Getting the right spatial mix: optimising the size, type and location of renewable energy facilities

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Abstract
Supply and demand modelling for facilities that require land related resources need to take into account the spatial distribution the resource. Using a Scottish case study, this short paper presents a method extension that to the p-median problem that identifies optimal locations and combinations of different types and sizes of land based biomass renewable energy facilities. Whilst there are many decision models and tools for siting other types of renewable energy (solar, wind, hydro), supply and demand tools decisions around land based biomass renewable energy do not exist. The p-median extension and optimisation allows the trade-offs between different decisions around land, for example related to agriculture, food security, biodiversity, flood risks, to be evaluated. In the context of Scotland, this methodology supports the many policy agendas around community initiatives, agri-renewables, circular economy, supply chains, local food agendas, carbon sequestration and green infrastructures.

Keywords
Supply and demand; renewable energy; biomass; land use

I INTRODUCTION

In much facility location analysis, the resources needed by a facility at potential locations are assumed to exist or that their supply is trivial. Much greater focus is given to identifying potential facility locations that meet the spatial distribution of demand, and where facility resources are considered these are typically done so from the perspective of transportation overheads, infrastructure and road networks.

Land based and biomass Renewable Energy (RE) facilities typically require consideration of the spatiality of supply as well as demand. The facilities require biomass feedstocks (inputs) that are usually derived from animal manures, crop residues, forestry / timber production. In the context of RE, as well as climate change mitigation, the objectives should also include net energy gains and minimal carbon impacts. Thus it is important to consider the resource catchments needed to supply RE facilities, rather than subsume financial transportation costs into site evaluation.

Recent work has extended the p-median problem to be able to handle the resource catchments needed to support facilities at potential locations in location allocation analyses (Comber et al., 2015) as well as demand. It has been further extended to locate multiple types of facility and to determine optima locations for pre-defined groups of different sized facilities which have

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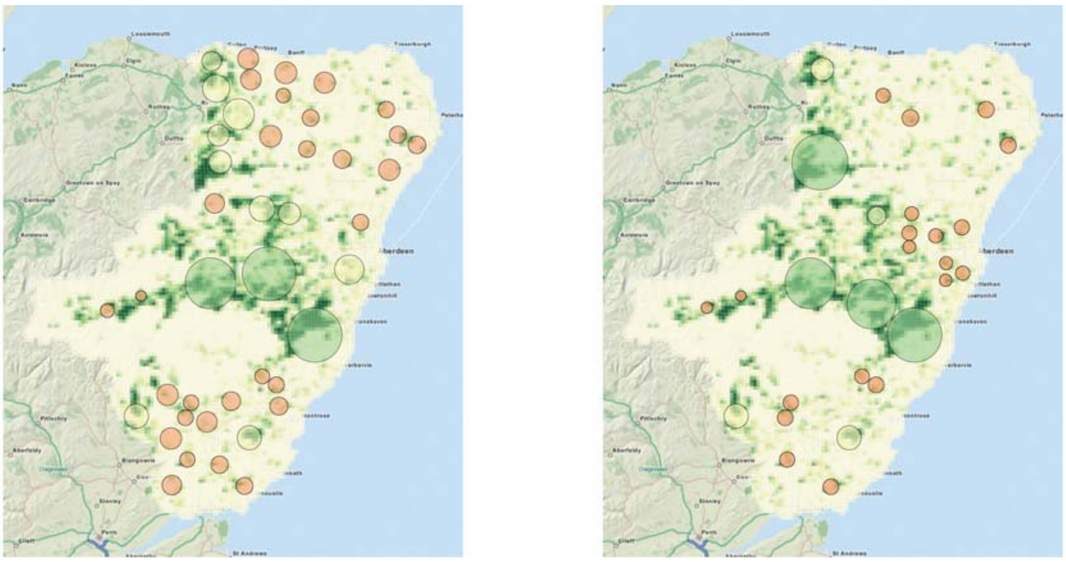
essentially imposed an optimal packing dimension onto the p-median problem (Comber et al, 2016).

This paper further extends these developments to the p-median problem to identify the optimal mix of facilities. The problem remains a packing problem but the extension seeks to identify the optimal mix as well as spatial arrangement of facilitates. The objective function remains the same (to minimise distances to demand and to forbid resource catchment overlap), but the search space is extended from sets of predefined facilities (e.g. 3 large, 10 medium and 20 small) to identifying the best combination of facilities for the study area being considered. The context for this extension is the need to accommodate competing land use demands, for example food security, flood defence or biodiversity.

