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The bioenergy potential of conservation areas and roadsides for biogas in an urbanized region

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HIGHLIGHTS

- We assessed the bioenergy potential of conservation areas and roadsides in Flanders.
- An area of 31,055 ha produces 203 kton DM of herbaceous biomass annually.
- The associated biomass supply chain was optimized with OPTIMASS in four scenarios.
- The net energy balance of the studied systems was 7 GJ ha^{-1} in the 2020 scenarios.
- We show that this biomass can play a role to meet the increased biomass demand in 2020.

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ABSTRACT

In many urbanized areas the roadside and nature conservation management offers a biomass-for-bioenergy resource potential which is barely valorized, because of the fragmented biomass production sites and the scarcity of accurate data on the spatial availability of the biomass. In this study, a GIS based assessment was performed to determine the regional non-woody biomass-for-bioenergy potential for biogas from conservation areas and roadsides in Flanders, Belgium. These systems, with an area of 31,055 ha, have an annual herbaceous biomass production of 203 kton dry matter. The full associated biomass-to-bioenergy supply chain was optimized in four scenarios to maximize the net energy output and the profit. The scenario analysis was performed with OPTIMASS, a recently developed GIS based strategic decision support system. The analysis showed that the energetic valorization of conservation and roadside biomass through anaerobic digestion had a positive net energy balance, although there is still much room for improvements. Economically, however, it is a less interesting biomass resource. Most likely, the economic picture would change when other ecosystem services delivered by the protected biodiversity would be taken into account. Future technical advances and governmental incentives, like green energy certificates, will be necessary to incorporate the biomass into the energy chain. By tackling the existing barriers and providing a detailed methodology for biomass potential assessments, this study tries to facilitate the valorization of conservation and roadside biomass in order to reconcile biodiversity and road safety goals with renewable energy targets.

1. Introduction

In 2007, the European Commission (EC) adopted the 'Climate Action and Renewable Energy Package', which aims at transforming the European Union (EU) into a low-carbon economy and increasing its energy security. In this package three binding objectives, known as the 20–20–20 targets, were set: a 20% reduction of greenhouse gas (GHG) emissions (compared to 1990), an improvement of the energy efficiency by 20% and an increase of the share of the total energy consumption produced from renewable sources to 20%, all by 2020 [1]. The European Renewable Energy Directive in 2009 translated these targets into specific goals for each Member state of the EU [2]. Based on the National Renewable Energy Action plans of the member states, bioenergy will account for 55% of the

Abbreviations: DM, dry matter; FM, fresh matter; BVM, Biological Valuation Map; LU, land unit; AF, area fraction; FC, Functional Class; RF, reduction factor; F2C, fraction of the roadsides of which the vegetation is cut twice per year; NEB, net energy balance; LIHD, Low-Input High-Diversity.

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renewable energy target of 2020 [3]. The annual demand for biomass was estimated to almost double from 5.7 EJ in 2012 to 10.0 EJ in 2020 [4], with an associated increase in global land footprint from 44.5 Mha in 2010 to 56.6 Mha in 2020 [5].

With the known problems of intensively managed bioenergy systems [6–8], there is a large role to play for various waste streams as feedstock for bioenergy production. Northwestern Europe is characterized by a dense road network and hence also roadsides. The total extent of the road network in eight Northwest European countries (Belgium, Netherlands, Luxembourg, UK, France, Germany, Ireland and Switzerland) is more than 2.5 million km [9,10]. In this highly urbanized region the establishment of conservation areas has been the key strategy to preserve species-rich ecosystems. The European network of conservation areas, Natura 2000, consist of more than 26.000 protected areas and covers almost on fifth of the land area of the European Union [11]. Although aiming at biodiversity conservation and road safety, a large amount of lignocellulosic biomass originates from the management of these systems. There has already been some effort to characterize and quantify their biomass and bioenergy production [12–17], but conservation areas and roadsides are a commonly neglected biomass source in biomass potential assessments [18]. Generally, biodiversity and other services are even considered to set constraints on biomass production [19]. To our knowledge, studies on the bioenergy potential of conservation areas are lacking, but see Meyer et al. [14] for an assessment on roadsides. To date, the energetic valorization of conservation biomass, i.e. biomass from conservation areas, or roadside biomass is still exceptional, because of the scarcity of accurate data on the spatial availability of the biomass and the fragmentation of the biomass production sites. Both problems are addressed in this study.

