts, as well as by providing a uniform data capturing system (and parameters).

A central body (as part of the state agency responsible for site administration) would therefore act as a 'guidance body' to industry players, and help create an institutional framework for the promotion of IS and circular economy specifically and directly for industry. Such a framework would not only expose potential IS relationships at a national level, but would also provide recommendations for legal and regulatory amendments to facilitate the process.

A clear instance where an intervention of this type would have been required has been noted within the results of Objective 3D. While the potential energy recovery has been quoted as ‘thermal’, it is technically possible to recover a portion of that energy in electrical form, which is typically preferable. Nevertheless, current legislative barriers (see Section 2.2) limit the sale of electrical energy to a second entity other than to the national DSO, unless recovered for self-consumption within the same entity.

The resource IO database should not be limited to the discovery of IS relationships alone. Beyond IS, the database exposes regions within a cluster which may be rich (or poor) in a particular resource. Such information could be considered as a valuable guideline for the development of new industries or the allocation of industrial space to prospective bodies, which would therefore be incentivised to locate their industry in close proximity to resource rich/poor counterparts with high IS potential.

Finally, the resource IO database also exposes the baseline consumption of particular forms of resources within the whole cluster, e.g. determining a baseline for ambient cooling temperatures throughout the industrial estate. Such data would therefore open opportunities to centralise resource management systems, and cater for such baseline in a more efficient manner (such as would be centralised heating or cooling systems covering the whole cluster).

Such systems may also be designed to take advantage of geographic/topographic features within the cluster such as, say, the proximity of the Ħal Far Industrial estate to the sea, a body providing a fluid at a relatively constant seasonal temperature.

References

[1] "A European Green Deal | European Commission." https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en (accessed Aug. 11, 2021).

[2] "EUR-Lex - 52020DC0098 - EN - EUR-Lex." https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM:2020:98:FIN (accessed Aug. 11, 2021).

[3] M. Mirata, "Experiences from early stages of a national industrial symbiosis programme in the UK: Determinants and coordination challenges," *Journal of Cleaner Production*, vol. 12, no. 8–10, pp. 967–983, 2004, doi: 10.1016/j.jclepro.2004.02.031.

[4] A. Marino and P. Pariso, "Comparing European countries' performances in the transition towards the Circular Economy," *Sci Total Environ*, vol. 729, p. 138142, Aug. 2020, doi: 10.1016/j.scitotenv.2020.138142.

[5] "Research helps Europe advance towards circular economy | EU Science Hub." https://ec.europa.eu/jrc/en/news/research-helps-europe-advance-towards-circular-economy (accessed Nov. 25, 2021).

[6] "Industrial Zones – INDIS Malta." https://indismalta.com/industrial-zones/ (accessed Aug. 12, 2021).

[7] X. Li, "Industrial Ecology And Industry Symbiosis For Environmental Sustainability," 2018.

[8] R. A. Frosch and N. E. Gallopoulos, "Strategies for Manufacturing 1 Waste from one industrial process can serve as the raw materials for another, thereby reducing the impact of industry on the environment," 1989.

[9] Z. Yeo, D. Masi, J. S. C. Low, Y. T. Ng, P. S. Tan, and S. Barnes, "Tools for promoting industrial symbiosis: A systematic review," *Journal of Industrial Ecology*, vol. 23, no. 5, pp. 1087–1108, Oct. 2019, doi: 10.1111/jiec.12846.

[10] G. A. Fuentes Barrera, X. Gabarrell i Durany, J. Rieradevall Pons, and J. G. Guerrero Erazo, "Trends in global research on industrial parks: A bibliometric

analysis from 1996–2019," *Heliyon*, vol. 7, no. 8, p. e07778, Aug. 2021, doi: 10.1016/j.heliyon.2021.e07778.

[11] I. Costa and P. Ferrão, "A case study of industrial symbiosis development using a middle-out approach," *Journal of Cleaner Production*, vol. 18, no. 10–11, pp. 984–992, Jul. 2010, doi: 10.1016/j.jclepro.2010.03.007.

[12] P. C. Chen and H. W. Ma, "Using an Industrial Waste Account to Facilitate National Level Industrial Symbioses by Uncovering the Waste Exchange Potential," *Journal of Industrial Ecology*, vol. 19, no. 6, pp. 950–962, Dec. 2015, doi: 10.1111/jiec.12236.

[13] D. Gibbs and P. Deutz, "Reflections on implementing industrial ecology through eco-industrial park development," *Journal of Cleaner Production*, vol. 15, no. 17, pp. 1683–1695, 2007, doi: 10.1016/j.jclepro.2007.02.003.

[14] J. Azevedo *et al.*, "Industrial symbiosis implementation potential—an applied assessment tool for companies," *Sustainability (Switzerland)*, vol. 13, no. 3, pp. 1–16, Feb. 2021, doi: 10.3390/su13031420.

[15] L. Fraccascia, V. Yazdanpanah, G. van Capelleveen, and D. M. Yazan, "Energy-based industrial symbiosis: a literature review for circular energy transition," *Environment, Development and Sustainability*, vol. 23, no. 4. Springer Science and Business Media B.V., pp. 4791–4825, Apr. 01, 2021. doi: 10.1007/s10668-020-00840-9.

[16] J. Korhonen, F. von Malmborg, P. A. Strachan, and J. R. Ehrenfeld, "Management and policy aspects of industrial ecology: An emerging research agenda," *Business Strategy and the Environment*, vol. 13, no. 5, pp. 289–305, Sep. 2004, doi: 10.1002/bse.415.

[17] A. Lindfors, M. Gustafsson, S. Anderberg, M. Eklund, and M. Mirata, "Developing biogas systems in Norrköping, Sweden: An industrial symbiosis intervention," *Journal of Cleaner Production*, vol. 277, Dec. 2020, doi: 10.1016/j.jclepro.2020.122822.

[18] A. S. Maqbool, F. M. Alva, and G. van Eetvelde, “An assessment of European information technology tools to support industrial symbiosis,” *Sustainability (Switzerland)*, vol. 11, no. 1, Dec. 2018, doi: 10.3390/su11010131.

[19] P. Ristola and M. Mirata, “Industrial symbiosis for more sustainable, localised industrial systems,” 2007.

[20] “EUR-Lex - 32009L0072 - EN - EUR-Lex.” https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A32009L0072 (accessed Oct. 06, 2021).

[21] “LEĠIŻLAZZJONI MALTA.” https://legislation.mt/eli/sl/545.31/mlt/pdf (accessed Oct. 06, 2021).

[22] M. Mirata and T. Emtairah, “Industrial symbiosis networks and the contribution to environmental innovation: The case of the Landskrona industrial symbiosis programme,” *Journal of Cleaner Production*, vol. 13, no. 10–11, pp. 993–1002, 2005, doi: 10.1016/j.jclepro.2004.12.010.

[23] A. Neves, R. Godina, S. G. Azevedo, C. Pimentel, and J. C. O. Matias, “The Potential of Industrial Symbiosis: Case Analysis and Main Drivers and Barriers to Its Implementation,” *Sustainability (Switzerland)*, vol. 11, no. 24, Dec. 2019, doi: 10.3390/su11247095.

[24] D. R. Lombardi and P. Laybourn, “Redefining Industrial Symbiosis: Crossing Academic-Practitioner Boundaries,” *Journal of Industrial Ecology*, vol. 16, no. 1, pp. 28–37, Feb. 2012, doi: 10.1111/j.1530-9290.2011.00444.x.

[25] E. A. Lowe, “Creating by-product resource exchanges: strategies for eco-industrial parks,” 1997. [Online]. Available: www.indigodev.com

[26] M. Mirata, H. Nilsson, and J. Kuisma, “Production systems aligned with distributed economies: Examples from energy and biomass sectors,” *Journal of Cleaner Production*, vol. 13, no. 10–11, pp. 981–991, Aug. 2005, doi: 10.1016/j.jclepro.2004.12.018.

[27] A. Johansson, P. Kisch, and M. Mirata, “Distributed economies - A new engine for innovation,” *Journal of Cleaner Production*, vol. 13, no. 10–11, pp. 971–979, Aug. 2005, doi: 10.1016/j.jclepro.2004.12.015.

[28] M. A. Butturi, F. Lolli, M. A. Sellitto, E. Balugani, R. Gamberini, and B. Rimini, “Renewable energy in eco-industrial parks and urban-industrial symbiosis: A literature review and a conceptual synthesis,” *Applied Energy*, vol. 255. Elsevier Ltd, Dec. 01, 2019. doi: 10.1016/j.apenergy.2019.113825.

[29] D. Gibbs and P. Deutz, “Implementing industrial ecology? Planning for eco-industrial parks in the USA,” *Geoforum*, vol. 36, no. 4, pp. 452–464, Jul. 2005, doi: 10.1016/j.geoforum.2004.07.009.

[30] S. V. Valentine, “Kalundborg Symbiosis: Fostering progressive innovation in environmental networks,” *Journal of Cleaner Production*, vol. 118, pp. 65–77, Apr. 2016, doi: 10.1016/j.jclepro.2016.01.061.

[31] E. Liwarska-Bizukojc and M. Bizukojc, “Environmental Engineering and Management,” 2018. [Online]. Available: http://www.eemj.icpm.tuiasi.ro/;http://www.eemj.eu

[32] R. R. Heeres, W. J. V. Vermeulen, and F. B. de Walle, “Eco-industrial park initiatives in the USA and the Netherlands: First lessons,” *Journal of Cleaner Production*, vol. 12, no. 8–10, pp. 985–995, Oct. 2004, doi: 10.1016/j.jclepro.2004.02.014.

[33] E. Lowe, “Eco-industrial Park Handbook for Asian Developing Countries Report to Asian Development Bank,” 2001. [Online]. Available: www.indigodev.com

[34] J. S. C. Low *et al.*, “A Collaboration Platform for Enabling Industrial Symbiosis: Application of the Database Engine for Waste-to-Resource Matching,” in *Procedia CIRP*, 2018, vol. 69, pp. 849–854. doi: 10.1016/j.procir.2017.11.075.

[35] R. Taddeo, A. Simboli, and A. Morgante, “Implementing eco-industrial parks in existing clusters. Findings from a historical Italian chemical site,” *Journal of Cleaner Production*, vol. 33, pp. 22–29, 2012, doi: 10.1016/j.jclepro.2012.05.011.

[36] G. B. Grant, T. P. Seager, G. Massard, and L. Nies, “Information and communication technology for industrial symbiosis,” *Journal of Industrial*

Ecology, vol. 14, no. 5, pp. 740–753, Oct. 2010, doi: 10.1111/j.1530-9290.2010.00273.x.

[37] "Ħal Far Industrial Estate – INDIS Malta." https://indismalta.com/industrial-zones/hal-far-industrial-estate/ (accessed Nov. 12, 2021).

[38] NSO, "Energy Statistics." https://nso.gov.mt/en/nso/Sources_and_Methods/Unit_B3/Environment_Energy_Transport_and_Agriculture_Statistics/Pages/Energy-Statistics.aspx (accessed Nov. 16, 2021).

[39] NSO, "External Trade Statistics." https://nso.gov.mt/en/nso/Sources_and_Methods/Unit_A4/International_Trade/Pages/External-Trade-Statistics.aspx (accessed Nov. 16, 2021).

[40] NSO, "Waste Statistics." https://nso.gov.mt/en/nso/Sources_and_Methods/Unit_B3/Environment_Energy_Transport_and_Agriculture_Statistics/Pages/Waste-Statistics.aspx (accessed Nov. 16, 2021).

[41] R. Álvarez and C. Ruiz-Puente, "Development of the Tool SymbioSyS to Support the Transition Towards a Circular Economy Based on Industrial Symbiosis Strategies," *Waste and Biomass Valorization*, vol. 8, no. 5, pp. 1521–1530, Jul. 2017, doi: 10.1007/s12649-016-9748-1.

[42] "What's the average survey response rate? [2021 benchmark] | Survey Anyplace." https://surveyanyplace.com/blog/average-survey-response-rate/ (accessed Nov. 21, 2021).

[43] "Climate of Malta - Wikipedia." https://en.wikipedia.org/wiki/Climate_of_Malta (accessed Jan. 26, 2022).

[44] M. Ioelovich, "Energy Potential of Natural, Synthetic Polymers and Waste Materials - A Review," *Academic Journal of Polymer Science*, vol. 1, no. 1, May 2018, doi: 10.19080/ajop.2018.01.555553.

