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Review of micro- and small-scale technologies to produce electricity and heat from Mediterranean forests' wood chips

Arnau González [a,1], Jordi-Roger Riba [a,*], Rita Puig [a,1], Pere Navarro [b,2]

[a] *Escola d'Enginyeria d'Igualada (EEI-Escola d'Adoberia), Universitat Politècnica de Catalunya. Plaça del Rei 15, 08700 Igualada, Catalunya, Spain*
[b] *Centre Tecnològic Forestal de Catalunya, Àrea d'aprofitaments fusters i biomassa, Ctra. Vella de Sant Llorenç, km 2, 25280 Solsona, Spain*

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A B S T R A C T

In the current energy conjunction, with an expected growth of energy consumption in a context of fossil fuel depletion, more focus is being placed on renewable energy sources (RES) for electricity generation. One of the most appealing alternatives is biomass, which can be efficiently used to generate electricity as well as heat with the application of cogeneration technologies that enhance the efficiency of the entire energy conversion process. The Mediterranean basin is a region with a recognized potential for electricity and heat production using primary forest biomass and sub-products from sawmills, among which highlight wood chips for their easiness to be obtained, processed and dried as well as for their good and stable burning or gasification behavior. However, in order to efficiently use the available resources, that is, minimizing logistical requirements to reduce the energy necessary for the electricity generation process, the biomass found in Mediterranean forests can only be used at micro- and small-scale levels to be compatible with sustainable forestry practices. This article is aimed to describe the different technological alternatives to convert wood chips into electricity and heat and it also reviews and compares the current performances in terms of efficiency of these technologies at the micro- and small-scale levels.

Contents

* Corresponding author. Tel.: +34 938035300; fax: +34 938031589.
E-mail address: jordi.riba@eei.upc.edu (J.-R. Riba).
[1] Tel.: +34 938035300; fax: +34 938031589.
[2] Tel.: +34 973481752; fax: +34 973480910.

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1. Introduction

Over the past decades, the levels of greenhouse gases (GHG) in the atmosphere and, specifically, of the most prevalent one, carbon dioxide (CO_2), have raised way over safe limits of Earth's boundaries [1]. Particularly, CO_2 levels have risen from around 280 ppm of pre-industrial era [1,2] to near-400 ppm at present time [4] continuing to grow at increasing rates [5]. Among the identified causes of worldwide GHG emissions, energy production is claimed to be the main one. In particular, CO_2 emitted from the combustion of fossil fuels for transportation, industry, electricity and heat production is the major contributor to the greenhouse effect [6]. Energy production is expected to have continuous growth during next decades [7], shaping a context of current and future global environmental issues, namely sea-level rise and weather pattern changes [8], worsening agriculture production [9] and producing water shortages in some places and intense flooding in some others [10,11]. Such changes will likely have significant implications in ecology, economics and public conflicts and policy [12]. In addition to these environmental concerns, fossil fuels have another important drawback: despite the fact that they are the main energy source throughout the world, they entered in a depletion process over the last decades, a concern to be added to the environmental degradation that they contribute to [7,13]. In a free-market economy, this means increasing prices and thus decreasing competitiveness. Moreover, in countries with low or even no indigenous fossil fuel availability, their usage results in energy dependency on foreign countries.

Facing all mentioned odds, there are the renewable energy technologies which often are indigenous sources of virtually perpetual energy, scalable and carbon neutral [14]. These technologies will help to implement the distributed generation model which consists on energy production close to both renewable energy sources (RES) and consumption. Consequently, large production plants could be partially substituted by small- and micro-scale plants [15]. Distributed generation, in turn, has been labeled as a key tool to address the problems of security of supply, CO2 emissions and to improve the efficiency of energy systems [16], as well as to overcome the problem of rising electricity costs and shortages [14]. Distributed generation has social benefits in terms of encouragement of development in rural areas by providing electricity at those places where the grid transmission is not reliable [14,17] and by generating new income opportunities through revaluation of local resources [18]. Therefore, several public policies have been set up in many countries in order to increase the share of RESs to the electricity supply, including the goal of reaching 20% of electricity share in both the European Union (EU) and the United States (US) or the goal of 35% share in Asian countries such as China or India [19].

However, RESs have an undeniably important drawback: from the three most exploited sources, hydroelectric, wind and photovoltaic (PV) power, two of them, namely wind and PV, are weather- or climatic-dependent [20], meaning that it cannot be assured their dispatch on demand because they only can be produced when the natural resource is available. To face and overcome this issue, more flexibility has to be achieved to ensure permanent meeting of demand by the supply side. Among the available grid-scale flexibility achievement techniques, which include demand-side management, overcapacity installation and large-scale storage systems, the latters are the best option because they allow maximizing the usage of generation without impacting the consumers' habits of use of electrical power [21]. According to Barnhart and Benson [21], large-scale storage systems include conventional batteries (Li-ion, sodium sulfur or lead-acid batteries), flow batteries (vanadium redox or zinc-bromine), compressed air electricity storage (CAES) and pumped hydro storage (PHS). Carrasco and Franquelo [22] also consider flywheels, hydrogen fuel cells, supercapacitors and superconducting magnetic energy storage (SMES) as feasible alternatives. If small-scale solutions, namely micro-wind turbines or stand-alone photovoltaic systems are chosen, battery energy storage systems (BESS) to be used as a backup are even more necessary due to their scalability and low cost [23]. Hence, additional costs should be attributed to the installation of these RESs if the requirement of storage is taken into account when designing a so-called hybrid system that includes renewable energy production technologies and storage systems [20]. Moreover, the small size of these systems adds another potential issue: the integration of many small power sources instead of a few large ones requires additional control measures to ensure stability, prevent failures and make mid- and long-term electricity production estimations [24,25]. According to some sources [19], the setup of large energy farms, both wind and photovoltaic, that supply power as a single power unit is also required in order to ease their integration into the electric grid.

Among all the RES, biomass is one of the most promising options. Particularly, the fact of being based on proven technologies, its flexibility of operation and installation [14], easy and efficient scalability and low and stable price because of being often a waste product [17] are strong reasons for its use. Moreover, biomass is the only renewable source that can be used in solid, liquid or gaseous form [26,27], which allows using it for industrial purposes in the case of solid biomass, for electricity and heat production when it is in both gaseous and solid phases, and for transportation purposes for liquid biofuels [28]. It also offers the possibility of having the plants near the resource, thus minimizing transportation costs [29] that lead to environmental impact reduction due to a more efficient utilization [30]. In addition, biomass is, together with hydro, the unique RES that can be stored and continuously used to have a predictable output not dependent of weather [31], so it would reduce the requirement of storage systems mentioned above. Finally, another important advantage of biomass is its flexibility to be converted to several forms of energy. Therefore, combined heat and power (CHP) technologies or combined cooling heat and power (CCHP) [32], which have better efficiencies [33], lower consumption [34] and CO_2 emissions [16] than heat and electricity production individually, can be used. Biomass-fuelled CHP systems have low operating and maintenance costs, high total efficiencies and low noise, vibration and emissions levels [16]. Moreover, heat pumps can be integrated with CHP plants to relocate the excess heat produced from the production site to a consumption node or to a storage facility [35]. CHP technologies reach the highest efficiencies if woody biomass is used rather than non-woody biomass [36], so it is interesting to use primary forest biomass and sub-products from sawmills for these purposes. Another important aspect to be considered is the