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Title: Energyscapes: linking the energy system and ecosystem services in real landscapes

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Abstract: The drive for sustainable energy production is leading to increased deployment of land based renewables. Although there is public support, in principle, for renewable energy at a national level, major resistance to renewable energy technologies often occurs at a local level. Within this context, it can be useful to consider the "energyscape" which we initially define as the complex spatial and temporal combination of the supply, demand and infrastructure for energy within a landscape. By starting with a consideration of the energyscape, we can then consider the positive and negative interactions with other ecosystem services within a particular landscape. This requires a multi-disciplinary systems-approach that uses existing knowledge of landscapes, energy options, and the different perspectives of stakeholders. The approach is examined in relation to pilot case-study comprising a 155 km² catchment in Bedfordshire, England.

Energyscapes Highlights

- Novel approach setting the whole energy system in a real landscape context.
- Describes a method that can be used to clarify how different groups view biomass deployment
- Uses different stakeholders perspectives of how the landscape interacts with all ecosystem services and how modifications of the energy system will influence them.
- Demonstrated for Marston Vale, a sub catchment of the Great Ouse in eastern England.
- Applicable across spatial scales and geographic zones.

1 **Energyscapes: linking the energy system and ecosystem services in real landscapes**

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32 **Abstract**

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34 renewables. Although there is public support, in principle, for renewable energy at a national level,
35 major resistance to renewable energy technologies often occurs at a local level. Within this context, it
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37 temporal combination of the supply, demand and infrastructure for energy within a landscape. By
38 starting with a consideration of the energyscape, we can then consider the positive and negative
39 interactions with other ecosystem services within a particular landscape. This requires a multi-
40 disciplinary systems-approach that uses existing knowledge of landscapes, energy options, and the
41 different perspectives of stakeholders. The approach is examined in relation to pilot case-study
42 comprising a 155 km² catchment in Bedfordshire, England.

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44

45 **1. Introduction**

46 Human use of energy is the major driver of anthropogenic climate change and challenges our ability
47 to live sustainably [1] and [2]. However energy and climate change are not the only issues that
48 determine sustainability, as we must also maintain and ideally enhance the ecological and social
49 systems on which we depend. The benefits (and dis-benefits) that we gain from ecological systems
50 are termed ecosystem services [3], [4], [5] and [6] and wise stewardship of the Earth requires us to
51 understand how changes in energy demand, production and supply affect such services. For some
52 ecosystem services, such as the provision of food, the interactions can be examined using established
53 spatial models. By contrast it has proved to be less easy to quantify the impact on the cultural
54 services within a given area, and it is often these issues that form the focus of objections to renewable
55 energy development.

56 The need for a low carbon energy system is seen as an essential part of the solution to anthropogenic
57 climate change and is recognized by Governments (e.g. [7]). However, there is growing recognition
58 that the deployment of low carbon energy technologies may have substantial impacts on a range of
59 ecosystem services in the locality where they are deployed [8]. Most land based renewables (LBR),
60 including bioenergy, have a lower energy content than fossil fuels and consequently have much larger
61 spatial footprints. This need for increased land area and more efficient use has led to a growing
62 interest in more distributed approaches to energy production and distribution as a way to reduce
63 carbon emissions [9]. In addition human population growth and increasing per capita consumption
64 places further demands on land to provide food, fiber, and potable water; space for accommodation,
65 occupation and recreation; and conservation of natural and social heritage. Modification of any of
66 these services may compromise the delivery of others and the risk of such trade-offs must be
67 recognized if conflicts between policies and goals are to be avoided.

68 New tools are needed to allow us to understand how changes to our energy system (both large and
69 small) interact with ecosystem services, both in terms of technical assessments and in terms of
70 planning decisions [10]. The standard approach for assessment involves planning applications and
71 environmental impact assessments that narrowly focus on selected elements and exclude other

72 important features. The situation is exacerbated by the potential deployment of different combinations
73 and scales of renewable energy technologies in different localities. In these circumstances, the largely
74 unknown synergies and conflicts generated by the technologies may well produce outcomes different
75 from the sum of their individual effects.

76 As the provision of energy becomes decentralized the issues become more location and site-specific;
77 it will become increasingly important to consider energy demand, production and supply in a more
78 local area or landscape context. Decision makers are faced with the challenge of developing systems
79 which will allow local sources of energy to be incorporated with currently centralized supplies. There
80 is currently uncertainty regarding the stability and temporal dynamics of the interactions between
81 different renewable technologies and local energy demand, this is complicated by the historical legacy
82 and the infrastructure needed to deliver the energy generated. Some of this uncertainty is associated
83 with the relatively poor availability of data with which to investigate local spatial interactions
84 consistently across regional or national scales. Perhaps surprisingly, even nationally available basic
85 resource data are often insufficiently detailed to reliably identify technically optimal locations for
86 smaller scale renewable energy installations, let alone support analysis of more subtle issues (e.g.
87 [11]). The widespread acceptance of the incompatibility of datasets and modeling across scales also
88 creates a schism between local and national planning.