[45] "Fuels - Higher and Lower Calorific Values." https://www.engineeringtoolbox.com/fuels-higher-calorific-values-d_169.html (accessed Jan. 29, 2022).

[46] E. Rudnik, "Recovery of zinc from zinc ash by leaching in sulphuric acid and electrowinning," *Hydrometallurgy*, vol. 188, pp. 256–263, Sep. 2019, doi: 10.1016/j.hydromet.2019.07.006.

[47] Yvonne. Voegeli, *Anaerobic digestion of biowaste in developing countries : practical information and case studies*. Eawag-Sandec, 2014.

[48] O. Arpa, R. Yumrutas, and A. Demirbas, "Production of diesel-like fuel from waste engine oil by pyrolitic distillation," *Applied Energy*, vol. 87, no. 1, pp. 122–127, 2010, doi: 10.1016/j.apenergy.2009.05.042.

[49] C. Montejo, C. Costa, P. Ramos, and M. D. C. Márquez, "Analysis and comparison of municipal solid waste and reject fraction as fuels for incineration plants," *Applied Thermal Engineering*, vol. 31, no. 13, pp. 2135–2140, Sep. 2011, doi: 10.1016/j.applthermaleng.2011.03.041.

[50] J. Bujak, "Experimental Study of the Lower Heating Value of Medical Waste," 2010.

[51] M. Müller, L. Tobiasen, and B. Kamuk, "Waste-to-Energy for District Heating," in *Encyclopedia of Sustainability Science and Technology*, Springer New York, 2013, pp. 1–17. doi: 10.1007/978-1-4939-2493-6_10-3.

[52] K. E. Tomberlin, R. Venditti, and Y. Yao, "Pulp & paper GHG emissions," 2020.

[53] H. Cai *et al.*, "Well-to-Wheels Greenhouse Gas Emissions of Canadian Oil Sands Products: Implications for U.S. Petroleum Fuels," *Environmental Science and Technology*, vol. 49, no. 13, pp. 8219–8227, Jul. 2015, doi: 10.1021/ACS.EST.5B01255.

[54] A. E. Nilsson *et al.*, "A review of the carbon footprint of Cu and Zn production from primary and secondary sources," *Minerals*, vol. 7, no. 9. MDPI AG, Sep. 13, 2017. doi: 10.3390/min7090168.

[55] L. Eriksson and L. Gustavsson, "Comparative analysis of wood chips and bundles - Costs, carbon dioxide emissions, dry-matter losses and allergic reactions," *Biomass and Bioenergy*, vol. 34, no. 1, pp. 82–90, Jan. 2010, doi: 10.1016/j.biombioe.2009.10.002.

[56] A. Alsabri, F. Tahir, and S. G. Al-Ghamdi, "Life-cycle assessment of polypropylene production in the gulf cooperation council (Gcc) region," *Polymers (Basel)*, vol. 13, no. 21, Nov. 2021, doi: 10.3390/polym13213793.

[57] A. L. Carrano, B. K. Thorn, and H. Woltag, "Characterizing the carbon footprint of wood pallet logistics," *Forest Products Journal*, vol. 64, no. 7–8. Forest Products Society, pp. 232–241, 2014. doi: 10.13073/FPJ-D-14-00011.

[58] "Producing gasoline and diesel emits more CO2 than we thought - Innovation Origins." https://innovationorigins.com/en/producing-gasoline-and-diesel-emits-more-co2-than-we-thought/ (accessed Jan. 29, 2022).

[59] "Polyethylene - Wikipedia." https://en.wikipedia.org/wiki/Polyethylene (accessed Feb. 02, 2022).

Appendix 1 - The Questionnaire

TAB 1

Scope of the survey

This research project shall seek to collect data related to resource flows (material and energy) within the Hal Far Industrial Estate, and map these resources, particularly waste. Armed with such information, the ultimate goal is to identify opportunities for resource sharing between neighbouring companies so as to valorise a resource which may otherwise be lost.

This study will therefore seek to establish the potential for industrial symbiotic relationships between operators (one man's waste is another man's treasure), an essential step towards the transition from a linear to a circular economy.

Who Should Compile the survey?

The survey is best compiled by **technical personnel** involved in the operations, technical or maintenance duties of the organisation. Some input may require the assistance of purchasing/supply chain personnel.

Why should an operator participate in this study?

Besides the obvious environmental benefits derived from a circular economy, operators may benefit from:

- a reduction in waste management fees
- a potential to commercialise resource streams which are currently being undervalued (wasted)
- a possibility to source resources locally (within the same geographic cluster), thus easing supply chain strains
- an improved relationship with other cluster operators
- an improvement in their energy efficiency
- the creation of a cleaner and safer working environment
- a lesser dependence on storage (not only waste storage, but also raw resources), freeing up valuable industrial footprint
- a claim towards and improved CSR profile

The survey is designed to value your time, and therefore facilitates participation

Assistance with filling the survey
Assistance with filling this survey is available at any time, by reaching out to the contact below:

Researcher Details:
Nicholas Vella
Institute for Sustainable Energy - University of Malta
nicholas.vella.99@um.edu.mt
WhatsApp: +35699444671

Quality of Data and Level of Detail

- *What to include*

The relevant data for this survey are resource streams which are generally **consistent** throughout extended periods
Ball-park estimates, rather than accurate figures, are sufficient for the scope of the study. Drop down options, binning data in 'ranges' have been provided for ease of use

Any resource stream (even if deemed as irrelevant), but which does not fit in the *'what to exclude'* list below

- *What to exclude*

Resource streams which are haphazard, **irregular** and/or infrequent
Streams which are **sensitive** (commercially, economically, Trademark or IP protected)
Resource streams which require strict levels of **control** (on supply/quality/chemical composition/certification in general)
Very **accurate** quantities - Ball-park estimates or 'ranges' (as provided in the drop down menus for ease of use) are sufficient
Highly specialised resource streams, which resource is highly specific to your manufacturing process alone.

Revising and Opting Out
While the success of the research is dependent on the wide participation of tenants, participation to the survey remains on a voluntary basis.
Participants may choose to opt-out at any point and have the right to obtain access to, rectify, and where applicable ask for the data to be erased.

Guidelines
Many of the fields contain pre-compiled drop down menus to provide a quick data entry experience. These are marked by Light Green boxes.

Beneath each drop down menu, areas for custom entries/notes/qualifiers have been made available, and are marked in light blue boxes. We understand that some of the drop down options may not be exhaustive, and therefore encourage the use of the custom entry fields when required. Participants may also opt to use the custom entry fields, rather than the drop down options, should these be preferred/quicker for the participant.

As noted earlier, accurate quantities are not necessary, and participants may either choose to provide ball park estimates in the light blue fields, or choose a 'range' provided in the drop down menu.

TAB 2

Company Name:

Address:

Contact Person:

Contact Number:

Contact email:

☐ Check to agree

Do you wish to be contacted with details of any findings related to your organisation?

About the Company

Do you employ any personnel specifically dedicated to resource maximisation and/or environmental issues?

Secrecy of Operation. Which of the following statements most applies to you:

GDPR: Contact details shall solely be used for the above mentioned purpose. Communication shall not feature any promotional material, and will be restricted to findings related to this study only. Contact details shall be removed once the study is completed.

Upon receiving this information, company details shall be replaced by an anonymous identifier (Participant XX). Any data which shall be published shall ONLY refer to this anonymous identifier. No contact information shall be published.

Sensitive Information:
The researcher understands that some data may, in some cases, be considered as sensitive. In such regard, the participant is reminded that he is at liberty to **omit or disguise such data**, so as to protect his interests. As noted earlier, the entry fields need not be 'accurate', but required as **'ballpark' figures** which, for your convenience, have been binned in ranges. In any case, if a resource is too sensitive to reveal in this survey, in practices it shall also be too sensitive to commercialise externally, and would therefore be also irrelevant to the study.

Researcher Details:
Nicholas Vella
Institute for Sustainable Energy - University of Malta
nicholas.vella.99@um.edu.mt

TAB 3

A) Do you use any fuels for purposes other than transport/mobility?

Fuel		**Primary Purpose**	**Weekly Qty**	**Unit**	**Secondary Purpose**	**Weekly Qty**	**Unit**	**Required Cleanliness Level**	**Source**
Petrol	*Select Range* ***OR***								
	Estimate ***(Optional)***								
Diesel	*Select Range* ***OR***								
	Estimate ***(Optional)***								
Bio-Diesel	*Select Range* ***OR***								
	Estimate ***(Optional)***								
Kerosene	*Select Range* ***OR***								
	Estimate ***(Optional)***								
LPG	*Select Range* ***OR***								
	Estimate ***(Optional)***								
Wood	*Select Range* ***OR***								
(as a fuel)	*Estimate* ***(Optional)***								
HFO	*Select Range* ***OR***								
	Estimate ***(Optional)***								
Other: (If any)									
	Select Range ***OR***								
	Estimate ***(Optional)***								
	Select Range ***OR***								
	Estimate ***(Optional)***								

Notes (Optional):

B) Heating Capacity

How much thermal energy (average weekly) does your process(es) require?

Type		Heat Source (Equipment Type)	Heat Transfer Media (if Applicable)	Temperature (Max) °C	Thermal Energy for the process (kWh/week)	Av Usage (hr/wk)
Industrial Equipment	*Select Range* ***OR***					
	Estimate ***(Optional)***					
Industrial Equipment	*Select Range* ***OR***					
	Estimate ***(Optional)***					
Industrial Equipment	*Select Range* ***OR***					
	Estimate ***(Optional)***					
Ambient Heating	*Select Range* ***OR***					
	Estimate ***(Optional)***					
Other: (If any)						
	Select Range ***OR***					
	Estimate ***(Optional)***					
	Select Range ***OR***					
	Estimate ***(Optional)***					

Alternatively: (If comfortable providing such data)

Having difficulty sourcing this information? Feel free to list your equipment and we will take reasonable estimates for you:

Brand	Model	Type	Av. Weekly Usage (hr)	Max Temp (°C)

TAB 4

C) Cooling Capacity

Do you employ cooling systems in your process? What is your (average weekly) energy requirement?

Type		Cooling Source (choose from list)	Heat Transfer Media (if Applicable)	Initial Temperature (Av) °C	Target Reduction in Temp (Av) °C	Energy (kWh/week)	Av Usage (hr/wk)
Industrial Equipment	*Select Range* ***OR***						
	Estimate ***(Optional)***						
Industrial Equipment	*Select Range* ***OR***						
	Estimate ***(Optional)***						
Industrial Equipment	*Select Range* ***OR***						
	Estimate ***(Optional)***						
Ambient Cooling	*Select Range* ***OR***						
	Estimate ***(Optional)***						
Other: (If any)							
	Select Range ***OR***						
	Estimate ***(Optional)***						
	Select Range ***OR***						
	Estimate ***(Optional)***						

Alternatively: (If comfortable providing such data)

Having difficulty sourcing this information? Feel free to list your equipment and we will take reasonable estimates for you:

Brand	Model	Type	Av. Weekly Usage (hr)	Change in Temp (°C)

TAB 5

D) Waste (Material Outflows)

- In the following section, kindly list materials whose generation is constant, and which are disposed of in a regular (weekly/monthly) pattern
- One-off waste streams need not be included in this list
- Participants are reminded that they are at liberty to omit and/or disguise waste streams which they deem as being of a commercially sensitive nature

Waste		Class	Type	Qty (Weekly)	Unit	Cleanliness at time of Disposal	Form at time of Disposal	Disposal Method	EWC code (if immediately available)
Waste 1	*Select Range* ***OR***	Fuels_and_Oils							
	Estimate ***(Optional)***								
Waste 2	*Select Range* ***OR***								
	Estimate ***(Optional)***								
Waste 3	*Select Range* ***OR***								
	Estimate ***(Optional)***								
Waste 4	*Select Range* ***OR***								
	Estimate ***(Optional)***								
Waste 5	*Select Range* ***OR***								
	Estimate ***(Optional)***								
Waste 6	*Select Range* ***OR***								
	Estimate ***(Optional)***								
Waste 7	*Select Range* ***OR***								
	Estimate ***(Optional)***								
Waste 8	*Select Range* ***OR***								
	Estimate ***(Optional)***								
Waste 9	*Select Range* ***OR***								
	Estimate ***(Optional)***								
Waste 10	*Select Range* ***OR***								
	Estimate ***(Optional)***								

Notes (Optional):

