Water Management in Sustainable Manufacturing

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Abstract

Sustainable manufacturing and conservation of resources are more than just energy management. A broader perspective is necessary as stewardship of resources goes to further extents. Water management is expected to take a more pronounced role amongst the metrics for sustainability. This is backed by the reality that freshwater resources are facing extensive stresses which are leading to events of potential scarcity. Opportunities for water management exist in all areas of its demand, especially in the manufacturing sector being a key economic activity, dependent on natural resources. In a local scenario, the effects of water scarcity are on the rise. This paper discusses the relevance of water management for achieving sustainable manufacturing. An evaluation of the water footprint assessment tool is included, as applied in case studies in the manufacturing sector. The assessment method is evaluated against criteria relevant for assessing water sustainability in the local context.

Keywords:

Corporate Water Use; Sustainable Manufacturing; Water Footprint; Water Management; Water Scarcity.

1 INTRODUCTION

Water is central in every sector related to the society and the economy. Human activities are underpinned by the use of water, thus the importance of its availability. However, freshwater scarcity is a considerable issue which is attracting increasing attention from various bodies and sectors. Freshwater scarcity is factored by the inability of the supply to meet the ever-increasing demand. It is driven by a number of changes; such as the increasing population which brings about an increase in food, energy and water requirements. Climate change is an important factor which is expected to considerably affect countries which are already facing scarcity issues [1].

Given the dependence on water, enterprises are expected to be aware of the risks associated with water resources. Manufacturing is a key economic activity which is a major driver of economic growth. The manufacturing sector is traditionally associated with the intensive impacts on the environment. In this modern day and age, the sector should be thriving for sustainability. As part of the efforts towards achieving sustainable manufacturing, enterprises should not only minimise waste and become more energy efficient, but also exhibit water stewardship practices.

Water resources in Malta are facing considerable pressure, and scarcity is an unfortunate reality [2, 3]. Therefore, sustainable manufacturing in the local scenario should begin with enterprises becoming more sustainable in their own manufacturing facilities. Corporate attention to water management would therefore contribute to a lesser environmental impact. This paper addresses issues with water management in the local manufacturing scenario.

2 WATER AND MALTA

2.1 Water Scarcity

Locations with high population densities and which have low freshwater availability, are most susceptible to experience scarcity [1]. This description corresponds to the demographic description of Malta. Malta is an archipelago of islands in the Central Mediterranean Sea with a total area of 316 km^2. With a population of around 416,000, the islands are amongst the most densely populated countries in the world [4].

In coping with the demand, the country has been over abstracting from the natural groundwater reservoirs without allowing time for natural replenishment. The exploitation index indicates that 48% more than the groundwater sustainable yield is being extracted annually. This puts the island as one of the world's top ten water-scarcest countries [5]. The local scarcity issue also concerns a facet of quality, given that saltwater intrusion is degrading groundwater to a brackish quality. Nitrates also affect the quality of groundwater, which arise from the percolation of agricultural fertilisers. Climate change is a contributing factor which is expected to affect annual rainfall rates in a negative manner, thus reducing the availability of renewable freshwater [2, 3]. These factors are part of a broader picture of risks represented in Figure 1.

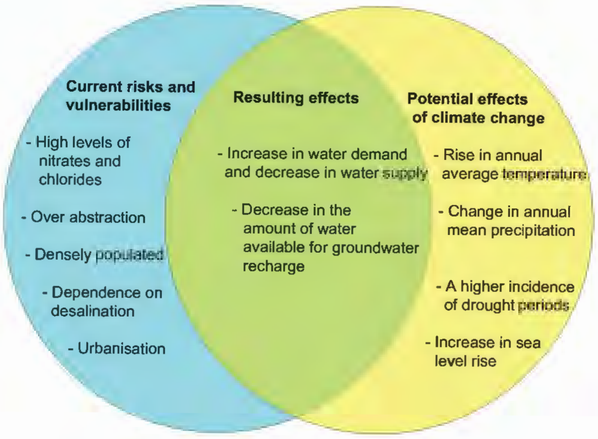

Figure 1: Overview of Risks and Vulnerabilities related to Groundwater [3].

