



More solar farms or more bioenergy crops? Mapping and assessing potential land-use conflicts among renewable energy technologies in eastern Ontario, Canada



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ABSTRACT

Renewable energy systems are land intensive at local scales. Appropriate siting can help to mitigate the extent to which RE implementation compromises existing land-based economies and ecosystem services. As such, an integrated approach to land-use and energy planning, or land-energy planning, can help to ensure that RE technologies can be intensively implemented while minimizing negative impacts. Requisite to the development of such plans is (a) estimating total land availability on which technologies capable of supporting RE production functions after considering various socio-political, economic and ecological constraints; (b) identifying potential sources of conflict among multiple RE options; and (c) assessing the trade-offs associated with allocating this land toward one energy system and not another. The purpose of this paper is to address these issues at a regional-scale in the context of intensifying solar and bioenergy production. A methodology is developed from which to (a) locate land that is most likely to support both dedicated bioenergy feedstock and solar photovoltaic (PV) production in an area; (b) identify the point at which mutual land must be used in order to achieve their market potential; and (c) estimate and evaluate trade-offs associated with choosing one system over another at mutual land, in this case total potential electricity production and energy density (MWh/ha), in the context of regional energy needs and existing renewable electricity assets. Mutual land is located through GIS-based land-suitability modeling and map overlay techniques. Comparisons of production potential and land-use efficiency are made for a range of fixed-axis solar PV technologies against two short rotation woody coppice systems (poplar; willow) and two perennial grass systems (switch grass; miscanthus). Rooftop space is found to be sufficient to provide the land area required for solar PV to meet mid-day regional electricity requirements. If all mutual land in the region were allocated toward dedicated bioenergy crops instead of solar PV systems, (a) a 100 per cent renewable electricity system is within the limits of technical feasibility, even in the absence of large-scale storage systems; and/or (b) bioelectricity systems could provide back-up electricity for rooftop solar PV systems. The policy implications of these findings are discussed.

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Introduction

The capacity to achieve a 100 per cent renewable energy (RE) system within any given area is limited by the availability of suitable land and the extent to which such land can be (re)allocated toward RE production without compromising existing land-based economic activities or ecosystem services (Palmas et al., 2014;

Schmidt et al., 2012; Stoeglehner, Neimetz, & Kettl, 2011; Stremke, 2010). These technical challenges are underpinned by social value differences. Indeed, decisions over how to allocate local land for the purpose of RE production are at the center of the political debate surrounding renewable energy (Ohl & Eichhorn, 2010; Walker, 1995). In this context, the political-economic and ecological sustainability of RE development requires appropriate system siting and the integrated management of an area's land and energy resources.

Among the many challenges and uncertainties underpinning RE technology implementation and resource management is the

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extent to which different RE technologies prefer and compete for the same type of land (Denholm & Margolis, 2008; De Vries, van Vuuren, & Hoogwijk, 2007); what is referred to henceforth as 'mutual land'. In some cases, competition for limited land can be productive and synergistic. Multiple technologies can be integrated or co-located at a given site in order to liberate more than a single source of RE from the same land base (Leone, 2011; Li, Stadler, & Ramakumar, 2011; Nema, Nema, & Rangnekar, 2009; Shafuallah, Amanullah, Shawkat Ali, Jarvis, & Wolfs, 2012). An example might be solar photovoltaic (PV) systems installed on a wind turbine or a biogas facility, or dedicated bioenergy crops grown among a wind farm. RE systems can also be incorporated into shared land-use schemes involving energy and non-energy activities. Integration of solar energy systems into the built environment (De Schepper, Van Passel, Manca, & Thewys, 2012; Singh, 2012; Wiginton, Nguyen, & Pearce, 2010) or solar and wind generating units into traditional farming activities (Dorpaz et al., 2011; Marrou, Wery, Dufour, & Dupraz, 2013) are the most prevalent examples of this land-energy strategy. In other cases, however, production potentials are not always cumulative because infrastructure and energy production activities cannot co-inhabit the same space (Biberacher, Gadocha, Gluhak, Dorfinger, & Zocher, 2008; De Vries et al., 2007). As such, competition for limited land results in a trade-off scenario as the allocation of mutual land toward one RE option might reduce or preclude the production potential from another option.