TAB 6

E) Material Inflow

- In the following section, kindly list materials which are sourced regularly as part of your operation
- Participants should not include those materials whose supply is either i) highly specialised and specific ii) subject to stringent quality control (eg. Plastics for medical devices) iii) subject to stringent regulatory control
- Participants are reminded that they are at liberty to omit and/or disguise material streams which they deem as being of a commercially sensitive nature

Materials		Class	Type	Required Form	Required Cleanliness Level	Qty (Weekly)	Unit	Source
Material 1	*Select Range* ***OR***							
	Estimate ***(Optional)***							
Material 2	*Select Range* ***OR***							
	Estimate ***(Optional)***							
Material 3	*Select Range* ***OR***							
	Estimate ***(Optional)***							
Material 4	*Select Range* ***OR***							
	Estimate ***(Optional)***							
Material 5	*Select Range* ***OR***							
	Estimate ***(Optional)***							
Material 6	*Select Range* ***OR***							
	Estimate ***(Optional)***							
Material 7	*Select Range* ***OR***							
	Estimate ***(Optional)***							
Material 8	*Select Range* ***OR***							
	Estimate ***(Optional)***							

Appendix 2 - IO Database - Energy Resource Thematic

Fuel	In/Out	Participant	Type	Purpose	Wkly Qty	Required Cleanliness	Source
1	I	P3	Diesel	Elec Gen	360 kg	Pristine	Purchased New
2	I	P5	Jet A1 Fuel	Testing	100 -1000 ltr	Pristine	Purchased New
3	I	P6	LPG	Furnace	1000 - 10000 kg	Pristine	Purchased New
4	I	P13	LPG	Process Heating	1200 m3	Pristine	Purchased New
5	I	P14	Diesel	HVAC	1000 -10000 ltr	V Clean	Purchased New
6	I	P14	Diesel	Process Heating	100 - 1000 ltr	V Clean	Purchased New

Entry No.	In/Out	Type	Participant	Source	Heat Transfer Media	Op Temp (°C)	Energy (kWh/Wk)	Av Usage (hr/Wk
1	Heating	Ind. Equip.	P1	Electrical	N/A	1000	100 - 1,000	C. 24 - 48
2	Heating	Ind. Equip.	P1	Electrical	N/A	850	100 - 1,000	C. 24 - 48
3	Cooling	Ambient	P1	AC/HVAC	Refrigerant	<40	100 - 1,000	C. 24 - 48
4	Cooling	Ind. Equip.	P3	Chiller (CL)	Water	38 ; dT 3	105,000	F. 144 - 168
5	Cooling	Ambient	P3	Chiller (CL)	Water	<40 ; dT5-10	50,000 - 100,000	E. 96 - 144
6	Heating	Ind. Equip.	P3	Electrical	N/A	300	57,000	F. 144 - 168
7	Heating	Ind. Equip.	P3	Electrical	Air	85	750	F. 144 - 168
8	Heating	Ambient	P3	Heat Pump	Water	>25 - 50	50,000-100,000	E. 96 - 144

Entry No.	In/Out	Type	Participant	Source	Heat Transfer Media	Op Temp (°C)	Energy (kWh/Wk)	Av Usage (hr/Wk
9	Heating	Ind. Equip.	P4	Electrical	N/A	>150-250	50,000-100,000	E. 96 - 144
10	Cooling	Ind. Equip.	P4	Chiller (CL)	Water	<40 ; dT5-10	10,000 - 50,000	E. 96 - 144
11	Cooling	Ambient	P5	AC/HVAC	Refrigerant	<40	100 - 1,000	C. 24 - 48
12	Heating	Ind. Equip.	P6	Boiler - LPG	Water	>50 - 70	10,000 - 50,000	F. 144 - 168
13	Heating	Ind. Equip.	P6	Boiler - LPG	Direct	>450	50,000 - 100,000	G. 24/7
14	Heating	Ambient	P6	Heat Pump	Refrigerant	>15 - 25	100 - 1,000	C. 24 - 48
15	Cooling	Ind. Equip.	P6	Stack Ventilation	Exhaust	450	10,000 - 50,000	G. 24/7
16	Heating	Ambient	P7	Heat Pump	Refrigerant	>15 - 25	10 - 100	A. 0 - 12
17	Cooling	Ambient	P7	AC/HVAC	Refrigerant	<40 ; dT5-10	100 - 1,000	A. 0 - 12
18	Heating	Ambient	P8	Heat Pump	Water	>15 - 25	100 - 1,000	B. 12 - 24
19	Heating	Ind. Equip.	P8	Heat Pump	Water	>50 - 70	10 - 100	B. 12 - 24
20	Cooling	Ambient	P8	AC/HVAC	Refrigerant	<40 ; dT5-10	1,000-10,000	B. 12 - 24
21	Cooling	Ambient	P9	AC/HVAC	Refrigerant	>40-60 ; dt20-30	100 - 1,000	G. 24/7
22	Heating	Ind. Equip.	P10	Electrical	Water	>25 - 50	100 - 1,000	E. 96 - 144
23	Heating	Ind. Equip.	P10	Electrical	N/A	>100-150	100 - 1,000	D. 48 - 96
24	Cooling	Ambient	P10	AC/HVAC	Refrigerant	>40-60 ; dt20-30	100 - 1,000	E. 96 - 144
25	Heating	Ind. Equip.	P11	Electrical	N/A	>50 - 70	10 - 100	C. 24 - 48

Entry No.	In/Out	Type	Participant	Source	Heat Transfer Media	Op Temp (°C)	Energy (kWh/Wk)	Av Usage (hr/Wk
26	Heating	Ambient	P11	Heat Pump	Refrigerant	>15 - 25	100 - 1,000	D. 48 - 96
27	Cooling	Ambient	P11	AC/HVAC	Refrigerant	<40 ; dT15-20	100 - 1,000	D. 48 - 96
28	Heating	Ind. Equip.	P13	Boiler - LPG	Steam	>100-150	10,000 - 50,000	G. 24/7
29	Heating	Ambient	P13	Heat Pump	Refrigerant	>15 - 25	100 - 1,000	D. 48 - 96
30	Cooling	Ind. Equip.	P13	Chiller (CL)	Water	Amb.; dT 5-10	2,000	G. 24/7
31	Cooling	Ambient	P13	AC/HVAC	Refrigerant	<40 ; dT15-2	100 - 1,000	D. 48 - 96
32	Heating	Ind. Equip.	P14	Boiler - Diesel	Steam	>100-150	1,000-10,000	B. 12 - 24
33	Heating	Ambient	P14	Boiler - Diesel	Steam	>100-150	50,000 - 100,000	E. 96 - 144
34	Heating	Ind. Equip.	P14	Heat Pump	Refrigerant	>25 - 50	1,000-10,000	C. 24 - 48
35	Heating	Ind. Equip.	P14	Heat Pump	Refrigerant	>25 - 50	1,000-10,000	G. 24/7
36	Cooling	Ind. Equip.	P14	Chiller (CL)	Water	Amb.; dT 20-30	1,000-10,000	B. 12 - 24
37	Cooling	Ambient	P14	Chiller (CL)	Water	Amb.; dT 20-30	100,000 - 200,000	E. 96 - 144
38	Cooling	Ambient	P14	AC/HVAC	Refrigerant	Amb.; dT 5-10	1,000-10,000	C. 24 - 48
39	Cooling	Ambient	P14	AC/HVAC	Refrigerant	Amb.; dT 5-10	1,000-10,000	G. 24/7
40	Heating	Ambient	P15	Heat Pump	Refrigerant	>25 - 50	1,000-10,000	C. 24 - 48
41	Cooling	Ambient	P15	AC/HVAC	Refrigerant	Amb.; dT 5-10	1,000-10,000	D. 48 - 96

Appendix 3 - IO Database - Material Resource Thematic

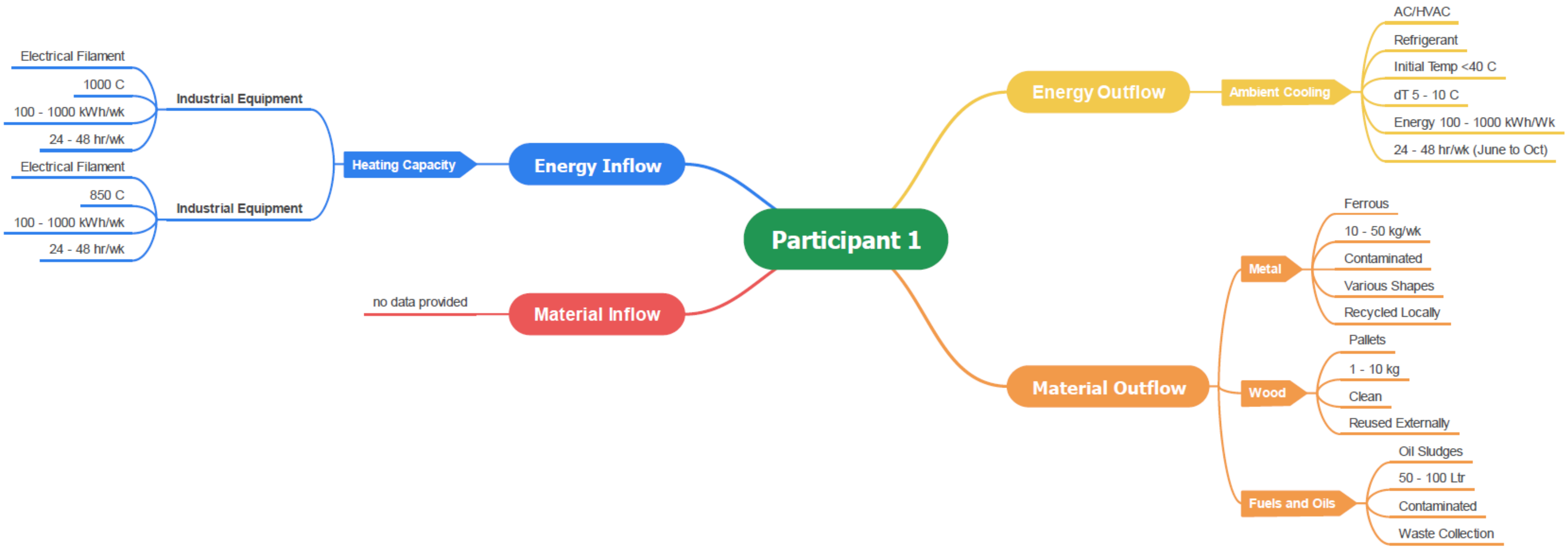
Entry no.	**In/Out**	**Participant**	**Class**	**Type**	**Qty**	**Condition**	**Form**	**Disposal Method …. (or) …**	**… Source**
1	O	P1	Metal	Ferrous	10 - 50 kg	Contaminated	Various	Recycled Locally	N/A
2	O	P1	Wood	Pallets	1 - 10 kg	Clean	N/A	Reused Externally	N/A
3	O	P1	Fuel and Oils	Spent Oils/Lubricants	50 - 100 L	Cont. Similar	Sludges	Recycled Locally	N/A
4	O	P3	Wood	Pallets	2,200 kg	Clean	N/A	Reused Externally	N/A
5	O	P3	Wood	Pallets	300 kg	Clean	Broken	Recycled Locally	N/A
6	O	P3	Metal	Ferrous	12 kg	Cont. Other	Drums	Recycled Locally	N/A
7	O	P3	Metal	Non-Ferrous	12 kg	Cont. Other	Tins	Recycled Locally	N/A
8	O	P3	Paper	Cardboard	47 kg	Clean	Sheets	Recycled Locally	N/A
9	O	P3	Polymer	HDPE	15 kg	Cont. Other	Bottles and Jerry Cans	Recycled Locally	N/A
10	O	P3	Polymer	PE	63 kg	Cont. Other	Bags	Recycled Locally	N/A
11	O	P3	Polymer	PP	32 kg	Cont. Other	Jumbo Bags	Recycled Locally	N/A
12	O	P3	Polymer	PP	495 kg	Cont. Other	Jumbo bags	Reused Internally	N/A
13	O	P4	Polymer	Rubber	1 - 10 t	Clean	Various	Recycled broker	N/A
14	O	P4	Mineral	Ceramic <15mm	1 - 10 t	Cont. Similar	Various	Landfilled	N/A
15	I	P4	Polymer	Rubber	10 - 50 t	Pristine	Strips	N/A	Purchased New
16	I	P4	Chemicals	Gasses (LIN)	50 - 100t	V.Clean	Cryogenic media	N/A	Purchased New
17	I	P4	Mineral	Ceramic <15mm	1 - 10 t	Pristine	Stones	N/A	Purchased New
18	I	P4	Polymer	Polycarbonate	1 - 10 t	Pristine	Granules	N/A	Purchased New
19	O	P5	Fuel and Oils	Spent Oils/Lubricants	10 - 50 kg	Cont. Similar	Liquid	Recycled broker	N/A
20	I	P5	Paper	Cardboard	10 - 50 kg	Any	Standard forms	N/A	Internal (re-used)