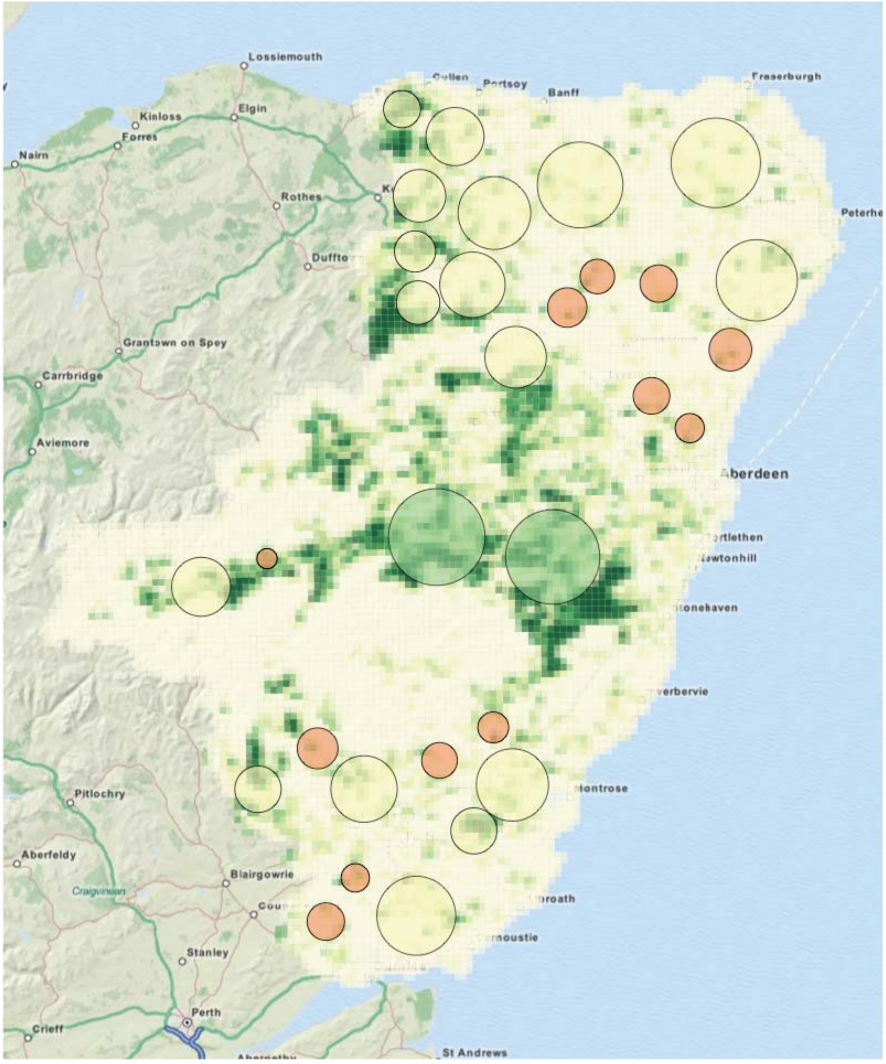
The spatial accuracy context of this work relates to the sensitivity of location–allocation algorithms and their associated evaluation functions to spatial consideration of resource catchments.

II INITIAL RESULTS

Consider the location, catchments and distribution of potential biomass RE facilities in Figure 1a along with the underlying spatial distribution of biomass from forestry. This shows an optimal arrangement for 3 Combined Heat and Power (CHP) units, with different capacities (energy outputs) and different input requirements for a case study in north east Scotland. The total potential amount of annual biomass from forestry is 1,895,677 t yr^{-1} and the mix of 3 20MW CHPs, 10 4MW CHPs and 30 1MW CHPs equates to a biomass feedstocks of 650,000 t yr^{-1} or 34% of the available supply and the production of 130MW.



a) b)



c)

Figure 1: Optimal spatial arrangements for sets of biomass CHP facilities with the same overall generating capacity a) for a predefined mix of capacities, b) for a different mix of capacities, and c) the optimal, optimal mix

The question addressed by this paper is whether a different spatial arrangement of different mix of facilities sizes, such as suggested in Figure 1b, would achieve the same energy generating capacity output but use the biomass resource more efficiently, ie with less energy expended on transportation.