89 The difficulty of understanding the impact of changes to the energy system is further compounded by
90 our limited understanding of how it affects the provision of ecosystem services at a range of scales,
91 from local to national and global. Each environmental function is potentially affected by changes to
92 land management and the exploitation of associated ecosystem services; their response may be
93 immediate or show delay and variation over time making the system impossible to model accurately.
94 While there is plenty of research devoted to developing approaches for the technical and economic
95 optimization of distributed generation systems (e.g. [12] and [13]), taking the perspective of the
96 whole system is rare [14]. Ecosystem services and their social effects, have been largely neglected
97 [15] and where they have been examined they are usually considered at the national or larger scales,
98 rarely considering local impacts, interactions and multiple effects [16]. Where environmental

99 considerations are taken into account, these are largely constrained to direct impacts such as
100 atmospheric carbon emissions (e.g.[17] and [18]). Our understanding of how to deploy energy
101 production technologies to minimize negative local impacts and maximize energy benefits is usually
102 incomplete and inconsistent. In fact, there is generally a disconnect in our understanding of actions
103 and impacts elsewhere.

104 From the problems described above, it is clear that we do not currently have sufficient understanding
105 of the processes and complexity in the real world to effectively forecast the impacts of changes to the
106 energy system. Here we propose an alternative method of viewing the system, which provides the
107 broader, whole system perspective that is needed for energy planning. It recognizes the importance of
108 different spatial scales and uses scenario studies to explore with stakeholders the desirability and
109 feasibility of particular local or regional interventions into the energy system. The approach requires
110 a change in paradigm for most energy researchers who take a strictly scientific reductionist view. We
111 recognize that this cannot be achieved rapidly, but in this paper we present a framework that will
112 enable and encourage new spatial models, theories and datasets to be developed, accessed and used
113 interchangeably (what is known as ‘plug and play’). It also allows existing national land use
114 databases such as the Countryside Survey [19] to be used to assist interpretation across scales and
115 targeting of resources to maximize the returns from existing data.

116 Most traditional modeling of the energy system employs an additive approach, concentrating on
117 energy sources. These are each examined and then their outputs summed; the calculations are usually
118 aspatial, taking no account of the geographic distribution of material, let alone any interactions. Even
119 where demand is included (e.g. [20]) geography and interactions are ignored. Efforts have been made
120 to link such energy production models to a spatial infrastructure (e.g. [21]), but not the whole system.
121 These models serve a valuable purpose in providing a crude estimate of overall potential, but they are
122 impossible to interpret for local environmental impacts [22] and are imperfect for assessment in the
123 context of productivity in the wider economy. Our long term vision is to develop a flexible spatio-
124 temporal analysis framework in which the impacts of changes in energy system configurations can be
125 identified for any specified area. The consequences of the change will be judged by a comprehensive

126 range of environmental and socio-technical indicators. The framework will need to represent (i)
127 actual and potential energy sources, (ii) energy transportation pathways, (iii) the energy demand
128 across a local area and (iv) be capable of seamlessly linking to examinations of other ecosystem goods
129 and services. Taken in its entirety, we call this the “energyscape” of the local area (a term first used
130 with this breadth by Louise Heathwaite [23]). Combining such a framework with, for example,
131 models of ecosystem behavior could provide a new means to facilitate “what-if” comparisons of
132 alternative approaches to distributed generation. Ultimately it might be possible to highlight the trade-
133 offs between different scenarios and, with recognition of the different value judgments and interests
134 associated with different stakeholders, reduce land use conflicts. Optimal energy solutions combining
135 the technical elements of the energy landscape should not only minimize their wider impact but also
136 be set in the context of sustainability.

137 Our project involved a one year pilot study to discover the potential benefits and obstacles in using a
138 whole system approach to evaluate the energy system. Our aim was to determine how an
139 understanding of the energyscape and ecosystem services could help guide the deployment of LBR.
140 To deliver this we examined energy system options in the context of the wider landscape by taking
141 into consideration the interactions both between the energy components and ecosystem services. We
142 are seeking to use it both as a proof of concept and a test bed in which we can identify the techniques
143 needed, beneficiaries and differences to the current reductionist approaches; a major deliverable for
144 the future will be a generic system that will advance evidence based sustainable development.