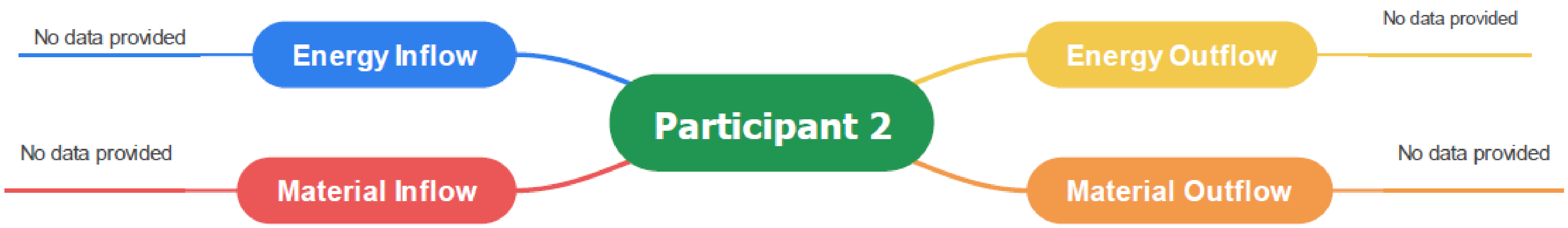
Entry no.	In/Out	Participant	Class	Type	Qty	Condition	Form	Disposal Method …. (or) …	… Source
21	I	P5	Wood	Pallets	1 - 10 kg	Any	Standard forms	N/A	Refurbished/ Recovered
22	O	P6	Metal	Non-Ferrous	250 - 500 kg	Cont. Similar	Zinc ash	Reused Externally	N/A
23	O	P6	Metal	Non-Ferrous	250 - 500 kg	Cont. Similar	Zinc dross	Reused Externally	N/A
24	O	P6	Metal	Ferrous	100 - 250 kg	Cont. Similar	Metal wire	Recycled broker	N/A
25	I	P6	Metal	Non-Ferrous	undisclosed	Pristine	Zinc	N/A	Purchased New
26	I	P6	Chemicals	Acid	undisclosed	V.Clean	HCL	N/A	Purchased New
27	O	P7	Polymer	PVC	0 - 1 kg	Clean	Compacted - wrapping film	Landfilled	N/A
28	O	P7	Wood	Pallets	10 - 50 kg	Clean	Undisclosed	Reused Externally	N/A
29	O	P7	Paper	Cardboard	1 - 10 kg	Clean	Various	Recycled broker	N/A
30	I	P7	Other	Gasses (Industrial Various)	undisclosed	Clean	Cylinders	N/A	Purchased New
31	O	P8	Other	MSW	1 - 10 kg	Cont. Similar	Bags	Landfilled	N/A
32	O	P8	Paper	Printing Material	2-5 kg	Clean	Sheets	Landfilled	N/A
33	I	P8	Paper	Paper	undisclosed	Pristine	Sheets (A4)	N/A	Purchased New
34	O	P9	Metal	Non-Ferrous	1 - 10 kg	Clean	Al Profiles	Reused Internally	N/A
35	O	P9	Metal	Ferrous	0 - 1 kg	Cont. Other	Shredded/Chip	Landfilled	N/A
36	O	P9	Wood	Pallets	1 - 10 kg	Cont. Similar	N/A	Reused Externally	N/A
37	I	P9	Metal	Non-Ferrous	50 -100 kg	Pristine	Undisclosed	N/A	Purchased New
38	I	P9	Wood	Pallets	10 - 50 kg	Clean	Any	N/A	Internal (re-used)
39	I	P9	Metal	Ferrous	10 - 50 kg	Pristine	Steel Plates	N/A	Internal (re-used)

Entry no.	In/Out	Participant	Class	Type	Qty	Condition	Form	Disposal Method …. (or) …	… Source
40	O	P10	Chemicals	Solvents	1 - 10 kg	Cont. Similar	Liquid	Recycled broker	N/A
41	O	P10	Paper	Cardboard	100 - 250 kg	Clean	Sheets	Recycled Locally	N/A
42	O	P10	Polymer	PVC	100 - 250 kg	Cont. Similar	Compacted	Landfilled	N/A
43	I	P10	Paper	Cardboard	100 - 250 kg	Pristine	Standard forms	N/A	Purchased New
44	O	P11	Metal	Ferrous	1 - 10 m3	Cont. Similar	Various	Recycled Locally	N/A
45	O	P11	Paper	Cardboard	10 - 50 kg	Clean	Sheets	Recycled Locally	N/A
46	O	P11	Polymer	PE (Plastic Wrapping)	1 - 10 m3	Cont. Similar	Various	Recycled Locally	N/A
47	I	P11	Metal	Ferrous	250-500 t	V.Clean	Machined Castings	N/A	Purchased New
48	I	P11	Metal	Non-Ferrous	100 - 250 t	V.Clean	Machined Castings	N/A	Purchased New
49	I	P11	Paper	Cardboard	250 - 500 kg	Pristine	Standard forms	N/A	Purchased New
50	I	P11	Paper	Paper	50 - 100 kg	Pristine	Sheets (A4)	N/A	Purchased New
51	I	P11	Polymer	PE	100 - 250 kg	Pristine	Roll	N/A	Purchased New
52	I	P11	Wood	Pallets	500 -1000 kg	V.Clean	Pallets	N/A	Refurbished/ Recovered
53	O	P12	Wood	Pallets	10 - 50 kg	Cont. Similar	N/A	Reused Externally	N/A
54	O	P12	Other	Waste Water	undisclosed	Cont. Other	Liquid	Sewers	N/A
55	I	P12	Chemicals	Various	undisclosed	Clean	Undisclosed	N/A	Purchased New
56	O	P13	Chemicals	Toxic	10 kg	Hazardous (ICS)	Solid	Incinerated	N/A
57	O	P13	Polymer	PVC	2 kg	Hazardous (ICS)	Various	Recycled broker	N/A
58	O	P13	Chemicals	Solvents	31 kg	Cont. Similar	Mixed	Incinerated	N/A
59	O	P14	Chemicals	Solvents	250 kg	Cont. Similar	Liquid	Recovered	N/A
60	O	P14	Other	Pharma Waste (Hazardous)	115 kg	Hazardous	In bags	Incinerated	N/A

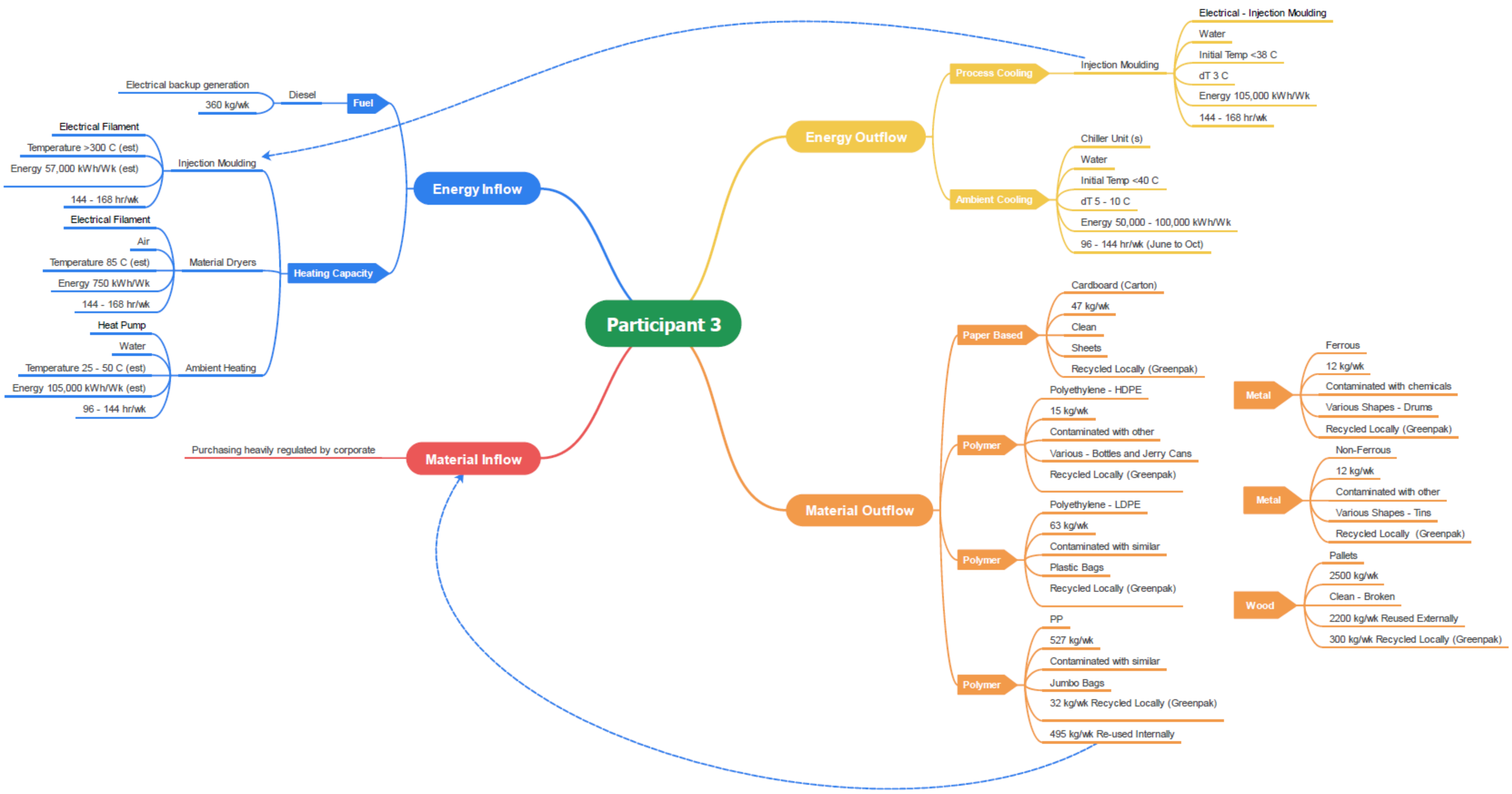
Entry no.	In/Out	Participant	Class	Type	Qty	Condition	Form	Disposal Method …. (or) …	… Source
61	O	P14	Other	Pharma Waste (Non-Hazardous)	38 kg	Clean	In Bags	Incinerated	N/A
62	O	P14	Paper	Cardboard	38 kg	Clean	Packaging	Recycled Locally	N/A
63	O	P14	Polymer	PE	19 kg	Clean	Solid - HDPE Drums	Recycled Locally	N/A
64	O	P14	Glass	Glass (Mixed)	undisclosed	Cont. Other	Shards	Recycled Locally	N/A
65	O	P14	Other	PPE and Filters	38 kg	Hazardous (ICS)	Solid	Incinerated	N/A
66	O	P14	Paper	Paper	19 kg	Clean	Shredded/Chip	Recycled Locally	N/A
67	O	P14	Metal	Non-Ferrous	19 kg	Clean	Blister Packs Shredding	Reused Externally	N/A
68	O	P14	Paper	Paper	10 kg	Clean	Sheets	Recycled Locally	N/A
69	O	P14	Food	Organic	230 kg	Clean	Mixed	Landfilled	N/A
70	I	P14	Paper	Paper	38 kg	Pristine	Standard forms	N/A	Purchased New
71	I	P14	Chemicals	Solvents	250 L	Pristine (ACS Grade)	Liquid	N/A	Purchased New
72	O	P15	Fuel and Oils	Spent Oils/Lubricants	10 - 50 L	Cont. Similar	Liquid	Reused Externally	N/A
73	O	P15	Paper	Cardboard	30 kg	Clean	Sheets	Recycled Broker	N/A
74	O	P15	Other	Tires	100 - 250 kg	Cont. Similar	Used/Worn	Recycled Broker	N/A
75	O	P15	Metal	Ferrous	10 - 50 kg	Clean	Various	Recycled Broker	N/A
76	O	P15	Wood	Strips of Wood	1 - 10 kg	Clean	Strips of Wood	Recycled Locally	N/A