2.2 Water Supply

Groundwater is the unique natural freshwater source in Malta, given that virtually no surface waters exist. The over abstraction of this natural source, makes the local water operator opt for desalinated seawater through reverse osmosis (RO) which is an energy intensive alternative consuming around 4% of the national electricity generated [5].

The local town water supply is a blend of approximately 44% groundwater and 56% desalinated seawater. Dependence on desalinated water is exhibiting an increasing trend. The main contributor to over abstraction of groundwater is that a considerable portion of national water consumption is unmetered, mainly through boreholes and non-revenue water. This is excluded from the 44% figure, a ratio which the local operator maintains in order to abstract only what is sustainably available.

Another unsustainable scenario which contributes to water losses, is the leakage in the urban water supply infrastructure. This pertinent issue is being addressed, with improvements being annually recorded [2, 6]. The present leakage factor accounts approximately to 14.8% of the total water supply [7].

Manufacturing facilities are connected to the town water distribution network. Town water typically requires a quality upgrade in order to meet process specifications, therefore demanding higher energy expenditure. Some enterprises opt for abstracted groundwater. This could either be pumped from a borehole within the vicinities of the factory or transported by bowser trucks from boreholes around the country.

3 WATER IN MANUFACTURING

3.1 Water Uses

This paper is concerned of promoting sustainable manufacturing in production facilities via water management. Therefore, a careful understanding of the uses of water in manufacturing operations is required. The direct water use in manufacturing systems could be classified in the following categories [8]:

- **Process Water:** Water used in the execution of manufacturing processes (such as in cleaning operations, transportation of material) or when it is incorporated as part of the product itself, serving as a raw material.
- **Cooling/Heating Water:** Water used to control the temperature of operations and equipment in the manufacturing facility. This portion of water use is required mainly by chilled water systems and/or cooling towers, which are used for machinery cooling and in boilers which are used for steam and heat generation.
- **Domestic Water:** Water used for the general sanitation and housekeeping of the manufacturing equipment and facilities. This includes service water which is the water used by employees for drinking and hygiene purposes. Water for irrigation may also be considered under this category.
- **RO Reject:** A by-product of the RO system which is more concentrated than the feed and can exhibit further uses (e.g. for domestic purposes).

Water operations in industrial facilities comprise a withdrawal from the supply, followed by a subsequent discharge into the sewer with a generally degraded quality. In Malta, all the discharge from industrial facilities should meet regulatory demands, and therefore enterprises treat their wastewater in-house before it is discharged into the sewer at a neutral quality level. This can be referred as consumption given that when water is treated in the municipal wastewater treatment plants, the treated sewage effluent is presently discharged into the sea, with negligible positive environmental effects. Plans for using this reclaimed water for second class uses are in the pipeline [6].

Indirect water use is also considered through the embedded water in the inputs and mechanisms of the manufacturing system, such as in raw materials, equipment and tooling [9]. Energy input incorporates an indirect water use due to water intensity in electricity generation. The water intensity in the generation of electricity is due to the generation of steam and cooling requirements. Therefore, this intensity is dependent on factors such as the plant technology (thermoelectric, hydropower etc.), energy carrier mix (fuel oils, gas etc.) and cooling technologies (once-through or recirculating) [9-11].

3.2 Corporate Water Stewardship

Enterprises are committing themselves to a more sustainable approach in their operations and corporate profiles. They are appreciating more the value addition which sustainable attitudes are contributing to their market performances [12, 13]. The idea that sustainability and profitability are two opposing factors in corporate performance, is nowadays considered an out-dated viewpoint [13]. As Figure 2 suggests, enterprises are still considering water sustainability as one of the lower priorities in their corporate agendas, where stewardship priorities lie with energy efficiency and minimisation of waste [12].

Figure 2: Key priorities for businesses [13].

The predicted increase in priority is mainly due to the potential risks associated with water scarcity [10, 12]. Water scarcity is highly localised therefore risks are also location dependant. These risks are termed as:

- physical risks;
- regulatory risks;
- reputational risks.

