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An environmental assessment of electricity production from slaughterhouse residues. Linking urban, industrial and waste management systems

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HIGHLIGHTS

- Animal by-products use for electricity generation is investigated as a case-study.
- Different methodological approaches to deal with by-products are explored in LCA.
- Adopting a holistic perspective is crucial to achieve a circular economy framework.

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ABSTRACT

The food processing industry continues to grow, generating large amount of organically rich waste flows per year: these processors face significant economic and environmental pressures for appropriate conversion and disposal of these waste flows. Solid waste disposal problems, mostly in highly urbanized environments, energy shortages (primarily oil) and/or high petroleum prices, as well as environmental issues such as the shrinking landfill capacity, can all be addressed by converting waste material into useful and saleable products. This paper brings to the attention a possible strategy in order to meet the general EU directives concerning the residues utilization and percentage contribution for the total energy consumption by 2020, by evaluating the use of animal by-products (category 3, as defined in the directive 2002/1774/EC) for energy purposes. Slaughterhouse waste represents an important potential source of renewable energy: on average, 40–50% of a live animal is waste, with a potential energy content close to diesel fuel. Treatment of animal waste from slaughterhouse and the subsequent conversion to electricity is investigated as a case study in the Campania Region (Italy): the animal waste undergoes a rendering process, to separate a protein-rich fraction useful for animal meal production and a fat-rich fraction, to be combusted in a diesel engine for power and heat generation (CHP). An environmental assessment of the entire process is performed by means of LCA, providing a quantitative understanding of the plant processing. The study aims to understand to what extent electricity production from animal fat is environmentally sound and if there are steps and/or components that require further attention. The environmental impacts of the electricity production from animal waste are investigated adopting different points of view and they are also compared to the impacts of Italian electricity production (mix of fossil fuels and renewables). The study confirms that waste recovery represents a triple win solution, dealing simultaneously with human security, pollution, and, last but not least, energy recovery.

1. Introduction

Urbanization and human population have considerably grown, in the last decades, along with industrialization development. This caused an increase of environmental pollution, as a side effect [1]. The relationship between economic growth and environmental pollution has become the subject of passionate research over the latest decade. Since there is a large and growing world-wide consumption of fossil fuels, the amount of CO_2 released to the atmosphere also increased [2]. In modern societies, the environmental pollution mainly relies on two key issues: (1) the depletion of fossil fuels and limited availability of other non-renewable resources; and (2) waste generation that is pushing to the limits the

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biosphere's ability to dilute waste. Both could be considered as by-products of the technological development of human society [3]. In natural systems, all material flows are circular and the very concept of waste does not apply: 'waste' products and flows from a process always become inputs to other processes. Instead, human dominated systems are typically unable to continuously re-use all waste flows, which puts increased pressure on the environment in terms of pollution as well as ever-increasing depletion of natural resources [4]. Particularly, the limited capacity of conventional oil production to meet growing demand and the limited amount of crude oil reserves, may have large impact on the evolution of human societies in the next years [5]. The increasing demand for fossil fuel gives rise to environmental concerns such as larger CO_2 and greenhouse gas (GHG) emissions and global warming. The world energy consumption doubled between 1971 and 2001 and the world energy demand is expected to increase by 53% within the year 2030 [6]. This context invigorated the necessity to look for environmental friendly renewable energy sources as well as to increase the overall resource use efficiency, within a circular economy framework. In many countries energy policies have been implemented to decrease consumption by means of increased energy efficiency as well as to increase the share of renewable energy in the energy country mix, not only to respond to the international pressure for low carbon energy transition but also to intensify their energy security and economic affordability for industries and end users as critical issues to deal with [7]. Furthermore, waste generation applies pressure on both the environment and the human health, thus calling for improved waste management strategies to replace the present polluting methods. For instance, landfilling is one of the most commonly used waste disposal method, and accounts for approximately 67% of the total collected MSW worldwide [8] (31% in the only European Community [9]) with heavy environmental consequences due to leachate contamination of underground water as well as methane release to the atmosphere; incineration, most often considered as another mainstream technology, has faced a rapid development in recent years, in spite of the fact that toxic substances such as heavy metals and dioxin released during combustion may cause negative effects to the environment and human health [10,11], entailing heavy costs for management [12] and being a cause of degradation for the standard of living of populations in urbanized environments. As a result, scientists and concerned managers avidly seek alternatives to fossil fuels: focus on recovery of materials, resources and energy from waste has increased significantly in the endeavor of reducing fossil fuel consumptions and resources depletion [13]. In addition, in those regions where landfilling (instead of, for example, incineration) is the most common disposal method, the recovery of the organics (e.g. kitchen waste, tissues, etc.) becomes a necessary priority in order to minimize landfilling volume and comply with legislative targets [14]. The recycling of materials, and thus the minimization of waste to be disposed of, is a basic concept which must be implemented in order to meet the sustainable development goals in both industrialized and developing countries. It has been claimed that the carrying capacity of the planet has already been exceeded in several areas, including climate forcing [15]. Energy efficiency and clean energy have been recognized as key factors to minimize the cost and negative effect of climate change on the environment and society [16]. The energy sector is the largest contributor to GHG emissions [17], and for this reason, strategies to reduce the emissions from this sector are a key point of climate change mitigation strategies [18]. Waste contains fossil derived materials such as plastics. Moreover, it also contains biogenic materials such as paper, card and food waste. All of these fractions can be potentially converted into energy. The implementation of waste-to-energy (WTE) supply chains was suggested as a suitable method for energy production from waste, in order to address two of the main waste management environmental issues (limited landfilling sites and leachate). The WTE supply chain, in its CHP (Combined Heat & Power) version, if properly managed provides a method for simultaneously addressing energy demand, waste management and GHG emissions within a circular economy perspective (CES) [19]. Although not exempt from criticisms when applied to the very complex composition of MSW (municipal solid waste), WTE-CHP is put forward as an alternative to waste landfilling or incineration without energy recovery [20]. The EU Directives on waste management prescribe prevention, reuse and recycling as the very first alternatives, indicating the energy recovery option only for smaller amounts for which the previous alternatives are not easily feasible or fail. This seems to be the case of fat fractions of slaughterhouse residues dealt with in this paper, after other uses have been explored.