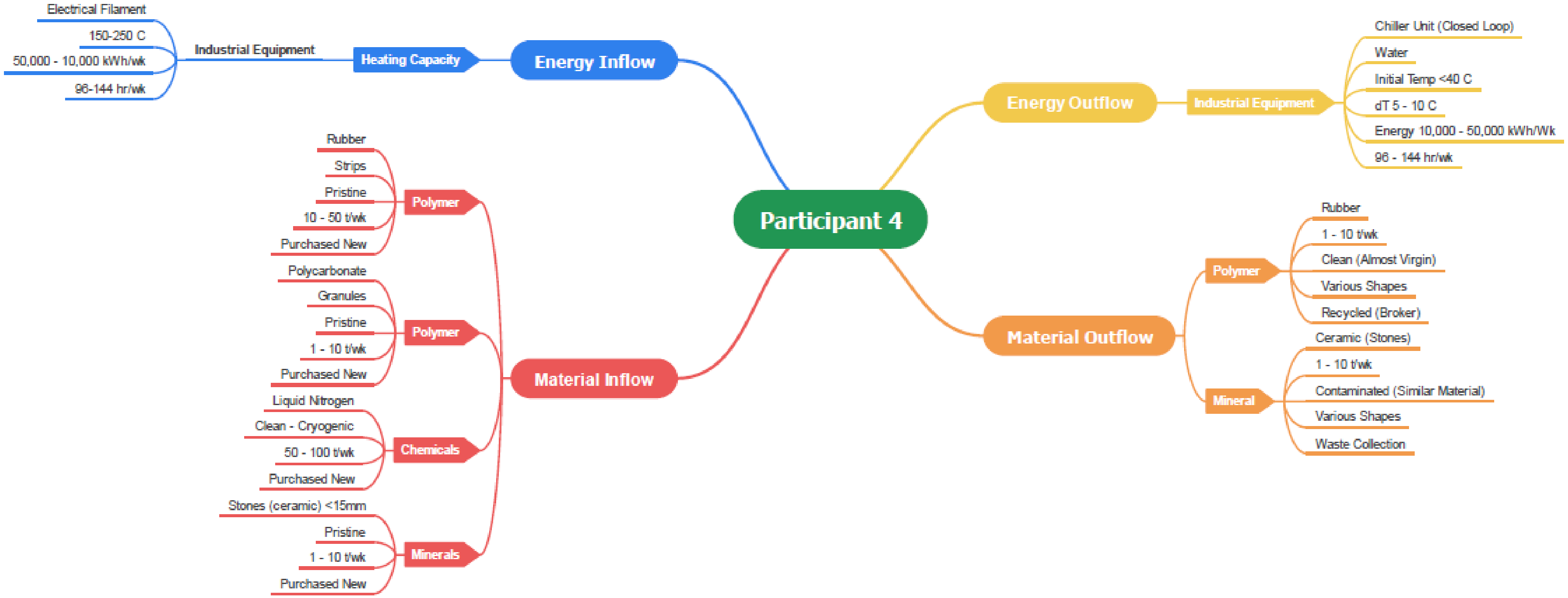
Appendix 4 - Individual Participant Entries


Participant 1
Energy Inflow
Heating Capacity
Industrial Equipment
Electrical Filament
1000 C
100 - 1000 kWh/wk
24 - 48 hr/wk
Industrial Equipment
Electrical Filament
850 C
100 - 1000 kWh/wk
24 - 48 hr/wk
Material Inflow
no data provided
Energy Outflow
Ambient Cooling
AC/HVAC
Refrigerant
Initial Temp <40 C
dT 5 - 10 C
Energy 100 - 1000 kWh/Wk
24 - 48 hr/wk (June to Oct)
Material Outflow
Metal
Ferrous
10 - 50 kg/wk
Contaminated
Various Shapes
Recycled Locally
Wood
Pallets
1 - 10 kg
Clean
Reused Externally
Fuels and Oils
Oil Sludges
50 - 100 Ltr
Contaminated
Waste Collection

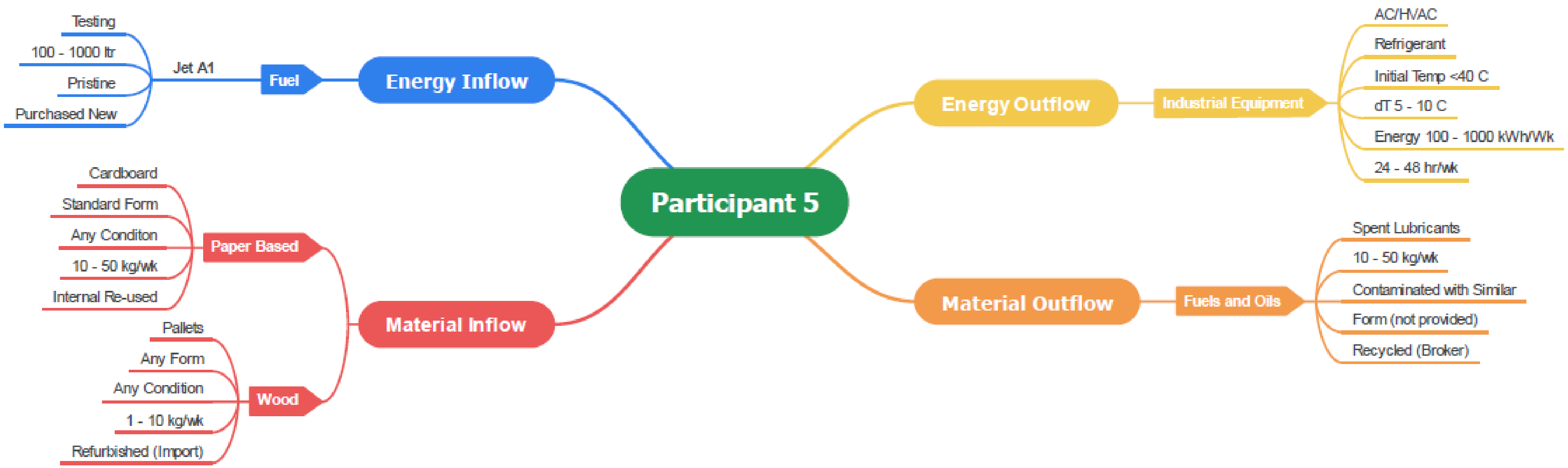


Tenant noted that the facility is used as a yard for the sole scope of storing and retrieving equipment, with no use of resources (either Material or Energy).

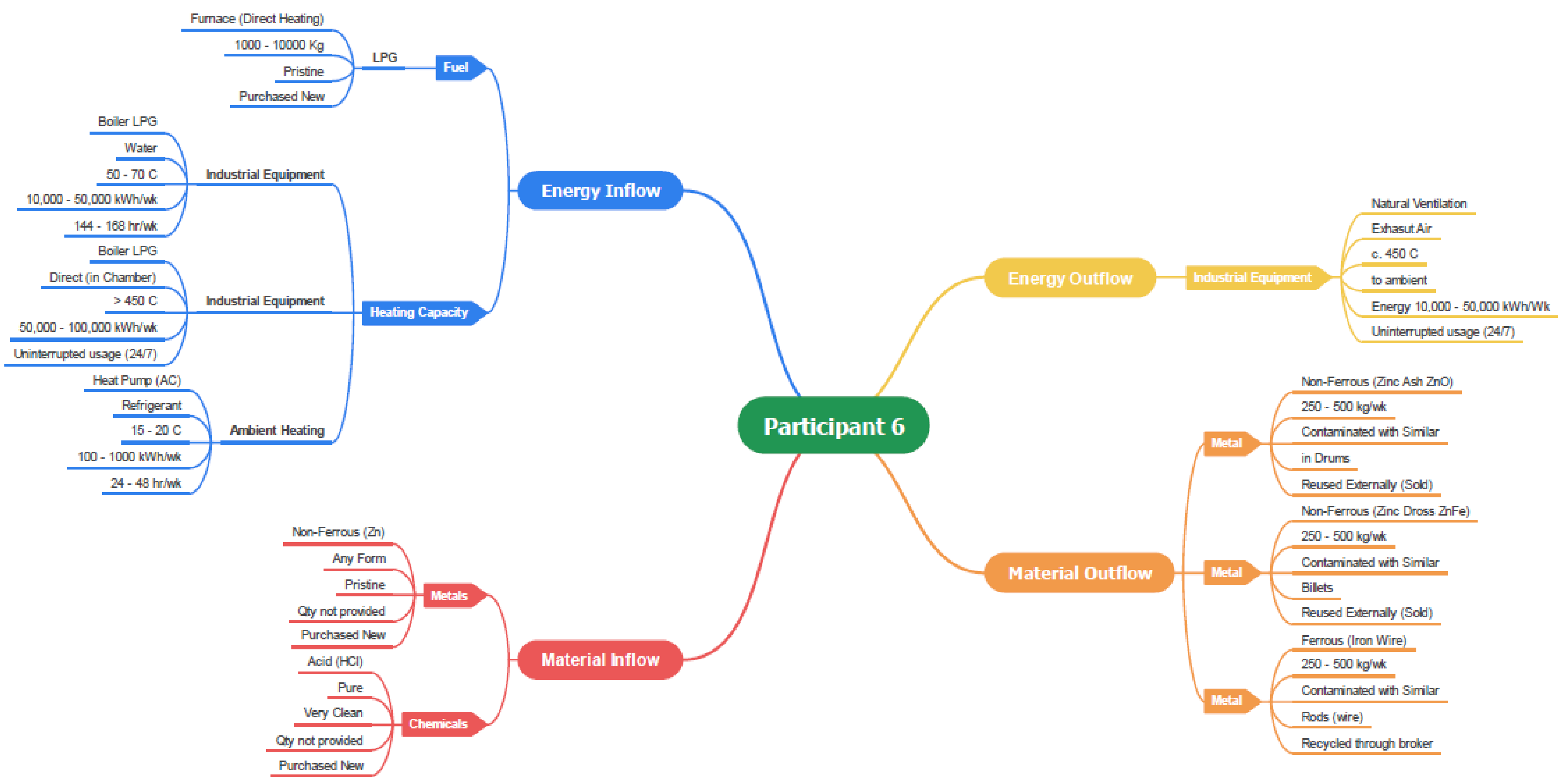

Participant 3
Energy Inflow
Fuel
Diesel
Electrical backup generation
360 kg/wk
Heating Capacity
Injection Moulding
Electrical Filament
Temperature >300 C (est)
Energy 57,000 kWh/Wk (est)
144 - 168 hr/wk
Material Dryers
Electrical Filament
Air
Temperature 85 C (est)
Energy 750 kWh/Wk
144 - 168 hr/wk
Ambient Heating
Heat Pump
Water
Temperature 25 - 50 C (est)
Energy 105,000 kWh/Wk (est)
96 - 144 hr/wk
Material Inflow
Purchasing heavily regulated by corporate
Energy Outflow
Process Cooling
Injection Moulding
Electrical - Injection Moulding
Water
Initial Temp <38 C
dT 3 C
Energy 105,000 kWh/Wk
144 - 168 hr/wk
Ambient Cooling
Chiller Unit (s)
Water
Initial Temp <40 C
dT 5 - 10 C
Energy 50,000 - 100,000 kWh/Wk
96 - 144 hr/wk (June to Oct)
Material Outflow
Paper Based
Cardboard (Carton)
47 kg/wk
Clean
Sheets
Recycled Locally (Greenpak)
Polymer
Polyethylene - HDPE
15 kg/wk
Contaminated with other
Various - Bottles and Jerry Cans
Recycled Locally (Greenpak)
Polymer
Polyethylene - LDPE
63 kg/wk
Contaminated with similar
Plastic Bags
Recycled Locally (Greenpak)
Polymer
PP
527 kg/wk
Contaminated with similar
Jumbo Bags
32 kg/wk Recycled Locally (Greenpak)
495 kg/wk Re-used Internally
Metal
Ferrous
12 kg/wk
Contaminated with chemicals
Various Shapes - Drums
Recycled Locally (Greenpak)
Metal
Non-Ferrous
12 kg/wk
Contaminated with other
Various Shapes - Tins
Recycled Locally (Greenpak)
Wood
Pallets
2500 kg/wk
Clean - Broken
2200 kg/wk Reused Externally
300 kg/wk Recycled Locally (Greenpak)



