Journal of Cleaner Production 102 (2015) 213–225

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Estimating the potential of roadside vegetation for bioenergy production

Alexey Voinov [a, *], Oludunsin Arodudu [b], Iris van Duren [a], Javier Morales [a], Ling Qin [a]

[a] ITC, University of Twente, Hengelosestraat 99, Enschede, Netherlands
[b] Leibniz Centre for Agricultural Landscape Research (ZALF), Eberswalder Straße 84, 15374 Müncheberg, Germany

ARTICLE INFO

Article history:
Received 26 December 2014
Received in revised form
27 March 2015
Accepted 12 April 2015
Available online 22 April 2015

Keywords:
LCA
Willow
Grass
Rotation cropping
Efficiency
EROEI

ABSTRACT

The Netherlands, like other European Union countries, is under intense pressure to increase its national share of energy from renewable sources in accordance with 2020 Kyoto Protocol obligations. Bioenergy in this context is especially interesting because it can replace liquid fuels so much in demand for transportation. In Europe, due to high population density, and intensive use of limited land resources, sources of biomass are quite limited. This study examines the potential of road verge for biomass production. In this case there is no conflict with agricultural production – “food for fuel” conflict – and very little problems with natural conservation, since we are focusing on already disturbed and heavily used and polluted areas. The road verge is also easily accessible and in most cases already has to be maintained and cultivated. We use GIS (Geographical information system) to identify the total area of land along the roads in the Netherlands that can potentially be used for bioenergy purposes. We then consider the opportunities and constraints of cultivating various types of biomass, mainly focusing on grasses and willow, short rotation coppice, as biomass sources on the road verge. Based on that, we distinguish between areas that are unavailable due to safety requirements, areas that are conditionally available provided that current regulations are revised and areas that are already unconditionally available. We assess the entire production chain in terms of Energy Return on Energy Invested (EROEI), and consider various combinations of grass and willow operations for bioenergy production. Looking at several roads in Eastern Overijssel, we have estimated that there is approximately 4.24–4.68 ha/km of road verge conditionally available along highways, A-roads, and some 0.80–2.67 ha/km available along local roads, N-roads. However, only 1.02–1.62 ha/km and 0.37–0.80 ha/km of A and N roads respectively are available unconditionally. The EROEI for some scenarios of both grass-based and willow-based production were quite high, 15–42, making such use of road verge quite promising.

1. Introduction

At present, coal and gas account for more than 50% of EU's electricity supply and will remain an important part of the energy mix (European Commission, 2007). However, the accelerating process of global warming, growing demand for energy, depletion of cheap fossil fuel supplies and environmental concerns are raising the significance of renewable energy (Luque et al., 2008). Over sixty percent of renewable energy in the Netherlands comes from biomass (Central Bureau of Statistics, 2009), which makes it the most popular renewable energy source in this country. Besides reducing greenhouse gases (GHG) emissions, biomass derived fuels are especially attractive because they can be easily stored and used as non-variable energy; same cannot be said of solar and wind power – the other most popular renewable energy sources (McKendry, 2002a; Demirbaş, 2005; Ölz et al., 2007).

The European Council in March 2007 endorsed a mandatory target of 20% share of energy from renewable sources in overall Community's energy consumption by 2020 (European Parliament and European Council, 2009). For the Netherlands, for example, the percentage of renewable energy in final energy consumption has to be increased from 3.4% in 2008 to targeted 14% in 2020 (a deficit of 10.6%) (Europe's Energy Portal, 2010). Under this

* Corresponding author. Tel.: +31 063 365 7124.
E-mail addresses: a.a.voinov@utwente.nl, aavoinov@gmail.com (A. Voinov), oludunsinarodudu@gmail.com, Oludunsin.Arodudu@zalf.de (O. Arodudu), vanduren@utwente.nl (I. van Duren), j.morales@utwente.nl (J. Morales), qinling2003@gmail.com (L. Qin).

http://dx.doi.org/10.1016/j.jclepro.2015.04.034
0959-6526/

pressure, the Netherlands is expected to fully embrace every opportunity to develop its bioenergy potential. This may include wood and wood wastes from forests and industries, sewage sludge from wastewater treatment plants, organic waste from households, oils and fats from food industry, manure from dairy farms and crops specifically grown for bio-energy such as rapeseed (*Brassica napus*), willow (*Salix*), *Miscanthus* (Basu, 2010), etc.

Until recently, most energy crop cultivation was done on arable land. However, low energy efficiency of energy crops (Firrisa et al., 2013; van Duren et al., 2015) and lack of free arable land are major limitations for the cultivation of these crops in Europe, especially in the more densely populated and developed countries like the Netherlands. In general, for reasons of food security, it is preferable to leave agricultural land available for food production and find other sources of biomass for bioenergy production (Londo, 2002; Faaij et al., 1998). Arodudu et al. (2013, 2014) argue that bioenergy production should be mainly focused on the waste flows (urban waste, agricultural crop residue, manure, etc. as well as biomass produced on waste land such as construction lots, eroded lands, etc.) and that only then it can be conducted with sufficiently high efficiency. In this regards, the land along the roads appears as a kind of wasteland and is a promising area where biomass can be harvested for bioenergy needs with little or no conflict with other potential uses. In fact, we argue that producing biomass along the roads can be promising and beneficial from a variety of perspectives, including economy, traffic safety, esthetics, etc. Moreover, these areas are easily accessible and are directly linked to major transportation routes, which makes its cultivation and delivery of products more efficient.

