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Assessing the impact of embodied water in manufacturing systems

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Abstract

In recent years the issue of improving energy and water efficiency in manufacturing systems has received increased attention. Rising energy prices, scarcity of quality water and imposed environmental regulations have been the main contributors to this issue. Water is consumed not only for raw material and products, but also for primary forms of energy, such as electricity. Therefore, it is important to measure energy and water consumption and to obtain insight into their usage patterns in manufacturing systems. In particular, such measurements can help to identify hotspots and inefficient processes. So far, a number of approaches have been developed to assess the environmental footprint of water and energy consumption, but few studies have been carried out to establish approaches to quantify their consumption, especially for water.

This paper introduces a simulation-based approach that can be implemented to model energy and water flows in manufacturing systems. The approach contains a generic state-based model for a single machine and follows a bottom-up approach to construct the model of the whole system. This approach provides a reliable base for simulating operating conditions and evaluating different what-if scenarios in order to improve system performance. Then, one of the most appropriate methods for water footprint assessment in manufacturing industry is chosen, and a manufacturing site of a pharmaceutical company, as a case is studied to show how the proposed model can be applied.

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1. Introduction

1.1. Water as a Resource

Freshwater is essential for humans and ecosystems. In many places, it has been overexploited for economic development, especially for agricultural and industrial activities. Moreover, with the global growth in population and the associated growth in consumption, the human demand for freshwater is constantly increasing [1]. We can expect to observe increasing pressure on freshwater resources due to climate change as well as extra water consumption for cultivation of biofuel crops that are intended to reduce greenhouse gas emissions. This may bring a wide range of social and environmental problems to society [2]. Withdrawal of freshwater that exceeds the environment's natural renewal in both quantity and rate has been documented in many parts of the world including Australia [3].

The consumption of water by different economic sectors has varied significance. For example, Fig 1 compares water consumption by industry and household in 2011-12 in Australia. During this year, approximately 60 per cent of water was consumed by agricultural activities. Other sectors, particularly manufacturing and mining are likely to make a significant contribution to water pollution, despite their relatively small proportion of water consumption. The agricultural use of water mainly concerns underground water, while manufacturing and mining use water present in water bodies such as rivers, or dams. More importantly, after extraction and use by industry or households, water is usually discharged with a reduced quality and is often more heavily polluted.

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Fig 1 Water Consumption, by Industry and Household, Australia 2011-12 [4]

1.2. Industrial Water Use

Water fulfils a variety of functions, depending on the nature of the industry or product. For example, manufacturing consumes water (either as a raw material or as process water) during the creation of products that are later consumed by other industries or households. Other industries, such as mining or electricity & gas production, require water to process raw materials or to generate primary forms of energy (e.g. electricity) that support production in other industries.

From an industry perspective, it is therefore important to consider the contribution of the water footprint of a process, product, or manufacturer in this broader context. There are two perspectives to consider [5] (i) the contribution of the water footprint of a specific process, product, or production system to the global water footprint and (ii) the contribution to the aggregated water footprint of a specific geographic area. Addressing the first question is important from sustainability point of view due to the fact that the world's freshwater resources are limited. Consequently, there should be serious concerns with any high usage beyond the reasonable maximum need from a technical or societal point of view.

Industrial activities may have negative impacts on the natural environment and upon human health. Moreover, these impacts will be of greater significance in water sensitive areas around the world. Therefore, the assessment of water footprints is an essential aspect of sustainability assessments for industries and products [1]. Traditional methods for analysing water footprints are not relevant for assessing the impacts of industrial water use. This is due to the fact that much of the time at least part of the used water is released back to the environment, which has a positive impact on the water availability for other uses [6]. Taking into account this fact makes traditional methods irrelevant for the industrial impact assessments.

Current studies have focused on the quantification of the consumptive part of water use, that is the volumes of water from different sources [7]. More specifically, the impact of water pollution by the industrial sector has been taken into account to a limited extent by including the (polluted) return flows. Thus, the calculation of the water footprints of industrial activities consists of two components: consumptive water and waste water production.



Fig 2 Schematic Representation of the Components of a Water Footprint for a Manufacturer, Adapted from [5]

From the sustainability point of view, one cubic meter of waste water from industry is not equal to one cubic meter of freshwater; since it generally pollutes a much greater volume of freshwater after discharge. Different authors suggest the impact could be as much as ten to fifty times the discharge volume [8].Therefore, it would be more realistic to assess the impact of water pollution by estimating waste water and quantifying the volume of water that is required to dilute waste flows to such an extent that water quality remains within acceptable water quality standards.

2. Water Footprint of a Product

The water footprint of a product is defined as the total volume of freshwater that is used directly or indirectly to manufacture that product. It can be subdivided into green, blue, and grey components and can be estimated by taking into account both water consumption and pollution at all steps of the production system. Figure 2 shows the components of a typical water footprint for a manufacturer [5]. As an indicator of 'water use', the water footprint differs from the classical measure of 'water withdrawal' in three respects; (i) it does not include blue water use insofar as this water is returned to its source, (ii) it is not restricted to blue water and contains green and grey water, and finally (iii) it includes both direct and indirect water use. In this framework, direct water use refers to the amount of water that enters to the system from outside, while indirect water use indicates to the water embodied in other inputs to the system such as material or energy carriers.

Therefore, the water footprint refers not only to the volume, but also to the type of water, the time, and the place the water was used. In fact, it is a multidimensional indicator pointing to different aspects of water use. There are several ways of expressing the efficiency of water footprint in industry, such as cubic meters of water per unit of money or water volume per unit of production.

2.1. Water Flow in Manufacturing Systems

From the perspective of manufacturing systems, the water footprint of an individual process unit is the basic block of all assessments. At the process chain level, the water footprint represents the aggregate of individual consumption by each process step relevant to the production of a particular product.

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