145 In this paper we propose a new approach incorporating the whole landscape in terms of structure and
146 process viewed from an energy perspective that can help surmount the problems of the complex
147 dynamic system described above. We will describe the components of our project that demonstrate
148 how to collect evidence for better planning, take account of different people’s perspectives and
149 prepare for dramatic changes in land use.

150 **2. Materials and Methods**

151 **2.1 Defining the energyscape**

152 Although the term “energyscape” was used in New Zealand for a project (started in 2007) which
153 developed long range assessments of national energy flows [24], there is, to our knowledge, no formal
154 definition of an “energyscape”. As a term, energyscapes sounds familiar and people intuitively make
155 their own definition, but our first goal was to formalize a succinct, explicit definition. As a large
156 interdisciplinary team of natural and social scientists we discussed (at length) and eventually agreed
157 on a working definition of an energyscape as “the complex spatial and temporal combination of the
158 supply, demand and infrastructure for energy within a landscape”. To ensure that this definition was
159 both comprehensive and complete we contributed and commented on ideas on a wiki on the World
160 Wide Web. The discussion focused on both the definition and the characteristics of an energyscape.

161 **2.2 Case study**

162 The second part of this paper briefly describes the application of an energyscapes framework for a
163 case study area. The selected case study site, covering 155 km², was Marston Vale (Figure 1), a sub-
164 catchment of the Great Ouse river in Bedfordshire, United Kingdom (UK). The land use, including
165 currently consented development, is reasonably typical of lowland England being 69% agricultural
166 land, 12% urban, 8% woodland and 11% other including water and landfill [25]. The population
167 density is predicted to increase to a level (3.1 people per ha), which is between the density for
168 England (3.9 people per ha) and the UK (2.5 people per ha). A full description of the site and the
169 methodology is provided by Burgess et al [26], but the key issues are mentioned here for clarity. As
170 a demonstration of the application of the energyscapes concept in Marston Vale, a GIS was
171 constructed using ArcGIS [27]. Datasets describing a broad range of environmental characteristics
172 (e.g. soil, climate, geology, topography) and land cover (using aerial photographs, Land Cover Map
173 2007 and field survey) were collated so that the existing functions of Marston Vale could be assessed.
174 The functions were examined through the application of different models for production of both
175 energy (e.g. biomass, wind, solar, ground-source heat, and landfill biogas) and other goods and
176 services (such as food) [28]. These were then examined under different scenarios developed, in part,
177 from the feedback from stakeholder workshops.

178 **2.3 Stakeholder perceptions of energy-ecosystem services interactions**

179 This section of the paper briefly outlines a method to improve our understanding of the perspectives
180 of different stakeholders on how change in the energy system will impact their local area. A two tier
181 approach was developed. Firstly each individual was asked to identify the ecosystem services that
182 they think are delivered by specific habitats. The dominant habitats were identified using Broad
183 Habitats [29], as mapped in Land Cover Map 2007 (Figure 1).

184 *Figure 1 about here*

185 The information was collected by asking a series of questions that covered the breadth of ecosystem
186 services with responses that range from strong agreement to strong disagreement. The approach and
187 analysis [30] was then extended in a second questionnaire to identify how people viewed the
188 sensitivity of different services to components of the renewable energy system. This was
189 summarized to represent the opinions of different stakeholders and help clarify the reasons for their
190 support, indifference or ambivalence. The Broad Habitats are a practical categorization of land into
191 different types devised following the Rio Convention for Biological Diversity [31] that can be
192 mapped locally. They provide a comprehensive coverage of all UK land and habitats against which
193 those requiring special protection or management can be viewed and are used by both conservation
194 agencies and Government to assess targets. As the spatial footprint of the energy system changes, it
195 can be expressed in units such as Broad Habitats so that the conflict with conservation policies can be
196 identified.

197 **3. Results**

198 **3.1 Exploration of a concept**

199 Our initial definition of an energyscape was “the complex spatial and temporal combination of the
200 supply, demand and infrastructure for energy within a landscape”. A further exploration of the term
201 focused on two components: the form and function of an energyscape (Table 1). Some of the
202 definitions included no consideration of energy demand. There was also a debate on the extent to
203 which “ecosystem services” were best considered as “separate from” or as “part of the energyscape”.

204 One pertinent comment from a local stakeholder meeting was “why are you inventing a new term:
205 why do you not simply refer to an energy landscape?”