To achieve this, the algorithm has been further extended to search through *all possible combinations* of the 3 types of facility to achieve the same capacity. The optimal spatial configuration is shown in Figure 1c and suggests that the following combination of CHPs to achieve 120MW and minimising resource transportation costs is as follows: 2 x 20MW, 17 x 4MW and 12 x 1MW.

III DISCUSSION

There are a number of critical methodological issues and spatial accuracy considerations related to this work.

In terms of method development, this paper describes a further extension to the algorithm, first described in Comber et al., (2015), which accommodates the spatial distribution of the resources needed to supply the RE facility and satisfy the energy demand at any given location. It extended the p-median problem to prevent facility locations with overlapping resource catchments from being selected. The first extension, described in Comber et al (2016), supported the allocation of a predefined number of different sizes of facility (3 small, 2 medium and 5 large, for example). However, this was based on a packing problem heuristic, which identified the location for n_1 largest facilities first, then the n_2 medium sized facilities and finally the n_2 largest facilities.

The extension reported here identifies the optimal mix of different sized facilities and considers all sizes of facility together. In each case the evaluation function was to minimise population distance to the resource supply. In this case this was done through a deterministic search. The resource catchment for each size of facility at each potential location was pre-computed and then the 'best' combination of n_1 20MW n_2 4MW and n_3 1MW facilities was determined. This was possible because of the relatively small number of potential sets of each $\{n_1, n_2, n_3\}$ combination. However for a larger study area, the number of potential combinations of facilities may preclude a deterministic search suggesting the need for search heuristics such genetic algorithms, or perhaps more pertinently to this type of study grouping genetic algorithms (Falkenauer, 1998) which have been shown to more effectively identify optimal groups sets of facilities than standard genetic algorithm (Comber et al., 2011).

In terms of the accuracy of the results generated by this method, they are subject to the usual considerations in any location-allocation application, namely the extent to which the evaluation function matches the problem specification and the reliability of the input data.

Here, optimality (the evaluation function) was determined by the degree to which potential facility locations minimised distance to population centres (ie they were not weighted by the population at those centres). There are two obvious areas to refine this function: first, to include population, for example, to generate demand weighted distances, reflecting differences in the spatial distribution of demand. However, this study used Output Area centroids as the demand locations. These are the smallest areal unit over which UK census data are reported (Martin, 1998) and were constructed such that they contain broadly an equal number of people (~350). Perhaps more interestingly data describing more nuanced measures of demand for RE could be used, such as the Call Credit Green and Ethical geo-demographic classification of the UK. Second, the object of any planning and policy in relation to renewable energy should be to minimise net carbon costs and maximise net carbon gains. This is rarely the case in the RE literature, which much effort seems to be spent on modelling transport costs in RE facility location decisions (eg Sultana and Kumar, 2012; Panichelli and Gnansounou, 2008; Sliz-Szkliniarza and Vogt, 2012). This is plainly daft as it renders the result of any analysis meaningless if there are radical changes in the price of oil. The optimal selection of suitable sites for RE facilities using these kinds of paradigms is critical if land based biomass resources are to be efficiently and maximally used to support a diverse range of objectives including food and energy security as well as environmental protection.

In summary the current method allows locations for multiple sizes of facilities to be evaluated. The algorithm could be applied to select optimal sites for multiple types as well as sizes of renewable energy facilities: CHPs, anaerobic digesters, gasification units etc. This would support truly holistic, strategic regional planning and well as community level energy initiatives. The latter are increasingly being supported in Scotland (eg http://www.localenergyscotland.org/cares).

The next steps in this work are multiple. First, to consider network distances to resources rather Euclidean distances, to explore how asymmetric, amorphous catchments may be incorporated, allowing them to fill the available space between already selected sites and to consider different combinations of feedstocks – domestic, forest and agricultural and household wastes – would could be used to refine the results of the analysis. Second, to develop methods for searching more efficiently, for example through heuristics, the use of *net* *energy gain* as an evaluation function, the spatial distribution of demand that is receptive to RE and whether network distances to resources improve the outcomes.

This paper presents a framework for doing this: compute all possible combinations of RE supply, identify the resource catchments needed for each of individual facility at each potential location, and then develop a search through this very highly dimensional decision space. Future work will consider the development and application of evaluation functions that minimise the distances (and net energy and carbon costs) that resources have to travel to supply the facility as well as more nuanced measures of potential demand.

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