GIS based assessments are being used to determine the biomass-for-bioenergy potential of various biomass streams and to optimize regional renewable energy systems with optimal locations of bioenergy facilities and allocation of biomass feedstock [20–23]. Van Meerbeek et al. [12,24] already determined the biomass composition, the biomass production and the bioenergy potential of a wide range of plant communities in temperate semi-natural ecosystems. The first goal of this study was the assessment of the total non-woody bioenergy potential of biomass from conservation areas and roadsides in Flanders, Belgium. The determination of the bioenergy potential was based on anaerobic digestion, because this technique offers many advantages to valorize the studied biomass like decentralized biomass utilization [25]. For the regional upscaling, we developed a new methodology to provide data on the spatial extent of these systems. The second goal was to spatially analyze and optimize the regional biomass-to-bioenergy supply chain to maximize the net energy output of the chain, bearing in mind the 20–20–20 targets of the EU. We also optimized the supply chain for maximal profit to enhance practical applicability of this study for policy makers. For this, we used OPTIMASS, an optimization model for the design and management of biomass supply chains, recently developed by De Meyer et al. [26]. By tackling the existing barriers, this study tries to facilitate the valorization of conservation and roadside biomass in order to reconcile biodiversity and road safety goals with renewable energy targets. Moreover, the detailed description of the methods applied in this study can be used as a guideline to conduct the same analysis in different areas.

2. Material and methods

2.1. Study area

This assessment is carried out for Flanders, the northern administrative region of Belgium, Western Europe, covering an area of 13,522 km^2. Flanders is a very densely populated region with an average population density of 478 inhabitants km^{-2} in 2012 and a range of 358–643 inhabitants km^{-2} for the provinces [27]. Consequently, the density of the road network is high (4.8 km/km^2). A network of conservation areas is set up to preserve the remaining semi-natural ecosystems in this highly urbanized region. In 2013, more than 67,000 ha of nature conservation area was effectively managed [28].

2.2. Nature conservation areas

2.2.1. Land cover data

The Biological Valuation Map (BVM, version 2.2) is a detailed land cover and vegetation map of Flanders on a 1:10.000 scale [29]. Based on a field survey, land cover classes and vegetation types were classified into approximately 380 map units. We selected the 94 map units with non-woody vegetation that can be harvested by mowing and aggregated these map units into 18 vegetation types (Table 1). The focus on anaerobic digestion excluded woody biomass from the study, because it is not suited for digestion due to its high lignin content [30]. The perimeter of the managed nature conservation areas was defined by merging vectorial data sets from the *Agency of Nature and Forestry* of the Flemish government and the two main non-profit nature conservation organizations *Natuurpunt vzw* and *Limburgs Landschap vzw*.

2.2.2. Biomass production

The average values of the annual biomass production (in ton dry matter (DM) ha^{-1} yr^{-1}) of the vegetation types are shown in Table 1. For reed marshes and humid tall-herb vegetation the length of the mowing interval (i.e. the mowing cycle, Table 1) is more than one year in order to preserve the specific vegetation [31,32]. The biomass yield per mowing cycle (i.e. the standing biomass at the end of a mowing cycle) divided by the number of years of the mowing cycle was considered to be the annual biomass production. Some vegetation types are mown twice a year in order to restore a more species-rich plant community. Those vegetation types were indicated with a mowing cycle of 0.5 year and the annual biomass yield was the sum of the two cuts. The majority of production values were based on earlier research [24]. The values for the remaining vegetation types were retrieved from the literature and a meta-analysis study [33].

2.2.3. Upscaling

The land units (LUs) for upscaling were defined as the map units of the BVM with harvestable non-woody biomass that lie within a conservation area. Each map unit in the BVM can contain a maximum of 6 different vegetation types, ordered according their area fraction (AF, %) within the map unit. We only included the 3 types with the biggest area fraction. The area fraction of each vegetation type within a LU, as applied in our calculations, was coupled with the number of occurring vegetation types in the LU (Table 2). The total biomass production per LU with *n* vegetation types was calculated according to equation (1).

$$\text{Biomass}_{\text{LU}}\left[\frac{\text{ton DM}}{\text{yr}}\right] = \sum_{i=1}^{n}\left(\text{Biomass}_i\left[\frac{\text{ton DM}}{\text{ha}\times\text{yr}}\right]\times \text{AF}_i \times \text{area}_{\text{LU}}\,[\text{ha}]\right) \tag{1}$$

The whole surface area of a LU cannot always be harvested, because of poor accessibility, topography or other obstacles. Based on Caron et al. [34], we assigned a reduction factor (RF) to each vegetation type (Table 1). The harvestable biomass per LU was calculated according to equation (2).

$$\text{Harvestable biomass}_{\text{LU}}\left[\frac{\text{ton DM}}{\text{yr}}\right] = \text{Biomass}_{\text{LU}}\left[\frac{\text{ton DM}}{\text{ha}\times\text{yr}}\right]\times \text{RF}_i \tag{2}$$