206 *Insert Table 1 about here*

207 Most of the definitions recognize that an energyscape has both a geographic extent and a timeframe
208 that reflect its evolution, development and potential. Although the definitions do not cite a specific
209 spatial scale, there are probably benefits to choosing a scale where the area has a functional identity.
210 For example, for the case study area, a locally-recognized sub-catchment was chosen. Whilst it is not
211 essential to use natural divisions of a landscape, a catchment’s boundaries reflect breaks and shifts in
212 natural processes and the viewshed associated with a catchment often creates a unit that can be
213 identified by people.

214 Although the spatial scale should represent a functional unit, it is recognized that any studied area will
215 not be a closed system but it will have inputs and outputs of energy and ecosystem services across the
216 boundary (Figure 2). Equally, the boundary may not be a crisp border as shown in Figure 1; some
217 parts may have a recognizable border, for example the M1 defining the south western border, but in
218 other places the definition is fuzzy. This vagueness does not devalue the region to different local
219 stakeholders but merely qualifies their considerations.

220 No single, pithy final definition was unanimously agreed on; our original definition was not
221 compromised by any of the suggestions which are not mutually exclusive. An energyscape definitely
222 has a spatial and temporal basis and focuses on both internal interactions between the energy system
223 components (demand, supply and delivery) and interactions with other components of real landscapes
224 such as people, structures, topography and ecosystem services.

225 *Figure 2 about here*

226 Energy may be produced, transmitted, stored and/or used by components of the energyscape within
227 the system boundary and only one of these elements is needed for the energy to be viewed as part of
228 the system. For example, we would argue that even if energy simply passes through the energyscape
229 through a high tension electricity network it should be included.

230 As the definition describes a complex dynamic system, when considering future options, potential
231 features of the energyscape not present at the time of observation should be included; the
232 classification of components and methods of linking (co-registering) data are key to this process. For
233 example, at the time of writing our case study area includes no energy from waste installations, but
234 they are being actively considered. It is only through a systematic approach that consideration of the
235 possible energy options (Table 2), and the key ecosystem services in an area (Table 3) will be
236 encouraged. Early involvement of a wide range of stakeholders is key to the process as their
237 perceptions of what is important and which ecosystem services matter to them provides important
238 guidance for development of scenarios, data gathering and planning of locations for LBR.

239 *Insert Table 2 about here*

240 **3.2 Inter-relationships with ecosystem services**

241 Ultimately any energyscape forms part of the wider biosphere, the self-regulating system containing
242 all ecosystems that overlaps the lithosphere, hydrosphere and atmosphere creating a zone that
243 supports life (Figure 3). The addition of solar and cosmic radiation generates the systems of climate,
244 terrain, soil/geology, hydrology and ecology that we exploit to support our life.

245 *Figure 3 about here*

246 Ecosystem services are defined as the products and services that people derive from ecological
247 systems. The Millennium Ecosystem Assessment [32] classified these services into four groups
248 provisioning, regulation, supporting and cultural. In addition to these , shown to the left in Figure 2
249 de Groot and others also highlight the carrier and habitat services as shown on the right [33] and [34].
250 Costanza and others have proposed additional characterizations as indicated in the box to the lower
251 right [35]. Such categorizations are useful to ensure that we consider the full range of benefits that we
252 gain from our environment.

253 The energy infrastructure physically ties energy components to the landscape. Energy sources, energy
254 demand and energy delivery systems potentially interact with most if not all ecosystem services; they
255 may also be explicit services (e.g. provision of energy) or implicitly embedded (e.g. regulation of

256 greenhouse gases) in specific categories. It is important not only to ensure that the key parts of the
257 energy system are considered, but how they differentially interact with different ecosystem services
258 through their physical location.

259 **3.3 Case study**

260 Within this paper only a brief indication of the outputs from the case study analysis has been
261 presented by way of a demonstration of the potential of this approach. Detailed results and analysis
262 are given by Burgess et al [26], Armitage et al.[28] and Wadsworth et al. [30]. As described earlier,
263 Marston Vale is a lowland predominantly agricultural landscape which currently offers provisioning
264 of human food, animal feed, and fiber. The existing land use was described through field survey and
265 remote sensing and the production through the key provisioning ecosystem services was modeled
266 (Figure 4).

267 *Figure 4 about here*

268 Other ecosystem services that were assessed include the regulation of biochemical processes (e.g. soil
269 carbon), culture (e.g. recreation) and conservation (provision of appropriate and sufficient habitats for
270 farmland birds). The local energy demand was also mapped (Figure 5) and, although simple spatial
271 overlay is not appropriate, this information is extremely useful in identifying the hot spots for service
272 that can be used to improve efficiency by matching to local generation. The information is also
273 valuable for validation and informing stakeholders about their regional energy self-sufficiency and
274 thus can provide an educational service.

