An Agent-based Model of Voluntary Incentive Programs for Sustainable Biofuel Development

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1 Research Purpose

Future demand for energy is expected to increase well beyond growth in proven fossil fuel reserves. Reliance on diminishing reserves will also amplify climate change. Renewable energy makes it possible for society to overcome these two interrelated problems. Second-generation bioenergy from woody biomass offers a promising renewable alternative for regions with ready access to forests, especially those incapable of fully harnessing wind, hydro, or solar technologies. However, the success of bioenergy greatly depends on the proper management of biomass harvesting activity to ensure bioenergy remains a sustainable renewable alternative.

Our research uses ForestSim, an agent-based model (ABM) of non-industrial private forest (NIPF) owners, to evaluate voluntary incentive programs (VIPs) and their ability to produce sustainable bioenergy outcomes. Under a VIP landowners receive a financial incentive for compliance with program guidelines. We compare traditional financial incentivization mechanisms to a newly emerging VIP scheme known as an agglomeration bonus [10]. These programs provide additional incentives based upon participation rate as an incentive for neighbors to recruit others. Model results show that agglomeration bonuses allow for better centralized management of forest resources and produce more sustainable outcomes.

2 Background

Previous research into NIPF owners has started with work in economics in an attempt to determine willingness-to-harvest with regards to woody biomass supply and the price points involved [1, 4]. Recently there has been growing interest in the use of ABMs in the context of CHANS [2]. With regards to bioenergy, ABMs have been used to evaluate factors affecting crop adoption and decision practices [7, 11, 13]. These ABMs exist within a broader research space that focuses on agriculture [5, 12], generalized land-use change [3, 19, 15], and policy analysis [20]. The field of forestry is starting also starting to see the adoption of ABMs being used. Previous work has focused on forest management [6] along with deforestation and reforestation cycles [18]. Finally, an ABM developed to model harvest decisions by small scale forest owners [16]. Our work is similar to the work of Leahy et al., but expands upon it by evaluating biomass production in the context of sustainability.

3 Model Design

ForestSim is a CHANS model of forest growth and harvest cycles in the Western Upper Peninsula (UP) of Michigan, USA. The Western UP is a heavily forested region with approximately 90% of the forest ownership divided between state and federal public forests, large-tract private forests for timber harvesting, and NIPF owners [17, 21]. The region also has high energy costs due to reliance upon generating stations in neighboring states which makes it an ideal candidate for local power generation using biofuel. Due to the region's forest ownership structure, NIPF owners are expected to have a significant impact upon the biomass available for generation.

The environment is based upon even-aged forest stands wherein each pixel represents approximately one hundred and twenty by one hundred and twenty meters. Stands are allocated a forest type based upon data from the National Land Cover Database 2011 (NLCD) [14]. After forest types are assigned, a grid of Perlin noise is generated and values are used allocate the average diameter at breast height (d.b.h.) for the trees in the stand. Forestry stocking tables are then used to determine the number of trees in the stand, with overall stocking values for the region corresponding to observed conditions [21]. Agents will use the stand values along with forest management plans to determine the best time to harvest.

NIPF agents are embedded within the landscape using an overlaid, digitized parcel boundary map to assign agents to all properties with a minimum of ten forested acres. Decision-making schemes were developed based upon semi-structured interviews with local forest owners and a general survey of NIPF owners in the UP [17, 8]. Agents are assigned a schema that is categorized as either rational economic decision making, or optimizing for ecosystem services. The economic decision making scheme contains rules that have the agent optimize for profits from their land. In contrast, the ecosystem services rules have the agent optimize for intangible uses of their land. Logistic regression was used to generate probabilities of adopting alternative management activities based on correlations with key forest owner attributes socioeconomic status, residency, attitudes toward alternative forest management options, and so forth. Agents use their assigned schema to determine whether and how to participate in a simulated market for biomass under alternative VIP incentivization scenarios.

When the model is running, the forest model is subjected to a growth cycle that is based upon typical trees for representational trees in the region (e.g. *Acer Rubrum*, *Pinus Strobus*, etc.) [9]. Natural thinning is also taken into account by the model and overstocked tree stands will be subjected to a randomized rate of die off. To allow for better performance at run time, regrowth and stocking model is done through parallel processing by segmenting data structures and running them on separate threads, scaled to the number of cores available.

During the simulation, agents use the current state of their forest stands and assigned decision-making schema to make a "harvest, no harvest" decision. When an agent makes a harvest decision, biomass is harvested from the forest in accordance with standard forestry practices [22]. Harvested biomass is then allocated for use by a biorefinery as appropriate and the stand is reseeded. After all agents have had an opportunity to run, the forest stands are updated to reflect any growth that may have occurred.

4 Conclusion

ForestSim makes it possible to explore how alternative VIP incentivization schemes impact potentially competing dimensions of sustainable bioenergy. To do this ForestSim compares the simulated results of alternative schemes as part of a multidimensional sustainability scorecard. Consistent biomass volume results in a high score from the standpoint of bioenergy plants. Public access to forest lands results in a high score for the social dimension. Using this scorecard, ForestSim demonstrates that VIP incentivization with an agglomeration bonus produces optimal sustainability outcomes when compared to no incentivization and alternative VIP schemes. Ultimately, ForestSim may allow us to develop a generalized framework to evaluate policy options in other heavily forested regions of the United States currently underutilizing available bioenergy potential.

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