The above mentioned risks may all translate into financial limitations. Therefore, it results imperative that enterprises use their water resources in a more sustainable manner [14]. Corporate reporting is one initiative, where accounting of water use is important. Manufacturing enterprises are to implement water management practices, which may indicate improvement areas for sustainable water use, mitigation of environmental impact and disassociation from the water-related risks.

3.3 Water Management Methodologies

Resource management is based on prior resource measurement. A number of drivers lead enterprises to reduce their water consumption [12]. A breadth of tools exist which support the identification of improvement areas and promote water efficiency.

An interesting tool is the Water Management Hierarchy [15], which prioritises the solutions for decreasing water consumption. This hierarchy assists management in prioritising solutions.

Two systematic techniques are used to analyse water flows inside the manufacturing system and identify opportunities which promote efficient water use. This is achieved via process integration. Water Pinch Analysis and Water Cascade Analysis are composed of graphical and numerical techniques respectively, which implement reduction in water use in identified improvement areas. The techniques lead to implementation of reuse and recycling by analysing water flows and quality [16, 17].

Lifecycle Assessment (LCA) is a standardised tool under the environmental management family of standards, ISO 14040-14044. This tool is typically used to assess the environmental impacts of a product or service across its lifecycle and is composed of four phases: goal and scope definition, inventory analysis, impact assessment and interpretation. It has typically relied on accounting for energy and greenhouse gas emissions and rarely tackled freshwater consumption. However, this is now an active area of research [14, 18]. Arguments which outline the ineffectiveness of LCA in accounting for freshwater consumption and its impacts are also suggested in research [9].

As Jefferies et al. point out, another tool which is analogous to the LCA is the Water Footprint Assessment (WFA) [19]. The authors indicate both similarities and differences when addressing freshwater consumption using both tools. The WFA was developed by Prof. Arjen Hoekstra and it accounts for both direct and indirect (virtual) water uses, serving as an indicator of freshwater appropriation for human activities. The phases of the WFA are represented in Figure 3 [20].

Figure 3: Water Footprint Assessment Phases.

WFA studies exist on the product level, where a supply chain approach is adopted to quantify water consumption along each production stage [19]. Ogaldez et al. point out that water consumption databases for manufacturing processes do not exist, compared to existent databases for crops [11]. The WFA Manual [20] then suggests that it is best to rely on data from the manufacturers when assessing manufacturing operations.

The WFA can be implemented on a number of levels, such as a manufacturing process, a product or a business [20].

4 BUSINESS WATER FOOTPRINT FOR A MANUFACTURING SYSTEM

Given the broad applicability of the WFA as an indicator for sustainability, this could be implemented on a basis of a manufacturing system. By definition, the water footprint of a business is the sum of the water footprint of the final products produced by the business. A business is an aggregation of different business units. A manufacturing facility fits the definition of a business unit [20]. The business water footprint enables an enterprise to calculate and report the freshwater consumption per year and/or per product [12]. The calculation is made according to equation (1).

$$WF_{Business} = WF_{Operational} + WF_{Supply\text{-}chain} \quad (1)$$

Schornagel et al. argue that the WFA is not suitable for industrial operations given that it does not balance flows inside the system [10]. This will be mediated by adopting elements from a water balance approach, and schematising water flow diagrams, in order to implement the WFA effectively as a tool for water management in a manufacturing facility [21].

4.1 Operational Water Footprint

The operational water footprint, $WF_{Operational}$ accounts for water consumption which occurs within the boundaries of the manufacturing facility. It is an aggregation of production and overhead operational water footprints. The former denotes the water footprint with a direct association to the production of end products and is the sum of process and cooling/heating water uses as described in section 3.1. The overhead is then equal to the domestic water use with all the activities as described above.

4.2 Supply Chain Water Footprint

The supply chain water footprint, $WF_{Supply\ chain,}$ comprises the virtual water and is composed of two components. The production component denotes the embedded water inside the raw materials, equipment and tools, which are required for production. The overhead component includes embedded water in electricity, transportation and so on.

