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Exploring bioenergy potentials of built-up areas based on NEG-EROEI indicators

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ABSTRACT

The production of bioenergy is dependent on the supply of biomass. Biomass production for bioenergy may cause large land use conversions, impact agricultural production, food prices, forest conservation, etc. The best solution is to use biomass that does not have agricultural or ecological value. Some of such unconventional sources of biomass are found within urban spaces. We employed Geographic Information System (GIS) and quantitative Life Cycle Assessment (LCA) methodologies to identify and estimate bioenergy potential of green roofs and other bioenergy options within urban areas. Net Energy Gain (NEG) and Energy Return on Energy Invested (EROEI) were used as indicators to assess the bioenergy potential of urban spaces within the Overijssel province of the Netherlands as a case study. Data regarding suitable areas were geometrically extracted from available GIS datasets, and used to estimate the biomass/bioenergy potential of different species with different yields per hectare, growing under different environmental conditions. We found that potential net-energy gain from built-up areas can meet 0.6–7.7% of the 2030 renewable energy targets of the province without conflicting with socio-ecological concerns, while also improving human habitat.

1. Introduction

The search for and discovery of renewable energy sources has increasingly gained momentum since the turn of the 21st century. This can be attributed to humanity's race against time, in its bid to slow down global warming effects, through meeting of emission reduction targets and other climate change obligations (Firrisa et al., 2014; Voinov and Filatova, 2014). Globally speaking, bioenergy is by far the most widely used renewable energy source, supplying about 10% of the world's primary energy consumption (IEA, 2013). It accounts for nearly 80% of the yearly global renewable energy production (Climate Consortium Denmark, 2011). In theory, assuming that no energy from fossil fuel is used in its production process (which is usually not the case in reality but technically possible), bioenergy can be referred to as a CO_2-neutral energy source; this is because the amount of CO_2 absorbed during photosynthesis equals the amount emitted when biomass is converted to energy (McKendry, 2002). Certainly, the continuous use of biomass, especially from forest floors, grasslands, croplands etc. for bioenergy may lead to the decline in valuable storages of soil organic carbon (Lippke et al., 2011; Holtsmark, 2012). This may lead to an annual change in carbon stocks, and the lengthening of environmental payback time of bioenergy; with carbon emissions taking longer to approach zero before becoming carbon negative (i.e. a change from carbon emissions to removal) as the ecological system establishes a new dynamic equilibrium (Sathre and Gustavsson, 2011; Böttcher et al., 2012). However, carbon is lost from soils anyway due to natural decomposition and recycling of waste materials from bioenergy production (e.g. the use of digestates from biogas produced from wastes as fertilizers) may help reduce carbon loss from soils (Arodudu et al., 2013; Hudiburg et al., 2011). Therefore we can still think of bioenergy as a major contributor to meeting emission reduction targets, and as a source of renewable energy that is a direct replacement of cheap oil (Dincer, 1999; McKendry, 2002; Read and Lermit, 2005; Zanchi et al., 2012). Despite the speculated high potentials of bioenergy for meeting future energy demands and climate change obligations, global concerns regarding its socio-environmental consequences

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remain dubious for sustainability scientists and policymakers around the world (de Fraiture et al., 2008; McLaughlin and Walsh, 1998; Muller et al., 2008; Lovett et al., 2011).

The European Union (EU) contributed about 24.3% (3326 MT out of 21,400 MT) of the 1990 global CO_2 emissions (Oberthür and Ott, 1999). As a major player in global policy making, and one of the world's worst polluters, the EU accepted responsibilities under the Kyoto emission reduction protocol treaty aimed at slowing global warming effects, by pledging a mandatory 30% reduction of its 1990 CO_2 emissions by the year 2020, and placing economic transition towards renewable energies on its political agenda (European Commission, 2009; Rosende et al., 2010). In line with achieving these objectives, the EU set mandatory renewable energy targets for all its member countries, specifically a minimum of 20% of its overall energy needs, and 10% of its total transport fuel needs from renewable energy sources by the year 2020 (European Commission, 2010). In order to meet its renewable energy targets, Netherlands as an EU Member state reviewed its renewable energy directive in 2007 based on present realities at that time. This was because, although consumption of renewable energy in the transport sector grew rapidly from 0.3% in 2006 to about 2% by the year 2007 (Rosende et al., 2010); the Netherlands national share of energy from renewable sources only grew from 2.4% in 2005 to 4% in 2010. Going by this statistics, meeting the 2020 renewable targets for the Netherlands would have been quite elusive, this forced the Government to set a new minimum target of 14% total energy from renewable sources by the year 2020 (54.5% of it from biomass sources) (European Commission, 2010; IEEP, 2010).