275 *Figures 5 about here*

276 The implications of expanding bioenergy provision were considered in a number of ways. One set of
277 scenarios examined the deployment of different products from food or fiber into energy and fuel,
278 leaving the landscape effectively unchanged. A second set of scenarios examined the conversion of
279 land currently used for agricultural production in specific locations within Marston Vale to energy
280 crop production and alternative forms of renewable energy, to meet a number of government-defined
281 targets for meeting energy demand.

282 **3.4 Stakeholder perceptions of energy-ecosystem services interactions**

283 The scenario outputs helped not only to inform and engage local stakeholders but also to elicit new
284 information about strategies and plans that are being developed. Different groups of stakeholders
285 were asked to respond to the questions relating the area's common Broad Habitats (Arable and
286 horticultural, Improved grass, Neutral grass, Broadleaved, mixed and yew woodland, Standing open
287 water, Rivers & stream, Boundaries and linear features and Urban & built up) to ecosystem services
288 and then questioned about their opinion of the sensitivity to different changes in the energy system
289 [30]. They were asked to score which ecosystem services were delivered by which Habitats using the
290 questions in Table 3. The first analysis highlights the relative position of different stakeholders and
291 suggests where issues may cause friction and where there are similar beliefs. They are then asked to
292 score the impact of LBR options against the Broad Habitats suggesting if they consider them to be
293 beneficial or damaging.

294 Table 4 provides an example of the output for one stakeholder's responses to questions of wind and
295 biomass for Marston Vale. The table shows the sum of the scores representing the stakeholder's
296 perception of threats (-2, -1) or benefits (1, 2) of new LBR development in different habitats and on
297 ecosystem services. The results suggest that the stakeholder has a number of concerns over wind
298 turbines seeing negative impacts with services delivered by a number of habitats. There is special
299 concern about the impact turbines would have on the regulating services provided by Deciduous,
300 mixed and yew woodland; it is only the Urban and built up habitats where he/she sees benefits. In
301 contrast, the options for bioenergy do not raise as many concerns for this individual. Only Boundaries
302 and linear features have a net negative score, the impact being from the cultural services; cultural
303 services appear to be the major cause for concern in biomass planting, with supporting services
304 benefiting and the others showing a balance. The analyses presented back to the stakeholder provided
305 scope for discussion and validation; they helped clarify an individual's position and allowed dialogue
306 to begin to understand concerns and express them to others.

307 **4. Discussion**

308 Bringing together an understanding of the energy system and ecosystem services is a complex task.
309 Ecosystem services are often viewed as spatial processes that can be categorized through their
310 delivery by specific habitats that are geographically fixed. Conversely, the energy system is
311 commonly viewed as aspatial and identified in units ranging from household to national, but ignoring
312 their location or geographic characteristics. The process of describing an energyscape can help, in
313 part, to address this by modeling energy demand, supply and flows through real landscapes, thereby
314 helping to identify links, obstacles and important associations.

315 In this context the energyscape provides a representative framework containing geographic and spatial
316 characteristics; it does not necessarily have to be a complex simulation model. The individual
317 elements of an energyscape can be land parcels, each of which can have its own energy flow (Figure
318 6), that can be joined together to describe even larger energyscapes. This description suggests that the
319 approach is bottom up and requires masses of detailed data and intensive analysis, but this need not be
320 the case. Targeted and representative sampling as used by opinion polls and the Countryside Survey
321 and hybrid models of the style used to combine input output statistics with life cycle analysis (e.g.
322 [36]) can improve the efficiency and improve the consistency across scales.

323 *Insert Figure 6 about here*

324 The term “energyscape” was new to stakeholders associated with the project. As already indicated
325 one respondent questioned the need for a new term, when the term “energy landscape” could be
326 created by combining existing terms. However the philosophy of the approach was seen as a useful
327 means through which changes in energy demand, sourcing and supply could be discussed in broad
328 terms for a specific area. The stakeholders were able to engage with issues, typically only considered
329 at a national or international level, in the context of a landscape that they understood. Different
330 groups of stakeholders saw benefits of the approach, for example local planners valued the
331 development of “independent” integrative tools, whilst local action groups agreed that it should
332 ensure that their goals were recognized whilst illuminating other issues that they had not considered.

333 The use of questions drawing information and opinions about the whole landscape and energy options
334 proved insightful in more ways than we had initially intended. One clear strength of the questionnaire

335 is that it brings all types of habitat and ecosystem service to the stakeholders' attention. The example
336 of the stakeholder whose results are presented in Table 4 suggests that on balance he/she is more
337 likely to support biomass (a positive aggregate score) in Marston Vale rather than wind (aggregate
338 negative). However, the information presented back to the stakeholder gives them an opportunity to
339 question their own values and judgments and discuss them with others. In particular, it identifies
340 which parts of landscapes are more valued (e.g. woodlands) and which less (e.g. built up). The results
341 are indicative not definitive and as the methodology is relatively simple (see [30]) it allows
342 stakeholders to both recognize and adjust their position and enter dialogue with others about the
343 specific areas they have concerns over.