The characteristic components of the WFA are to be included when assessing water use in a manufacturing system. This decomposition will help assess the sustainability of the operational water footprint by distinguishing between renewable and non-renewable sources. The components are:

- **Blue Water** represents water sourced from the natural reservoirs. This comes from groundwater aquifers and constitutes around 44% of local town water supply. Borehole water and water purchased for drinking dispensers (e.g. 5 gallon bottles) contribute to this blue component.
- **Green Water** represents water sourced from a renewable source. This is considered when harvested rainwater is used in the production facilities.
- **Grey Water** represents polluted water-discharge such as wastewater from laundry, wash hand basins, water from machinery cleaning, etc.

The above factors are dependent on the availability and reliability of water-use data from the manufacturing site. When assessing for sustainability, the local context is to be a main criterion, given that the water footprint is geographically explicit [20]. The blue water footprint is highly unsustainable in the local scenario because of the pertinent over-abstraction problem. In mitigating this, alternative water sources should be considered. As such, the green water footprint will promote a more sustainable business water footprint when aggregating components. The focus of this work is on minimising consumption, and is minutely concerned of pollution, given that this is tackled by a legislative framework. Therefore, the attention will not focus on grey water.

5 CASE STUDIES

A number of manufacturing enterprises in Malta were approached to assess their water use and promote sustainable water management through WFA. The goals and scope of the study were defined. This meant that the business water footprint components to be included were those which had the water data readily available. In fact, supply-chain water footprint had to be omitted given that local manufacturers had no relevant data.

Water flow diagrams where schematised in order to better understand the flows in the manufacturing systems. Figure 4 represents the legend adopted for the schematic diagrams; the arrows on the left represent the water sources, whilst arrows to the right indicate what happens with the effluent from one process to another.

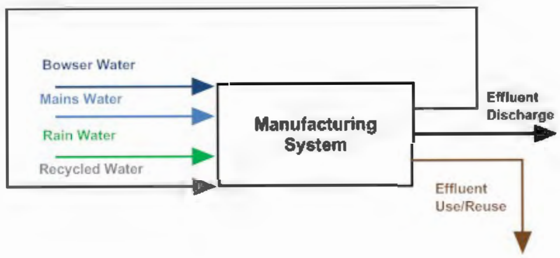

Figure 4: Water Flows in Manufacturing Systems.

5.1 Description

Two local small and medium-sized enterprises (SMEs) and one large company served as case studies. The case study companies are listed as following:

Case Study A: Seifert MTM Systems are manufacturers of industrial thermal management systems such as heat exchangers, air conditioning equipment and so on. The company employs 190 employees. Process water is used in surface treatments and cleaning. The rest is used for domestic purposes. They make use of an industrial chiller rather than cooling towers. Sources of water include borehole water and town water.

Case Study B: Pharmaceutical Company is a manufacturer of active pharmaceutical ingredients employing 35 people. Its name is kept undisclosed as requested. Process water is used in minimal quantities as a product ingredient but mainly for the cleaning-in-place of equipment between the production of different material batches. They exhibit a cooling/heating water footprint due to the use of a cooling tower and a boiler use. Apart from domestic water, a pronounced proportion of their operational water footprint is in rejected water from in-house reverse-osmosis plants and in backwash of sand filters. Water is sourced entirely from town water.

Case Study C: STMicroelectronics-Malta employs 1570 people and is one of the leading semiconductor manufacturers. It is also the largest manufacturing enterprise in Malta. Process water is the largest proportion of the operational water footprint and is used in wafer sawing and package cutting. Cooling towers provide cooling water and the domestic water footprint is quite pronounced given the large facilities, a 24-hour/7-day week operation, and the number of employees. This company recycles most of its process water, exhibiting excellent sustainability in terms of mitigation of environmental and social repercussions, with a positive financial gain. Sources of water include town water, rain water and recovered condensate from HVAC equipment.

5.2 Water Footprint Results

Data was made available by the companies through flow meter readings which are read periodically. Monitoring of consumption differs significantly between the case studies and thus the gaps in data availability and significance differed accordingly. Meter readings were aggregated in order to outline proportions between areas of water use, as this would potentially help identify areas of improvement. This is represented in Figure 5, with absolute values in m^3/annum and the respective percentage values. The figure also shows the water sources making the water footprint components, in order to aid sustainability assessment by distinguishing groundwater use from alternative water sources. The water footprint accounts help identify unsustainable footprints, such as the blue water component in all case studies and the RO reject water footprint in case study B.