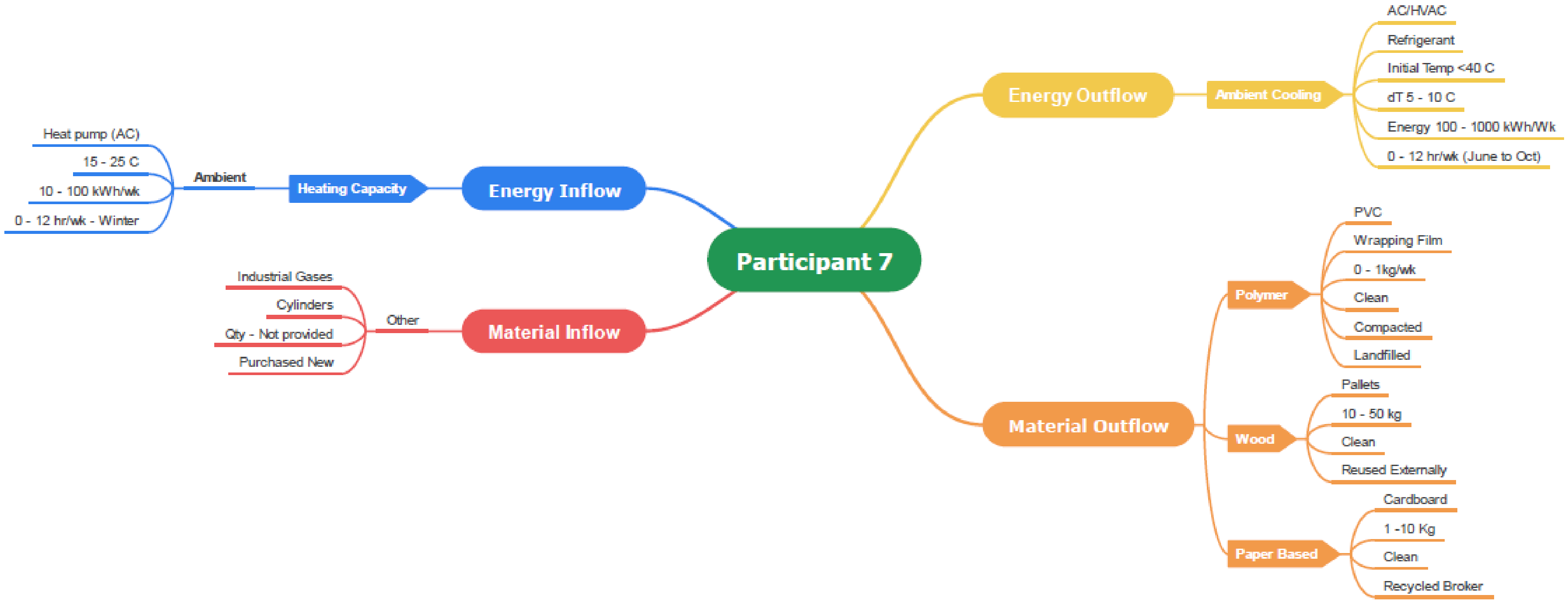
Participant 4
Energy Inflow
Heating Capacity
Industrial Equipment
Electrical Filament
150-250 C
50,000 - 10,000 kWh/wk
96-144 hr/wk
Material Inflow
Polymer
Rubber
Strips
Pristine
10 - 50 t/wk
Purchased New
Polymer
Polycarbonate
Granules
Pristine
1 - 10 t/wk
Purchased New
Chemicals
Liquid Nitrogen
Clean - Cryogenic
50 - 100 t/wk
Purchased New
Minerals
Stones (ceramic) <15mm
Pristine
1 - 10 t/wk
Purchased New
Energy Outflow
Industrial Equipment
Chiller Unit (Closed Loop)
Water
Initial Temp <40 C
dT 5 - 10 C
Energy 10,000 - 50,000 kWh/Wk
96 - 144 hr/wk
Material Outflow
Polymer
Rubber
1 - 10 t/wk
Clean (Almost Virgin)
Various Shapes
Recycled (Broker)
Mineral
Ceramic (Stones)
1 - 10 t/wk
Contaminated (Similar Material)
Various Shapes
Waste Collection

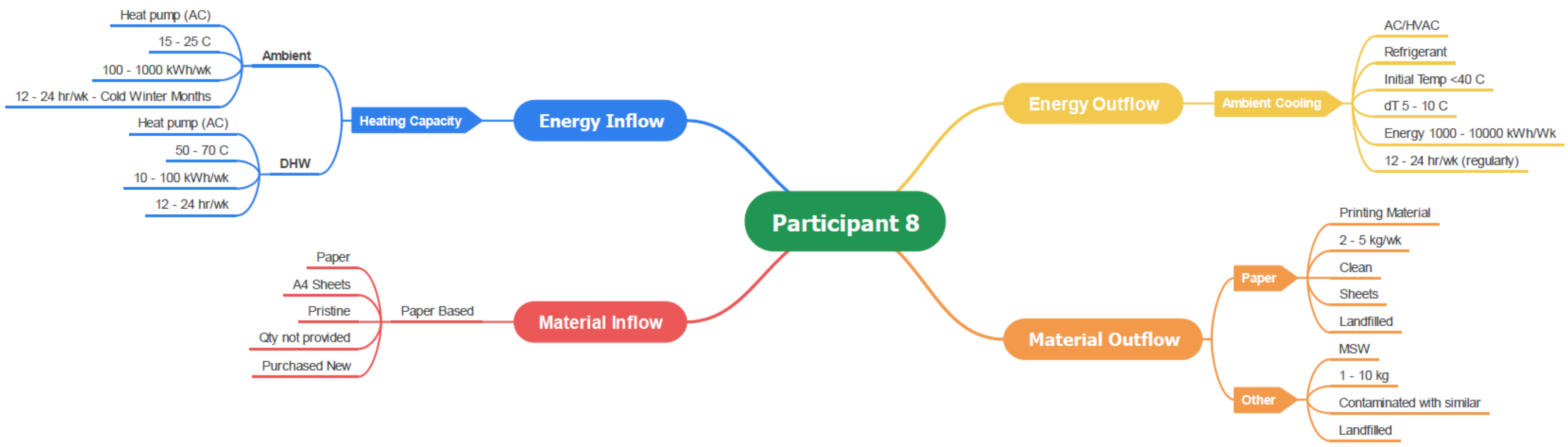


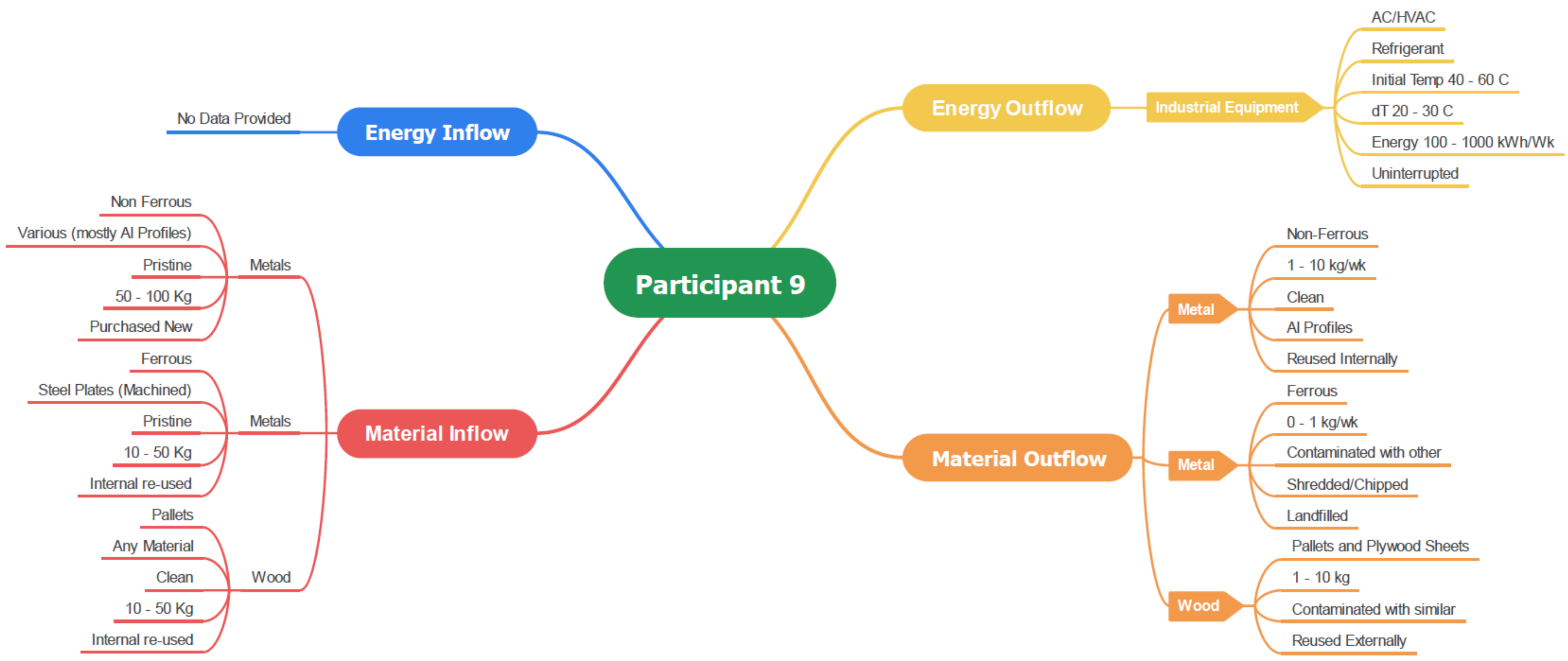
Participant 5
Energy Inflow
Fuel
Jet A1
Testing
100 - 1000 ltr
Pristine
Purchased New
Material Inflow
Paper Based
Cardboard
Standard Form
Any Conditon
10 - 50 kg/wk
Internal Re-used
Wood
Pallets
Any Form
Any Condition
1 - 10 kg/wk
Refurbished (Import)
Energy Outflow
Industrial Equipment
AC/HVAC
Refrigerant
Initial Temp <40 C
dT 5 - 10 C
Energy 100 - 1000 kWh/Wk
24 - 48 hr/wk
Material Outflow
Fuels and Oils
Spent Lubricants
10 - 50 kg/wk
Contaminated with Similar
Form (not provided)
Recycled (Broker)