344 Until the energyscapes term is more commonly used, the feeling was that a longer description may
345 help gain its acceptance and use of additional phrases such as 'the local energy landscape' might be
346 beneficial. It is informative to note that the term ecosystem services is still not widely used at a local
347 level, despite being well known in academia and national policy circles.

348 **5. Conclusion**

349 Energyscapes is a valuable term to engage people in discussion about how the energy system interacts
350 with their local environment and the other ecosystem services that it provides. It sets the specific
351 components of the energy system in context of local energy demands and with other parts of the
352 energy system, and offers a mechanism for making decisions that are more transparent and equitable;
353 we hope that it can make a useful contribution to a wider public debate on our energy futures. In the
354 same way that 'carbon footprint' or 'food miles' have become well-known terms that are widely (if
355 loosely) used in and by the public, we hope that one day people will have a popular term to refer to
356 the main local characteristics of energy demand, transport and supply. We propose that people
357 discussing local wind farms or local authority development plans may start with the phrase 'our
358 energyscape is...'.
359

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- 453

454 **Table 1** Options for the definition of an energyscape

455 **Table 2A** hierarchical list of components of the energy system used to check options for a location. It
456 can be expanded in both directions adding further components (rows) or breaking the existing
457 components into more detail (columns).

458 **Table 3** Table of questions given to stakeholders to ask how they value different ecosystem
459 services. All questions are asked for every habitat present, with the term *habitat* in the
460 question being replaced by specific names (e.g. *Improved grassland*). Only the Broad
461 Habitats commonly found in Marston Vale were used in this instance

462 **Table 4** Summary responses from an individual stakeholder who was asked to score the impact of
463 two new energy sources (wind and biomass) on the provision of the individual ecosystem
464 services listed in Table 3 (+2, +1, 0, -1, or -2) within seven habitats commonly found in
465 the study area. The responses are summed and grouped by ecosystem service category.

466

- 467 **Figure 1** Broad Habitats in Marston Vale from the satellite derived Land Cover Map 2007.
468 Categories Arable & horticultural (Au, Ba), Coniferous and Deciduous woodland (C, D,
469 Fd), Agricultural and amenity grasslands (Gi) semi-natural grasslands, heaths and scrub
470 (Gr, H, Hga, M, Sc), Urban and industrial (U, Ud, Ui, Us) Rivers, lakes and ponds (Wl)
- 471 **Figure 2** A diagrammatic representation of the spatial domain of an energyscape as an open system
472 with flows to other (energy) systems. The broken line indicates the energyscape boundary
- 473 **Figure 3** Categories of ecosystem services drawn from [32], [33], [34] and [35]
- 474 **Figure 4** Modeled land use in the Marston Vale in 2009 (from [26])
- 475 **Figure 5** Modeled estimates of the intensity of demand for energy in the Marston Vale
- 476 **Figure 6** Energy flow through elements of an energyscape

an energyscape is
a spatial and temporal representation of a landscape
a spatial domain defined from an energy perspective
a framework
a functional unit
a description of the relationships between spatial patterns and man's energy system
a whole system model

that
describes the interactions between energy system components and other ecosystem services
visualizes the capture, conversion, transmission, use and disposal of energy relevant to human activities
emphasizes the capture, conversion, transmission, use and disposal of energy for human use
represents man's energy system and can be interrogated and manipulated to support the delivery of sustainable development
tells you how much land could/should be devoted to energy and at what cost
integrates all the processes related to man's use of energy

Energy Sources	Fossil fuels	Coal Oil Gas Peat
	Nuclear	Fission Fusion
	Renewables	Wind Bioenergy Solar photovoltaic Solar thermal Hydro Heat pumps Wave & tidal Geothermal Landfill gas Waste
Energy Transport & Storage	Electricity	Cable Battery
	Gas	Pipeline Tanks
	Liquid fuel	Pipeline Road & rail transport Tanks
	Solid fuel	Road & rail transport Storage bunkers
	Heat	Pipe Water storage
Energy Demand Management	Heat	Household insulation
	Power	Efficient equipment Standby systems
	Motion	Car sharing Speed restriction
	Light	LED Natural light