This insight provides a basis for manufacturing systems to formulate responses, and implement water management practices which reduce the operational water footprint.

6 RESULTS ANALYSES

Results from case study A show that the domestic water use is more pronounced, meaning that water conservation efforts

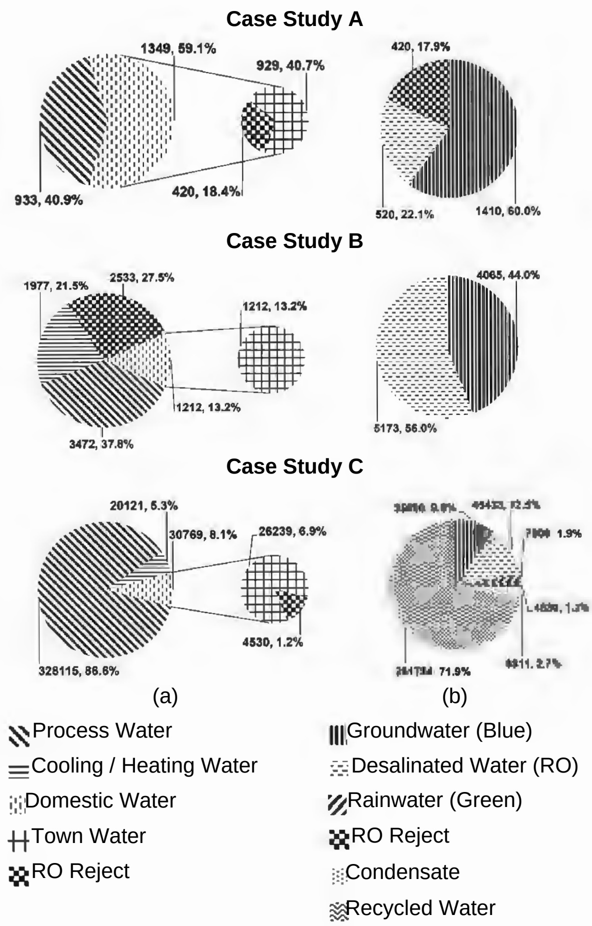

Figure 5: Results: a) Water Uses and b) Water Sources.

in this area would result in high savings. Process water is already minimised through water cascading. Given that this company makes use of chillers instead of cooling towers, a minimal amount of water is consumed for cooling purposes. More than a fourth of the operational water footprint of case study B is discharged RO brine. This could have other potential uses, such as in toilet flushing systems. This practice is wasteful and unsustainable. On the other hand, RO Reject is fully exploited by case studies A and C. The domestic water use in case study B is on the lower end given the low number of employees. Case study C requires most of its water for process use, however most of this is recycled, considerably reducing the operational water footprint. This case study taps into alternative sources of water.

Use of blue water and desalinated seawater is highly unsustainable given the direct pressure on water and energy resources respectively. In the case of a water scarce country, the use of natural water sources should be a last resort. This shows that case studies A and B have an unsustainable operational water footprint. Their footprint components show potential for the introduction of alternative sources such as rainwater harvesting and grey water recycling. This would offset the blue water footprint with a sustainable green one.

7 DISCUSSION

The case study results, indicated in Figure 5, provide a better basis on which improvements may be identified. The former provides meaningful information to manufacturing enterprises which want to reduce their operational water footprint in achieving sustainable manufacturing in their own facilities. The WFA provides the guidelines to assess for sustainability, such as for local water scarcity where attention is put in minimising the blue water footprint. Sustainability may be assessed on different levels, other than manufacturing facilities. The level of detail is also dependent on the impacts associated to the local environment. Following a sustainability assessment, together with the water footprint results, the improvement areas may be identified and solutions prioritised. Identification of water efficiency initiatives is required prior to their implementation. Following the results, a number of opportunities and barriers to water management could be identified.