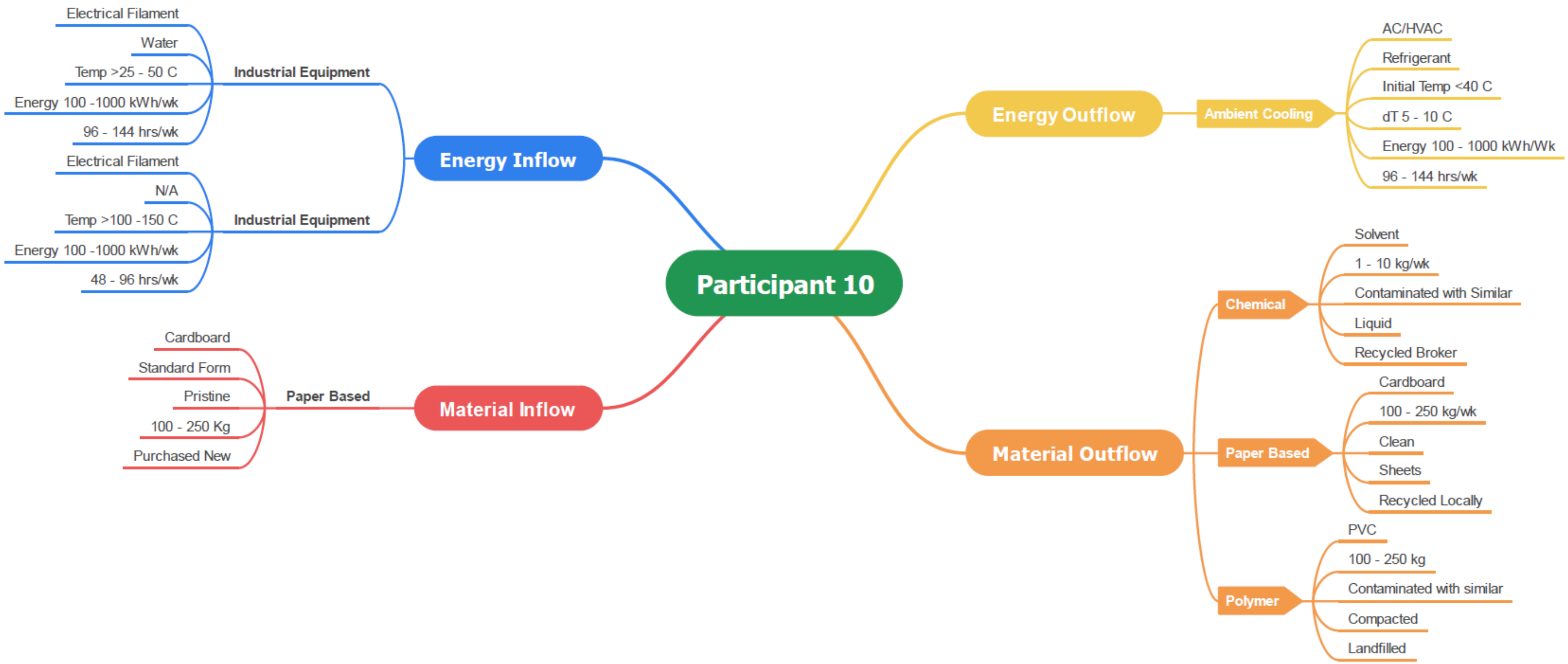


Participant 6
Energy Inflow
Fuel
LPG
Furnace (Direct Heating)
1000 - 10000 Kg
Pristine
Purchased New
Heating Capacity
Industrial Equipment
Boiler LPG
Water
50 - 70 C
10,000 - 50,000 kWh/wk
144 - 168 hr/wk
Industrial Equipment
Boiler LPG
Direct (in Chamber)
> 450 C
50,000 - 100,000 kWh/wk
Uninterrupted usage (24/7)
Ambient Heating
Heat Pump (AC)
Refrigerant
15 - 20 C
100 - 1000 kWh/wk
24 - 48 hr/wk
Material Inflow
Metals
Non-Ferrous (Zn)
Any Form
Pristine
Qty not provided
Purchased New
Chemicals
Acid (HCl)
Pure
Very Clean
Qty not provided
Purchased New
Energy Outflow
Industrial Equipment
Natural Ventilation
Exhasut Air
c. 450 C
to ambient
Energy 10,000 - 50,000 kWh/Wk
Uninterrupted usage (24/7)
Material Outflow
Metal
Non-Ferrous (Zinc Ash ZnO)
250 - 500 kg/wk
Contaminated with Similar
in Drums
Reused Externally (Sold)
Metal
Non-Ferrous (Zinc Dross ZnFe)
250 - 500 kg/wk
Contaminated with Similar
Billets
Reused Externally (Sold)
Metal
Ferrous (Iron Wire)
250 - 500 kg/wk
Contaminated with Similar
Rods (wire)
Recycled through broker


Participant 7
Energy Inflow
Heating Capacity
Ambient
Heat pump (AC)
15 - 25 C
10 - 100 kWh/wk
0 - 12 hr/wk - Winter
Material Inflow
Other
Industrial Gases
Cylinders
Qty - Not provided
Purchased New
Energy Outflow
Ambient Cooling
AC/HVAC
Refrigerant
Initial Temp <40 C
dT 5 - 10 C
Energy 100 - 1000 kWh/Wk
0 - 12 hr/wk (June to Oct)
Material Outflow
Polymer
PVC
Wrapping Film
0 - 1kg/wk
Clean
Compacted
Landfilled
Wood
Pallets
10 - 50 kg
Clean
Reused Externally
Paper Based
Cardboard
1 -10 Kg
Clean
Recycled Broker

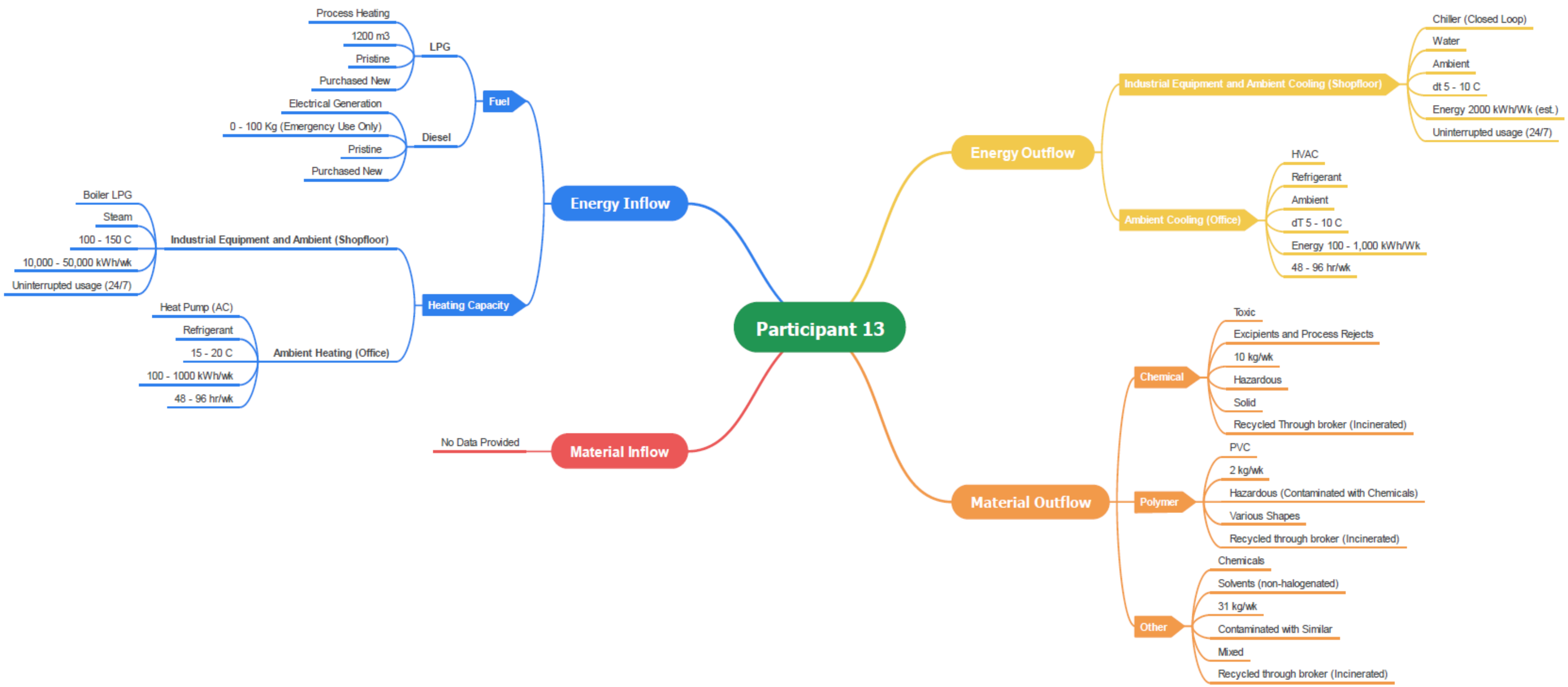

Participant 8
Energy Inflow
Heating Capacity
Ambient
Heat pump (AC)
15 - 25 C
100 - 1000 kWh/wk
12 - 24 hr/wk - Cold Winter Months
DHW
Heat pump (AC)
50 - 70 C
10 - 100 kWh/wk
12 - 24 hr/wk
Material Inflow
Paper Based
Paper
A4 Sheets
Pristine
Qty not provided
Purchased New
Energy Outflow
Ambient Cooling
AC/HVAC
Refrigerant
Initial Temp <40 C
dT 5 - 10 C
Energy 1000 - 10000 kWh/Wk
12 - 24 hr/wk (regularly)
Material Outflow
Paper
Printing Material
2 - 5 kg/wk
Clean
Sheets
Landfilled
Other
MSW
1 - 10 kg
Contaminated with similar
Landfilled


Participant 9
Energy Inflow
No Data Provided
Energy Outflow
Industrial Equipment
AC/HVAC
Refrigerant
Initial Temp 40 - 60 C
dT 20 - 30 C
Energy 100 - 1000 kWh/Wk
Uninterrupted
Material Inflow
Metals
Non Ferrous
Various (mostly Al Profiles)
Pristine
50 - 100 Kg
Purchased New
Metals
Ferrous
Steel Plates (Machined)
Pristine
10 - 50 Kg
Internal re-used
Wood
Pallets
Any Material
Clean
10 - 50 Kg
Internal re-used
Material Outflow
Metal
Non-Ferrous
1 - 10 kg/wk
Clean
Al Profiles
Reused Internally
Metal
Ferrous
0 - 1 kg/wk
Contaminated with other
Shredded/Chipped
Landfilled
Wood
Pallets and Plywood Sheets
1 - 10 kg
Contaminated with similar
Reused Externally

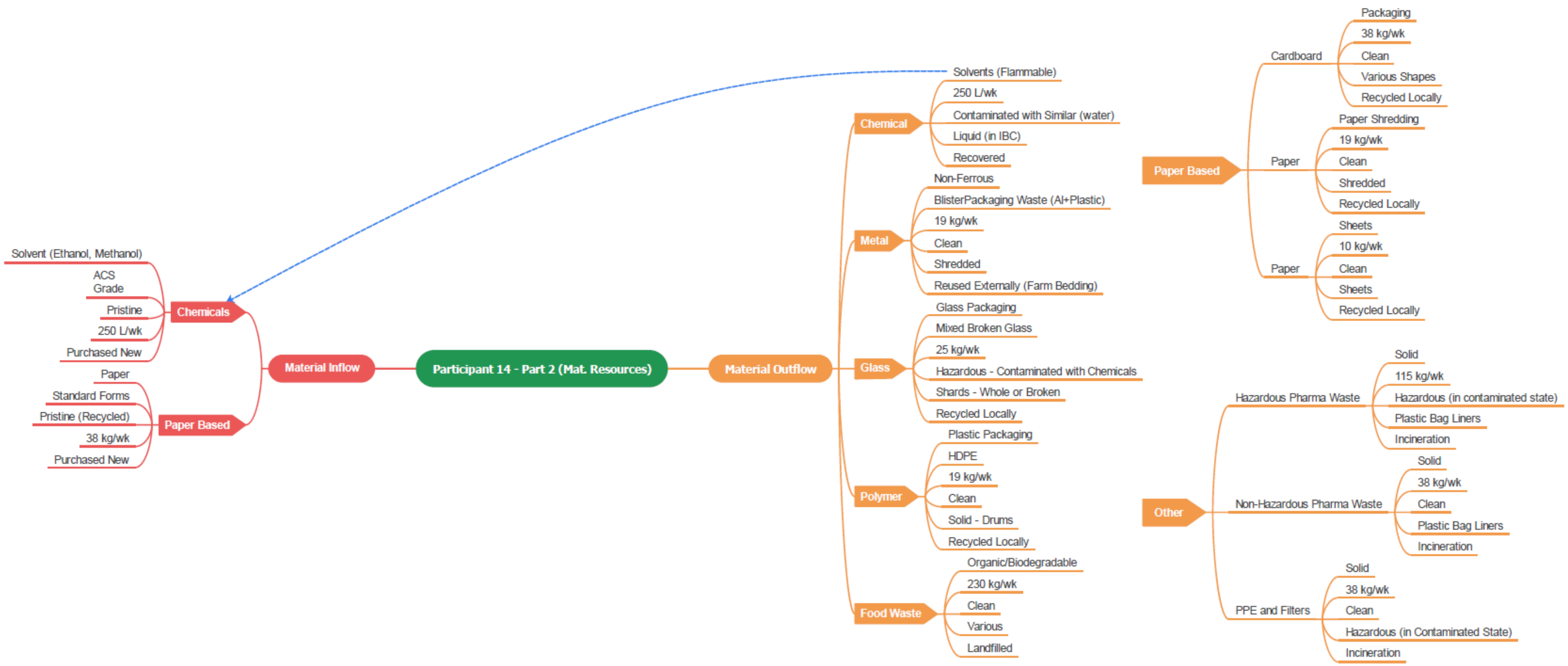

Participant 10
Energy Inflow
Industrial Equipment
Electrical Filament
Water
Temp >25 - 50 C
Energy 100 -1000 kWh/wk
96 - 144 hrs/wk
Industrial Equipment
Electrical Filament
N/A
Temp >100 -150 C
Energy 100 -1000 kWh/wk
48 - 96 hrs/wk
Material Inflow
Paper Based
Cardboard
Standard Form
Pristine
100 - 250 Kg
Purchased New
Energy Outflow
Ambient Cooling
AC/HVAC
Refrigerant
Initial Temp <40 C
dT 5 - 10 C
Energy 100 - 1000 kWh/Wk
96 - 144 hrs/wk
Material Outflow
Chemical
Solvent
1 - 10 kg/wk
Contaminated with Similar
Liquid
Recycled Broker
Paper Based
Cardboard
100 - 250 kg/wk
Clean
Sheets
Recycled Locally
Polymer
PVC
100 - 250 kg
Contaminated with similar
Compacted
Landfilled