The Netherlands ranks among the top 10 high road density countries in the world (Encyclopedia of the Nations, 2007). With a total of more than 137,000 km of roads, it has an average road density of 5 km per km^2 of surface area (Visser, 2010). This indicates that there might be large areas of available road verge in this country. Easy access to this land is another advantage cutting the cost of harvesting and transportation of biomass. Haines-Young et al. (2000), Truscott et al. (2005) proved that vehicular activities can elevate the nitrogen concentration of road verges. This can reduce the fertilizer requirements for crop growth on the road verge. Huang's study (1987), furthermore confirmed that planting of shrubs in the median and road verge could stop errant vehicles in case of accident and absorb the impact, without doing much damage to the car. Also, the shrub barrier could reduce traffic noise and headlight glare (van der Heijden and Martens, 1982), contributing to sound environment and road safety. As with other biomass for bioenergy production, utilizing roadside biomass will provide for carbon sequestration, will encourage technological development and innovation, and offer opportunities for employment and regional development (Vollebergh, 1997; Volk et al., 2004). In this study, we have been mostly focusing on the Easternmost part of the Overijssel province in Netherlands, however our analysis and methods are quite general, and could be easily applied elsewhere and scaled up to the whole of Netherlands and beyond.

Road verges are maintained as transition zones between different land uses and in most cases appear as strips on both sides of the road. Road verges are mown to ensure visibility along roads in case of an accident, to enhance visibility of road signs and constructions (e.g. electricity boxes), to get rid of excessive nutrients in soils and for esthetic and maintenance purposes. For example, in Overijssel, the mowing policy recommends that road verges be mown twice a year. A maximum of 20 cm height of grass is allowed at the end of the 26th and 45th weeks (mowing weeks). The mowing exercise is preferably carried out in the evening to reduce possible negative effects on transportation (Rijkswaterstaat, 2008). In the Netherlands, municipal authorities are responsible for more than 90% of the Dutch roads while the national government is only responsible for 4% (Central Bureau of Statistics (2011)). The 4% managed by the national government include all the motorways (A-roads) and a few national highways (N-roads); these are mown more regularly than other roads. Vegetation along these roads is currently managed by Rijkswaterstaat (Public Works Department), the executive body of the Ministry of Transport and Water (A. Reuver, personal communication, 7 October 2010). According to the “Overview of the vegetation along National Road” (Rijkswaterstaat, 2008), management of verge grasses involves choosing between different species types and different manual or automated methods for pruning, mowing, chipping and cutting. In reality, grass is the main target vegetation and a combined cutting and suction method is used to mow verge grasses. The Dutch environmental management act (2004) states that the removed grass must be delivered to and processed by a waste processor which has a valid license. Usually, the grass is either deposited to waste landfill or composted (J. W. Slijkhuis, personal communication, 5 November 2010; H. Nieuwenhuis, personal communication, 19 January 2011). However in all cases these operations are treated as an expense that should be preferably minimized (Van Strien et al, 2005). This attitude should be changed if the harvested biomass becomes treated as a valuable resource for bio-energy production.

Maximization of biomass cultivation in road verges requires choosing the most suitable crop species for the purpose, which would imply such characteristics as (Ponton, 2009):

- Ability to grow and reproduce at a very fast rate
- Ability to produce high yield
- Perennial nature
- Having little or no need for annual ploughing once planted
- Adaptability to marginal land
- Having minimal fertilizer requirement.

Some of these requirements are exactly opposite to the current practices of maintenance of the road verges. Since large trees along the road is a safety concern, feasible energy crops for road verges are restricted to small trees, shrubs and grasses (Faaij et al., 1998). Based on these reasons, energy crops suitable for road verge include:

- Short rotation woody crops, e.g. willow and poplar (Fischer et al., 2010; Zuwala, 2012; González-García et al., 2014)
- Perennial grasses, e.g. *Miscanthus*, switchgrass (*Panicum virgatum*), reed canary grass (*Phalaris arundinacea*) (Huisman, 2003).

Since perennial grasses have been largely treated before (e.g. Arodudu et al., 2013) in this study, where possible, we will focus more on willow short rotation coppice (SRC) as the biomass feedstock. Local clones of willow SRC have been well developed and observed in Europe. However, in the Dutch context, few trials have been carried out to study the biomass production of local clones (Kuiper, 2003; Bussel, 2006). Their studies suggest that for the Netherlands, productive local clones of willow SRC include Zw. Driebast (*Salix triandra*), Het Goor (*Salix alba*), Belders (*Salix alba*), Tora (*Salix viminalis x Salix schwerinnii*), Bjorn (*Salix viminalis x S. schwerinnii*), Black Spaniard (*S. triandra*), Loden (*S. triandra*) and Jorr (*Salix viminalis*). Despite the fact that certain clones produce more biomass than the others, it is recommended to mix different willow species and varieties for pest and disease prevention (Ramstedt, 1999; Londo et al., 2004).

Willow is well adjusted to the Dutch climate conditions (Gigler, 1999; Londo, 2002) and has a long history of cultivation in the Netherlands (Schepers et al., 1992). The biomass produced with willow SRC is potentially high. In Dutch conditions the productivity