1.1. Urban waste and its energy potential

Most waste generation (in particular food waste) occurs in cities, where more than 50% of world population lives. Cities are increasingly concerned of both energy consumption and waste generation and their possibility to close the loop requires accurate energy/urban planning. Urban/local energy planning was developed later than urban planning, in order to suggest conceptual strategies for economic, environmental and energy-related regulations and policy implementation. Therefore, environmentally friendly city planning needs to facilitate the integration of 'urban planning' and 'energy planning' into a unified 'urban/local energy planning' system and to support adequate technology for each process [21]. Innovative waste refining processes provide potential solutions for energy and materials recovery. The generation of agro-industrial waste has been rising to such alarming levels that the public has become aware of the problems caused by inaccurate management. Nowadays the generation of waste biomass is so abundant and so centralized that there is insufficient capacity for its natural degradation, and various treatment techniques have to be applied. Animal slaughterhouse waste is also city related, in that the demand for meat-based diet is growing in cities and is not expected to decrease in the short run. Slaughterhouses represent one of the most important sectors of the meat industry [22]. Non-edible feedstocks, such as animal fat waste (AFW), have recently increased in popularity as alternatives to vegetable oils in the production of biodiesel [23–26]. Animal by-products are defined by European Directive 2002/1774/EC as entire bodies, or parts of animals or products of animals, not intended for human consumption. The Directive lists three different categories of animal by-products: Category 1 - all by-products likely to be the vehicles of infectious diseases-, Category 2 - all materials coming from manure, digestive tract contents and material collected when treating waste water-, Category 3 - by-products fit for human consumption, but not intended for it for commercial reasons [27]. Animal fats are primarily derived as by-products of meat animal processing facilities and of the rendering process. A large percentage of livestock live weight (an amount of about 48% by mass) consists of byproducts (i.e. fat and meal) [28] which show an energy content not far from diesel fuel (animal fat: 3.98E+04 J/g average, animal meal: 1.85E+04 J/g average) [29,30]. Ariyaratne et al. [30] also show how meat and bone meal can be used as renewable energy source in substitution of pulverized coal in rotary kiln burners (up to 40%, reducing annual CO_2 emissions of these burners by 10%). Studies about AFW address the need to manage these residues in a way that is capable to simultaneously dispose of the waste material and also obtain benefits from co-products, both in terms of energy (biodiesel and bio-methane [6,20,22–26,29–40]) and added value industrial products [41–44]. However, the existing literature about AFW conversion lacks of three main