Ground-mount solar energy facilities and dedicated bioenergy feedstock systems are exemplary here. Dedicated bioenergy feedstock production is integral to the success of bioenergy development strategies (Sims, Hastings, Schlamadinger, Taylor, & Smith, 2006). In order to avoid conflict between food and fuel production it is often suggested that dedicated bioenergy crops ought to be grown only on 'marginally' productive land, or at least on idled or abandoned agricultural land (Fargione, Plevin, & Hill, 2010; Gelfand et al., 2013; Zumkehr & Campbell, 2013). Early observations of development patterns show that ground-mounted solar photovoltaic (PV) systems are also being deployed on marginally productive and idled agricultural land (Elkind, 2011; Goodrich, James, & Woodhouse, 2012). The panel area of a solar PV system is typically 30–40% of the total PV farm surface and casts shadows (Dijkman & Benders, 2010) which prohibits major biomass harvesting activities (although production of specialty shade-tolerant and less intensive crop types is still possible in some cases; see Dorpaz et al., 2011; Marrou et al., 2013). This inherent system design quality brings large-scale solar PV systems in direct competition with dedicated bioenergy crops for land and sunlight. On one hand, loss of even marginal bio-productive land for the purpose of recovering intermittent solar resources might have serious consequences on the capacity of an area to achieve energy sustainability. Studies have shown that meeting ambitious RE production targets, and especially 'regional energy autarky', requires a substantial increase in the use of forest and agricultural resources, and especially dedicated bioenergy crops, for the provision of base-load or dispatchable heat and power (Schmidt et al., 2012), not to mention renewable fuels and chemicals (Sims et al., 2006). On the other hand, the amount of land required for utility scale solar PV systems is often claimed to be insignificant, especially since land supporting ground-mount solar PV systems can be reverted to its original use upon decommissioning (CANSIA, No date; Denholm & Margolis, 2008).

The concepts and techniques with which solar and bioenergy resource and land suitability assessments are conducted have undergone significant improvements in recent years. Rather than leaving 'technically suitable area' as an aggregate category, Dawson and Shlyter (2012) map sites of varying degrees of suitability, where higher and lower suitability are based on factors such as access

roads and ecological conditions. Calvert, Pearce, and Mabee (2013) review recent efforts at combining geophysical, cartographic, and techno-economic modeling in order to locate preferred areas for system siting based on ecological and socio-economic factors. Aydin, Kentel, and Duzgun (2013) use fuzzy set theory and multi-criteria decision analysis (MCDA) in order to develop a spatial decision support system that balances multiple trade-offs. Wanderer and Herle (2014) add user preferences into an MCDA in order to create a spatial decision support system for solar energy system siting. Efforts are currently underway to design spatial decision support systems that integrate all potential renewable resources in a given area and, most importantly, to assess synergies and trade-offs for the purpose of maximizing spatial efficiency (Palmas et al., 2014). More comprehensive reviews can be found in Calvert et al. (2013) and Resch et al. (2014).

These improvements notwithstanding, questions related to potential land-use trade-offs remain woefully understudied (Palmas et al., 2014). Many studies which locate and quantify RE production potentials in an area, including those reviewed above, do not examine the possibilities or impacts of competition over limited land inputs (see also De Vries et al., 2007; Lopez, Roberts, Heimiller, Blair, & Porro, 2012; Milbrandt, Heimiller, Perry, & Field, 2014; Yue & Wang, 2006). In other cases, competition over land is not considered as analysts assume that land will be allocated toward technologies that recover the highest quality resource at the given site (e.g., Biberacher et al., 2008; Dominguez, Casals, & Pascua, 2007). Similarly, Dijkman and Benders (2010) compare energy resources at a given site based only on their energy density. In order to plan and engineer a sustainable energy system, however, energy resources must be evaluated not by *quantity* alone but also by the *form* and *timing* of energy resources and how all three properties relate to regional energy demand profiles (Blaschke et al., 2013; Feder, 2004; Nogueira, Moreira, Schuchardt, & Goldemberg, 2013).

In order to bridge these analytical gaps, this paper develops and applies a GIS-based method to (a) locate land that is most likely to support both biomass and solar PV production in an area; (b) estimate individual and collective production potentials using the resources that might be recovered from these sites; (c) identify the point at which mutual land must be utilized in order to reach the market potential for each respective resource; and (d) estimate and interpret trade-offs associated with choosing one system over another at mutual land, in this case total potential electricity production and energy density (MWh/ha), in the context of regional energy needs and existing renewable electricity assets. The geographic area chosen for this study is the eastern region of the Canadian province of Ontario due to its mixed land-covers and land-uses as well as favorable geography for both solar and bioenergy development (Fig. 1). Building on previous research in the study area (Calvert & Mabee, 2014; Mabee & Mirck, 2011; Nguyen & Pearce, 2010; Wiginton et al., 2010), mutual land is located through GIS-based land-suitability modeling and map overlay techniques. Spreadsheet-based linear models are used to compare the estimated energy outputs from a range of fixed-axis solar PV technologies against two short rotation woody coppice systems (poplar; willow) and two perennial grass systems (switch grass; miscanthus). The analysis assumes the goal of local energy self-sufficiency and therefore contributes to understanding the potential opportunities, barriers, and risks to the intensive development of local RE resources.

The rest of the paper is broken down into four parts. In the following section we detail the method by which we identify mutual lands and assess land allocation trade-offs in our study region. In the third section, our results are summarized according to two questions: where might solar and bioenergy systems

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