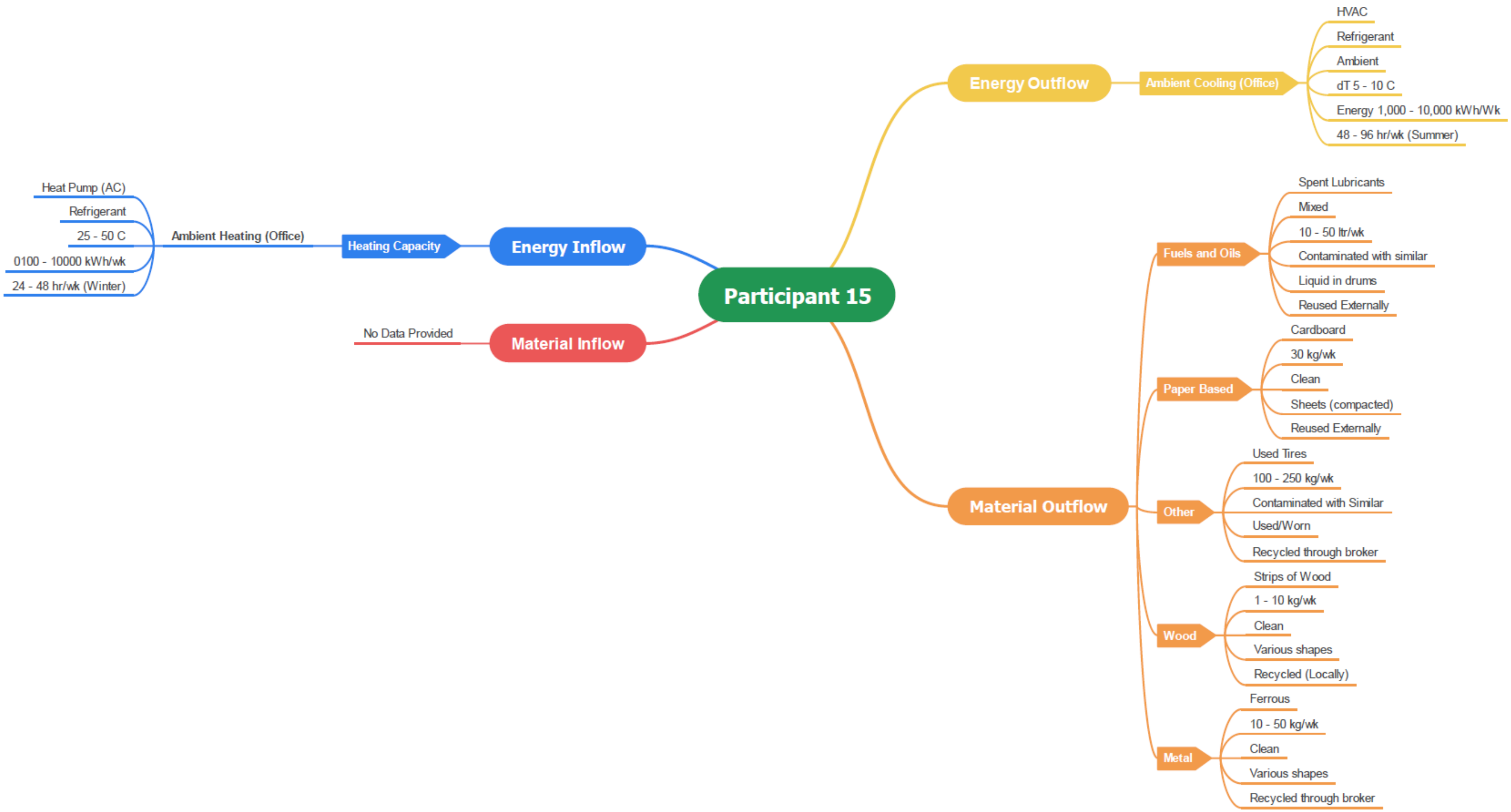

Participant 11
Energy Inflow
Industrial Equipment
Electrical Filament
Direct (Hotplates)
Temp >50 - 70 C
10 -100 kWh/wk
24 - 48 hr/wk
Ambient Heating
Heat Pump (AC)
Refrigerant
15 - 25 C
100 - 1000 kWh/wk
48 - 96 hr/wk
Material Inflow
Metals
Ferrous
Machined Castings
Very Clean
250 - 500 t/wk
Purchased New
Metals
Non-Ferrous
Castings and Motor Windings
Very Clean
100 - 250 t/wk
Purchased New
Paper Based
Cardboard
Standard Form (Sheets)
Pristine
250 - 500 kg/wk
Purchased New
Paper Based
Paper
Standard Form (Sheets)
Pristine
50 - 100 kg/wk
Purchased New
Polymers
Polyethylene
Wrapping in roll form
Pristine
100 - 250 Kg/wk
Purchased New
Wood
Pallets
Any Material
Very Clean
500 - 1000 kg
Refurbished / Recovered
Energy Outflow
Ambient Cooling
AC/HVAC
Refrigerant
Initial Temp <40 C
dT 15 - 20 C
Energy 100 - 1000 kWh/Wk
48 - 96 hr/wk
Industrial Equipment
No Cooling Systems
Material Outflow
Metal
Ferrous
0 - 1 m3
Contaminated with similar
Various Shapes
Recycled Locally
Paper Based
Cardboard
10 - 50 Kg
Clean
Sheets
Recycled Locally
Polymer
Polyethylene
Wrapping Film
1 - 10 m3
Contaminated with Similar
Various Shapes
Recycled Locally

Participant 12
Energy Inflow
No Energy Processes Employed
Material Inflow
Chemicals
Various Types
No further Data Provided
Energy Outflow
No Energy Processes Employed
Material Outflow
Wood
Pallets
10 - 50 Kg/wk
Contaminated with Similar
Various Shapes
Reused Externally
Wastewater
Contaminated with Other


Participant 13
Energy Inflow
Fuel
LPG
Process Heating
1200 m3
Pristine
Purchased New
Diesel
Electrical Generation
0 - 100 Kg (Emergency Use Only)
Pristine
Purchased New
Heating Capacity
Industrial Equipment and Ambient (Shopfloor)
Boiler LPG
Steam
100 - 150 C
10,000 - 50,000 kWh/wk
Uninterrupted usage (24/7)
Ambient Heating (Office)
Heat Pump (AC)
Refrigerant
15 - 20 C
100 - 1000 kWh/wk
48 - 96 hr/wk
Material Inflow
No Data Provided
Energy Outflow
Industrial Equipment and Ambient Cooling (Shopfloor)
Chiller (Closed Loop)
Water
Ambient
dt 5 - 10 C
Energy 2000 kWh/Wk (est.)
Uninterrupted usage (24/7)
Ambient Cooling (Office)
HVAC
Refrigerant
Ambient
dT 5 - 10 C
Energy 100 - 1,000 kWh/Wk
48 - 96 hr/wk
Material Outflow
Chemical
Toxic
Excipients and Process Rejects
10 kg/wk
Hazardous
Solid
Recycled Through broker (Incinerated)
Polymer
PVC
2 kg/wk
Hazardous (Contaminated with Chemicals)
Various Shapes
Recycled through broker (Incinerated)
Other
Chemicals
Solvents (non-halogenated)
31 kg/wk
Contaminated with Similar
Mixed
Recycled through broker (Incinerated)

Participant 14 Part 1 (Energy Resources)
Energy Inflow
Fuel
Diesel (Gasoil)
HVAC
1000-10000 ltr
V. Clean
Purchased New
Diesel (Gasoil)
Process Heating
100-1000 ltr
V. Clean
Purchased New
Heating Capacity
Industrial Equipment
Boiler Diesel
Steam
100 - 150 C (Steam Temp)
10,00 - 10,000 kWh/wk
12 - 24 hr/wk (Load Time)
Ambient Heating (Shopfloor)
Boiler Diesel
Steam
100 - 150 C (Steam Temp)
50,000 - 100,000 kWh/wk
96 - 144 hr/wk (Load Time)
Ambient Heating (Office)
Heat Pump (AC)
Refrigerant
25 - 50 C
1000 - 10,000 kWh/wk
24 - 48 hr/wk (Winter)
Ambient Heating (Warehousing)
Heat Pump (AC)
Refrigerant
25 - 50 C
1000 - 10,000 kWh/wk
Uninterrupted (Winter)
Energy Outflow
Industrial Equipment
Chiller (Closed Loop)
Water
Ambient
dt 20 - 30 C
Energy 1,000 - 10,000 kWh/Wk
12 - 24 hr/wk (Load time)
Ambient Cooling (Office)
Shopfloor
Chiller (Closed Loop)
Water
Ambient
dt 20 - 30 C
Energy 100,000 - 200,000 kWh/Wk
96 - 144 hr/wk (Load time)
Offices
HVAC
Refrigerant
Ambient
dT 5 - 10 C
Energy 1,000 - 10,000 kWh/Wk
24-48 hr/wk (Summer)
Warehousing
HVAC
Refrigerant
Ambient
dT 5 - 10 C
Energy 1,000 - 10,000 kWh/Wk
Uninterrupted (Summer)


Participant 14 - Part 2 (Mat. Resources)
Material Inflow
Chemicals
Solvent (Ethanol, Methanol)
ACS Grade
Pristine
250 L/wk
Purchased New
Paper Based
Paper
Standard Forms
Pristine (Recycled)
38 kg/wk
Purchased New
Material Outflow
Chemical
Solvents (Flammable)
250 L/wk
Contaminated with Similar (water)
Liquid (in IBC)
Recovered
Metal
Non-Ferrous
BlisterPackaging Waste (Al+Plastic)
19 kg/wk
Clean
Shredded
Reused Externally (Farm Bedding)
Glass
Glass Packaging
Mixed Broken Glass
25 kg/wk
Hazardous - Contaminated with Chemicals
Shards - Whole or Broken
Recycled Locally
Polymer
Plastic Packaging
HDPE
19 kg/wk
Clean
Solid - Drums
Recycled Locally
Food Waste
Organic/Biodegradable
230 kg/wk
Clean
Various
Landfilled
Paper Based
Cardboard
Packaging
38 kg/wk
Clean
Various Shapes
Recycled Locally
Paper
Paper Shredding
19 kg/wk
Clean
Shredded
Recycled Locally
Paper
Sheets
10 kg/wk
Clean
Sheets
Recycled Locally
Other
Hazardous Pharma Waste
Solid
115 kg/wk
Hazardous (in contaminated state)
Plastic Bag Liners
Incineration
Non-Hazardous Pharma Waste
Solid
38 kg/wk
Clean
Plastic Bag Liners
Incineration
PPE and Filters
Solid
38 kg/wk
Clean
Hazardous (in Contaminated State)
Incineration


Participant 15
Energy Inflow
Heating Capacity
Ambient Heating (Office)
Heat Pump (AC)
Refrigerant
25 - 50 C
0100 - 10000 kWh/wk
24 - 48 hr/wk (Winter)
Material Inflow
No Data Provided
Energy Outflow
Ambient Cooling (Office)
HVAC
Refrigerant
Ambient
dT 5 - 10 C
Energy 1,000 - 10,000 kWh/Wk
48 - 96 hr/wk (Summer)
Material Outflow
Fuels and Oils
Spent Lubricants
Mixed
10 - 50 ltr/wk
Contaminated with similar
Liquid in drums
Reused Externally
Paper Based
Cardboard
30 kg/wk
Clean
Sheets (compacted)
Reused Externally
Other
Used Tires
100 - 250 kg/wk
Contaminated with Similar
Used/Worn
Recycled through broker
Wood
Strips of Wood
1 - 10 kg/wk
Clean
Various shapes
Recycled (Locally)
Metal
Ferrous
10 - 50 kg/wk
Clean
Various shapes
Recycled through broker