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A decision support system for eco-efficient biorefinery process comparison using a semantic approach

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A B S T R A C T

Enzymatic hydrolysis of the main components of lignocellulosic biomass is one of the promising methods to further upgrading it into biofuels. Biomass pre-treatment is an essential step in order to reduce cellulose crystallinity, increase surface and porosity and separate the major constituents of biomass. Scientific literature in this domain is increasing fast and could be a valuable source of data. As these abundant scientific data are mostly in textual format and heterogeneously structured, using them to compute biomass pre-treatment efficiency is not straightforward. This paper presents the implementation of a Decision Support System (DSS) based on an original pipeline coupling knowledge engineering (KE) based on semantic web technologies, soft computing techniques and environmental factor computation. The DSS allows using data found in the literature to assess environmental sustainability of biorefinery systems. The pipeline permits to: (1) structure and integrate relevant experimental data, (2) assess data source reliability, (3) compute and visualize green indicators taking into account data imprecision and source reliability. This pipeline has been made possible thanks to innovative researches in the coupling of ontologies, uncertainty management and propagation. In this first version, data acquisition is done by experts and facilitated by a termino-ontological resource. Data source reliability assessment is based on domain knowledge and done by experts. The operational prototype has been used by field experts on a realistic use case (rice straw). The obtained results have validated the usefulness of the system. Further work will address the question of a higher automation level for data acquisition and data source reliability assessment.

1. Introduction

The bioconversion of lignocellulosic biomass has been extensively studied in the past 30 years. Enzymatic hydrolysis of the main components of the biomass is one of the promising methods to further upgrading it into biofuels (Fig. 1). The structural heterogeneity and complexity of cell wall constituents such as crystallinity of cellulose microfibrils, specific surface area and porosity of matrix polymers are responsible for the recalcitrance of cellulosic materials. Biomass pre-treatment is consequently an essential step in order to reduce cellulose crystallinity, increase surface and porosity and separate the major constituents of biomass (e.g. cellulose, hemicellulose, lignin, phenolic acids). The objective of such pre-treatments depends on the process type and biomass structure. For instance, pre-treatment methods can be divided into different categories: mechanical, physical, chemical, physicochemical and biological or various combinations of these (Fig. 2). Each method has its drawbacks such as energy

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0168-1699/

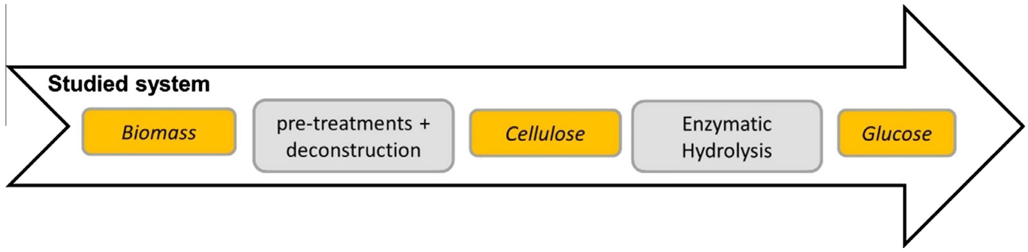

Fig. 1. Biorefinery pre-treatment process.