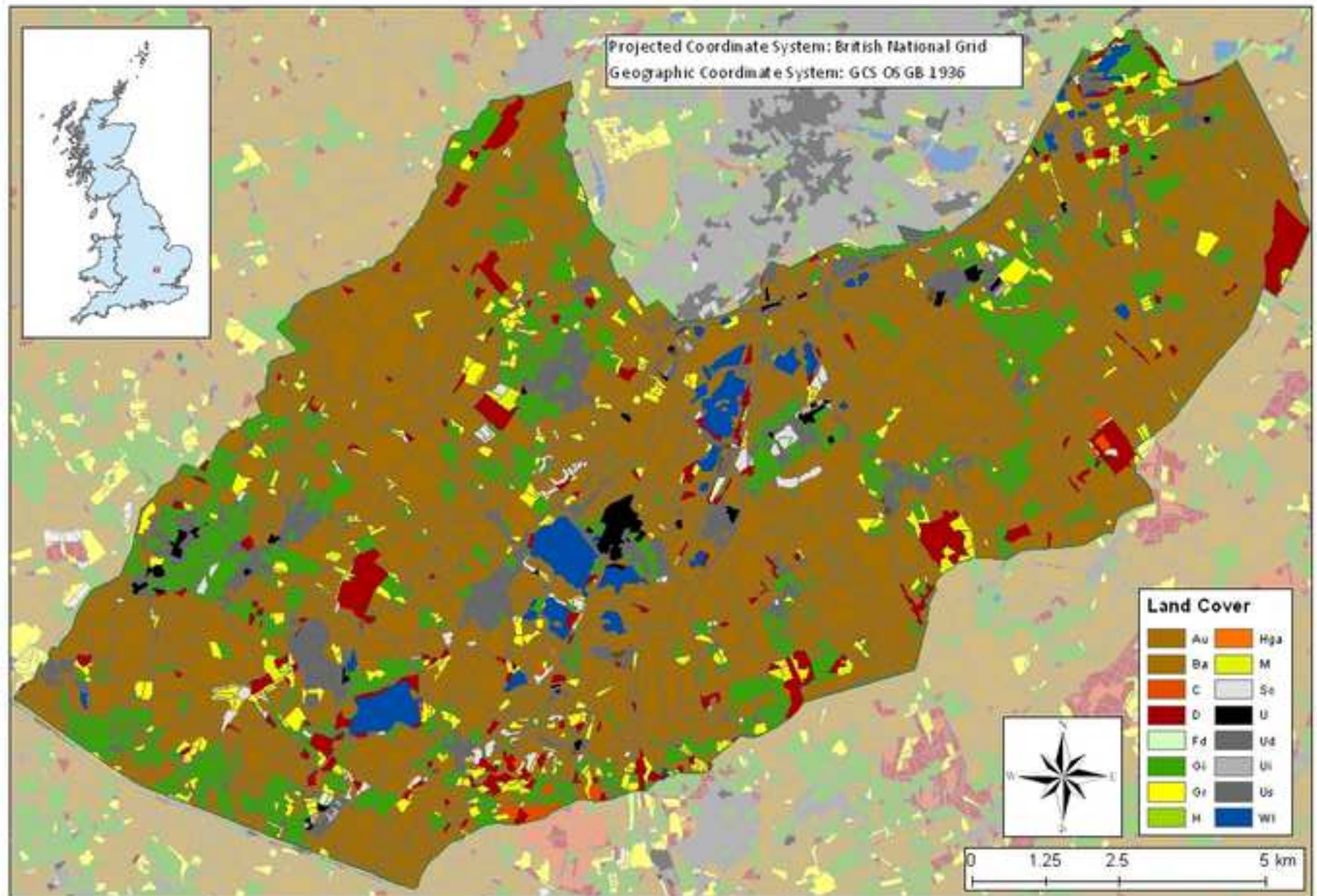
Cultural services	Does the <i>habitat</i> make you think ...
Aesthetic	... it is beautiful?
Heritage	... about the past?
Jobs	... of opportunities for employment?
Recreation	... you want to spend more time here?
Scientific & educational	... there is a chance to learn or observe something interesting?
Spiritual	... about the future?
Habitat services	Is the <i>habitat</i> where you would expect to see....
Flora	... wild plants
Fauna	... wild animals
Provisioning services	What do you get from the <i>habitat</i>...
Fiber	... fiber such as wood, flax or wool?
Food	... food for people or livestock?
Freshwater	... freshwater e.g. springs?
Fuel	... fuel e.g. firewood or biodiesel?
Genetic	... a genetic resource for the future?
Medicinal/ornamental	... Medicinal or ornamental plants?
Regulating services	Does the <i>habitat</i> help ...
Air quality	... improve the air we breathe e.g. dust, smells, ammonium?
Assimilation of carbon	... lock up carbon from the atmosphere in the soil or plants?
Buffer - chemicals	... e.g. reduce pollution from acid rain, nutrients or pesticides?
Buffer - physical	... e.g. reduce erosion or flooding?
Buffer - economic	... e.g. "safe" jobs in times of recession?
Climate	... moderate the local (or global) climate?
Disease, pests & natural hazards	... reduce the impact of pest and diseases, e.g., aphids, Lymes disease, etc.?
Erosion	... prevent erosion?
Fire	... prevent wildfires?
Pollination	... provide nectar resources for bees and other pollinators.
Water flow	... moderate water flows (quantity) e.g. floods and droughts?
Water quality	... improve water quality?
Supporting services	Does the <i>habitat</i> help support other services by ...
Nutrient cycling	... reducing nitrogen and phosphorus losses?
Primary productivity	... growing vegetation?
Soil formation	... encouraging soil formation?
Hydrological cycling	... circulating water around the environment?