Despite widespread optimism and speculations on the potential role of biomass in meeting renewable energy targets globally, there are still conflicts and controversies ranging from indiscriminate land cover/use change to effects on food prices and social equity (Dale and Beyeler, 2001; Clarke and Lawn, 2008; Lovett et al., 2011; McBride et al., 2011; Bagstad and Shammin, 2012). However, the socio-ecological burdens constituted by these constraints become quite passive and harmless if bioenergy is produced from by-products, or harvested in areas that are of least ecological value or agricultural importance (Dale et al., 2013; Arodudu et al., 2013). Such sources may include: crop residues, algae, animal waste, domestic and commercial organic waste (food, fruits and vegetables), as well as biomass produced in urban or residential settings (Kapdan and Kargi, 2006; Murphy and Power, 2008; Shilton et al., 2008; University of York, 2011).

In this paper, we focused on available and prospective (unconventional) sources of biomass, whose exploitation do not conflict with the socio-ecological functions of urban landscapes. Prospective or unconventional sources of biomass are those sources that are not associated with biomass production conventionally, while available sources are those already harnessed for bioenergy production. The sources we considered in the course of this study included: rooftops, construction sites, recreational parks, seasonal leaf-fall, garden wastes and domestic organic wastes (e.g. food, vegetable, fruit wastes etc.). Aside energy production, there are many other socio-economic and environmental benefits of producing biomass within human dominated urban spaces and ecosystems, which makes it even more attractive and desireable. Examples of such socio-economic and environmental benefits include: enhancement of biodiversity by serving as habitats for birds, bees, reptiles, insects etc.; more efficient management/use of urban waste; urban flood prevention through reduction of runoffs; reduction of medication costs through improvement of air quality and human health; saving energy costs for cooling and/or heating by reducing urban heat island effects and regulating the urban climate; reduction of urban greenhouse effects through carbon sequestration functions; minimization of urban fire disasters and sometimes for aesthetic purposes (ACC, 2010; ARDEX TPO Membranes, 2009; CFFA, 2001; Peck and Kuhn, 2003; Safeguard Europe Limited, 2010).

Although urban spaces ocuppy a very small portion of the total Earth's land surface (about 3%), it remains the most populated human dominated ecosystem (houses over 50% of human beings on planet Earth), and therefore has disproportionate effects on the global environment (Millennium Ecosystem Assessment, 2005). Despite its small size in comparison to other human dominated ecosystems (e.g. arable land, managed forestlands etc.), it harbours most biomass flow activities, and uses most of the biomass produced on the Earth's land surface (Seto et al., 2011). Consequently, the search for renewable energy (especially biomass sources) should not be restricted to the remaining 97% amendable human dominated and natural ecosystems alone, but also to the less amendable, 3% urban spaces that account for more than 50% of the world's economic activities and biomass flows (Chalmin and Gaillochet, 2009). Since global population and urbanization trends is projected to continue to rise unabatedly, exploring biomass flows within urban ecosystems has the potentials to contribute significantly to future global renewable energy and carbon emission reduction targets if properly harnessed (IEA, 2013).

In this age of transition from fossil fuel to renewables, there is need to bear in mind the fact that producing bioenergy also requires energy, which at present is mostly available in form of fossil fuel. Estimation of bioenergy potentials and consequent decision making regarding the feasibility and viability of exploiting bioenergy sources ought to factor in energy used in the process of growing, collecting, drying, fermenting, and converting biomass into energy. In order to take all that into account it is improtant to use the appropriate indicators (Clarke and Lawn, 2008; Bagstad and Shammin, 2012). Within the context of assessment and comparison of bioenergy potential of different bioenergy options within built-up spaces and its significance for set renewable energy targets, we employed a combination of Geographic Information System (GIS) and quantitative Life Cycle Assessment (LCA) methodologies. The bioenergy potential of different biomass sources within urban spaces were assessed using two indicators: Net Energy Gain (NEG) and Energy Return on Energy Invested (EROEI). NEG on the one hand is an indicator of the actual amount of energy added by a particular biomass source to the set renewable energy targets, while EROEI on the other hand analyzes the energy efficiency (i.e. energy gained per unit energy invested) of exploiting a particular biomass source for bioenergy production (Berglund and Borjesson, 2006; Correia et al., 2010).

Specifically, we compared rooftop biomass production with rooftop solar photovoltaic panels because of their rise in popularity, and anticipated competition between them (as alternative rooftop renewable energy technologies) in the emerging green era (Municipality of Enschede, 2010). The comparison was done in terms of their energy potentials (using NEG and EROEI) and considering the environmental benefits. The case study area chosen for this research was the Overijssel province of the Netherlands (Fig. 1). The Netherlands because it is one of the most urbanized countries in the world, and the Overijssel province because it can be considered as a model of the whole country, since the mix of its land use types is close to what is estimated for the country as a whole (built-up – 10% in Overijssel vs. 14% in NL, agriculture – 79.8% vs. 74.3%, and forest – 10.2% vs. 12.1%) (CORINE, 2006). This makes the outcome of this study inferable for the whole country. In line with the new minimum target set by the Government of the Netherlands, in order to meet its EU Kyoto Protocol renewable energy obligations, the role of biomass in Overijssel Province's energy-mix as extrapolated from PGG's (Platform Groene Grondstoffen) estimate by the year 2030 is expected to rise to 60 PJ (Rabou et al., 2008). This study