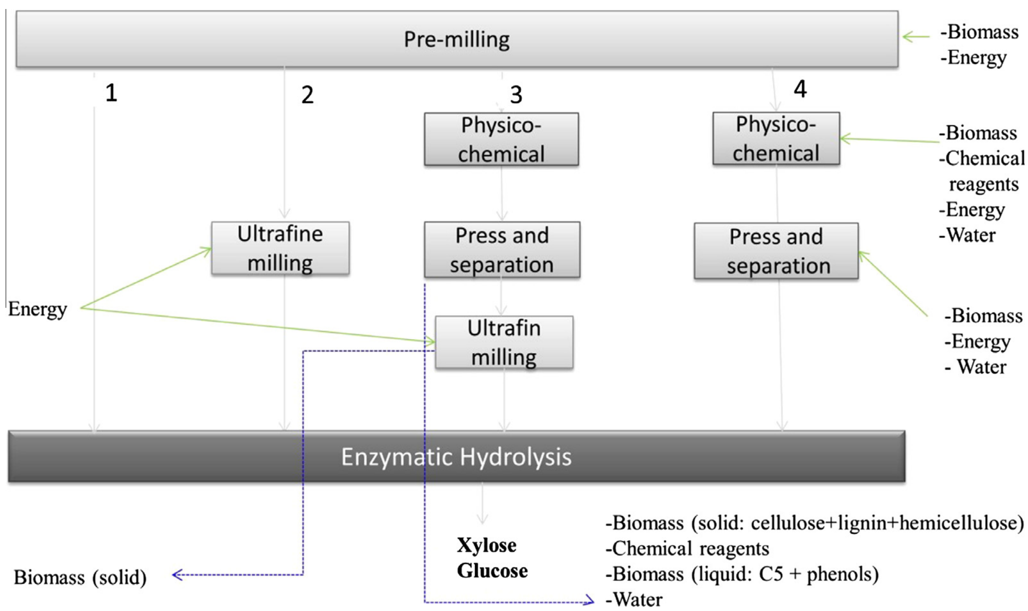

Fig. 2. Four different biorefinery processes to transform biomass into glucose.

consumption, corrosion of processing tools, water consumption, introduction of inhibiting effects, or the high number of separation and purification steps. Low or no water consumption during ligno-cellulosic pre-treatment can decrease the generated effluents, and also reduce the energy input for the biomass pre-treatment (Zhu and Pan, 2010; Barakat et al., 2014).

In recent years, environmentally friendly pre-treatments such as milling or ultrasonic, plasma and wet explosions have been studied for biomasses such as woods, bagasse, rice and wheat straw (Kumar et al., 2009; Zhu and Pan, 2010; Adapa et al., 2011; Schultz-Jensen et al., 2011; Sheikh et al., 2013). Currently, these processes are not cost-effective, not only because of high investment costs but also because they can be very heavy on energy. For example, the total energy requirement of milling processes depends on the physicochemical properties of biomass and on the ratio of particle size distribution of materials before and after milling, this ratio being strongly dependent on the equipment or machine used. The environmental factor, energy consumption and energy efficiency are classically used to compare the performances, efficiencies and environmental impacts of different pre-treatment processes (Zhu and Pan, 2010; Barakat et al., 2014; Chuetor et al., 2015). However, survey articles concerning these three criteria for chemical, physicochemical and mechanical treatment of lignocellulosic biomass remain scarce. Moreover, the rapidly increasing scientific literature in this domain would make such surveys quickly obsolete. To take advantage of this huge and potentially valuable source of information, innovative tools able to integrate continuously new information are required.

The main obstacle holding back the use of those scientific data is their textual format and heterogeneous structure. Our first aim in this paper is to show the relevance of semantic web-based KE methods to structure the experimental information and express it in a standardized vocabulary. Such structuring can be done using an ontology (the semantic part of our model) to represent the experimental data of interest (see step 1 in Fig. 3). Ontologies are knowledge representation models that facilitate linkage of open data and offer automated reasoning tools. Once structured in ontologies, collected information and data are made homogeneous and can be processed to compute criteria allowing the comparisons of processes.

Our second aim in this paper is to demonstrate the feasibility of a pipeline (see Fig. 3), taking as inputs process data found in scientific documents, and whose final output is a ranking of those processes integrating data source reliability. Note that our system is partially inspired from previous semantic approaches used to facilitate "a priori" calculation of environmental indicators in industrial symbiosis (Trokanas et al., 2015; Raafat et al., 2013).

To illustrate our proposal, we present a first attempt to compare different pre-treatment processes (Fig. 2) in terms of sugar yield after enzymatic hydrolysis and of environmental factor, by reusing data already published in the scientific literature. Energy efficiency is out of the scope of this paper as there is a lack of data about energy consumption in the current literature. The illustrating example concerns glucose extraction in rice straw and compares the four processes presented in Fig. 2. These processes may include a sequence of unit operations, as shown in Table 1.