7.1 Opportunities

With respect to the water management hierarchy [15], the identified opportunities were to start from replacing the use of freshwater with *alternative water sources.* This is proposed as a contribution to the mitigation of water scarcity, by reducing the blue water footprint. Rainwater harvesting is only performed by case study C, whereas this exhibits potential in the other companies, especially in case study A where the rainwater potential, found according to the local mean rainfall, would theoretically offset the current operational water footprint by more than 100%. Annual rainfall in Malta is at around 500-600 mm/a in 6-7 rainy months [2, 4] and therefore the potential for collection exists and remains to be locally exploited [6]. The quality of rainwater is suitable for second class quality water uses, such as cleaning and irrigation. Underground cisterns for rainwater harvesting also exhibit the potential for cooling by serving as a heat sink. Another alternative source is the recovery of condensate from HVAC equipment, which may also be exploited for reducing the blue water footprint. Case study B shows an exceptional water footprint of in-house RO-reject which is currently discharged to the sewer. Case studies A and C are examples of best practice in this case, where their reject streams are used for toilet flushing purposes.

Technology plays its role in reducing water consumption such as when considering cooling technologies. The existent methods show a distinction in terms of water consumption (e.g. once-through cooling against recirculating cooling). The water-energy link is evident in these considerations. Case studies B and C use cooling towers. Climatic considerations should also be apprehended. The local climate is typically hot and humid. Local manufacturing enterprises typically use cooling towers for normal operation and chillers as a backup in the hotter months. An estimate showed that, with the current utility prices, the energy cost associated with chillers would totally outweigh the water cost associated with cooling towers. This makes companies opt for the latter even though the former are negligibly water intensive and could be more suitable for the local climate.

Even though the *3R's (reduce, reuse and recycle)* have become more of a 'cliché', their implementation on a level of manufacturing facilities can yield a contribution to the minimisation of the operational water footprint. The domestic water footprint can be effectively reduced by implementing domestic retrofits such as faucet aerators to wash hand basins and water saving bags to flushing cisterns. These efforts may be enhanced by considering reuse and recycling of water streams. Case study C is an example of good practice in terms of recycling. However it is important to point out that daily volumes of water use may not always justify the implementation of recycling. Therefore, an enterprise-specific feasibility assessment is required.

Any successful water management plan is dependent on *management commitment.* This can be a driver to water management and more sustainable manufacturing simultaneously. The environmental management systems (e.g. ISO14000:1), should be used to meet not only environmental impacts in terms of discharge but also in terms of resource utilisation. The inclusion of water management as a company strategy would be a positive contribution [12]. This strategy may be extending from the operation of a manufacturing facility to corporate levels, where stakeholder involvement may promote demand for sustainable performance. Furthermore, this management drive can also lead to local industrial symbioses where companies in common industrial estates could collaborate in sharing their water resources.

7.2 Barriers

The *'business-as-usual' approach* resists change and keeps enterprises away from the adoption of sustainable measures. This attitude can also lead to an under-appreciation of risks as outlined in section 3. Proactive management, in conjunction to a paradigm shift would avoid such hurdle.

The *monitoring of water consumption data* exposed a number of issues from the case study results. Metering and sub-metering activity was found to be seldom rigorous. The practice of metering discharge flows is practically inexistent. These data gaps result in a difficulty to balance water flows and detect water losses such as in leaks.

Financial justification of water conservation projects can be considered the largest hurdle. This is mainly due to the current water tariff which does not include a resource and environmental cost. Therefore, local water pricing does not reflect the water scarcity scenario. This creates unattractive payback periods which do no not justify water conservation measures. This is especially true in cases of SMEs.

8 SUMMARY

This paper looked into the implementation of water management for promoting sustainable manufacturing in industrial facilities. The local situation of water resources was initially reviewed followed by a review of the relevance of water to manufacturing enterprises and some methodologies which support water management. The business water footprint was adopted as an indicator for sustainability and the operational water footprint was assessed in three case studies. The respective results provided a basis for which sustainability could be assessed. These results led to the identification of opportunities and barriers to water management in manufacturing.

The local manufacturing sector needs to become more water-sustainable. Opportunities for future work exist in determining the feasibility of certain initiatives, such as rainwater harvesting or wastewater recycling, which may support decision making in local enterprises. Feasibility assessments should include a technical and financial justification which would look into the cost-effectiveness of water conservation projects.

9 ACKNOWLEDGMENTS

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