Table

Energy Source	Ecosystem Service Group	<i>Broad Habitat</i>						
		<i>Arable & horticultural</i>	<i>Boundary & linear features</i>	<i>Broadleaved, mixed & yew woodland</i>	<i>Improved grassland</i>	<i>Rivers & streams</i>	<i>Standing open water & canals</i>	<i>Urban & built-up</i>
Wind	Cultural	0	-4	-3	0	0	0	1
	Provisioning	0	0	-4	0	0	0	0
	Regulating	-1	0	-13	0	0	0	2
	Supporting	0	0	0	0	0	0	0
	Total	-1	-4	-20	0	0	0	3
Biomass	Cultural	-1	-6	-2	0	0	0	4
	Provisioning	-1	0	3	-1	0	0	0
	Regulating	1	0	0	-2	0	0	0
	Supporting	3	0	0	4	0	0	0
	Total	2	-6	1	1	0	0	4

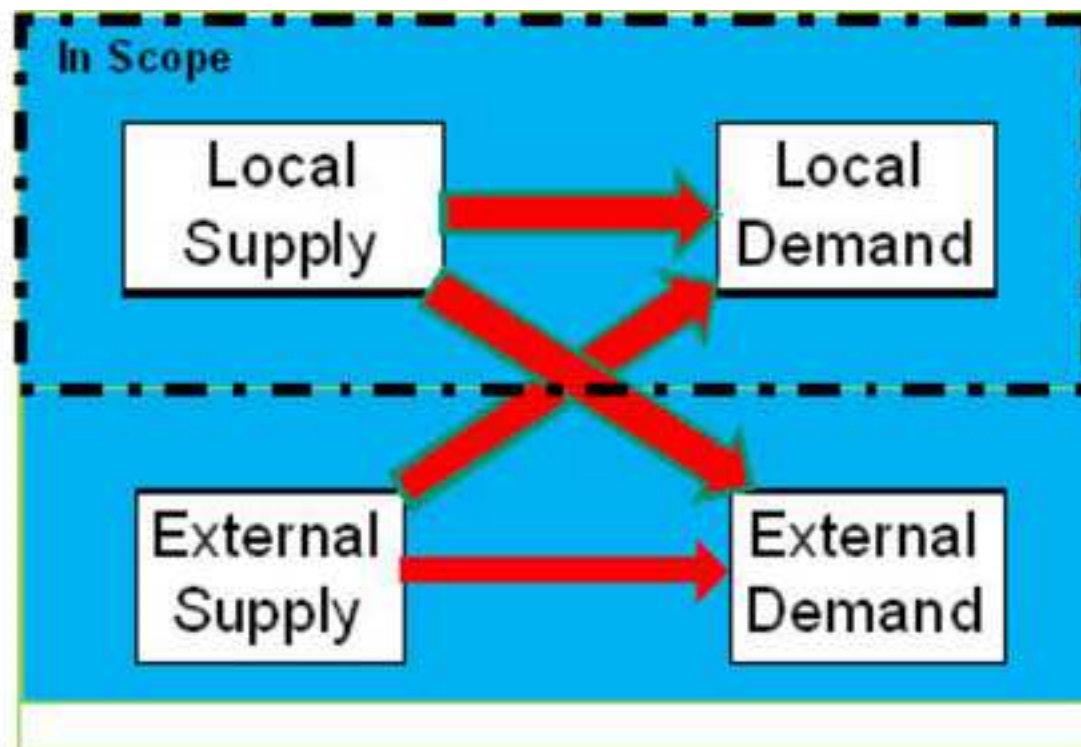
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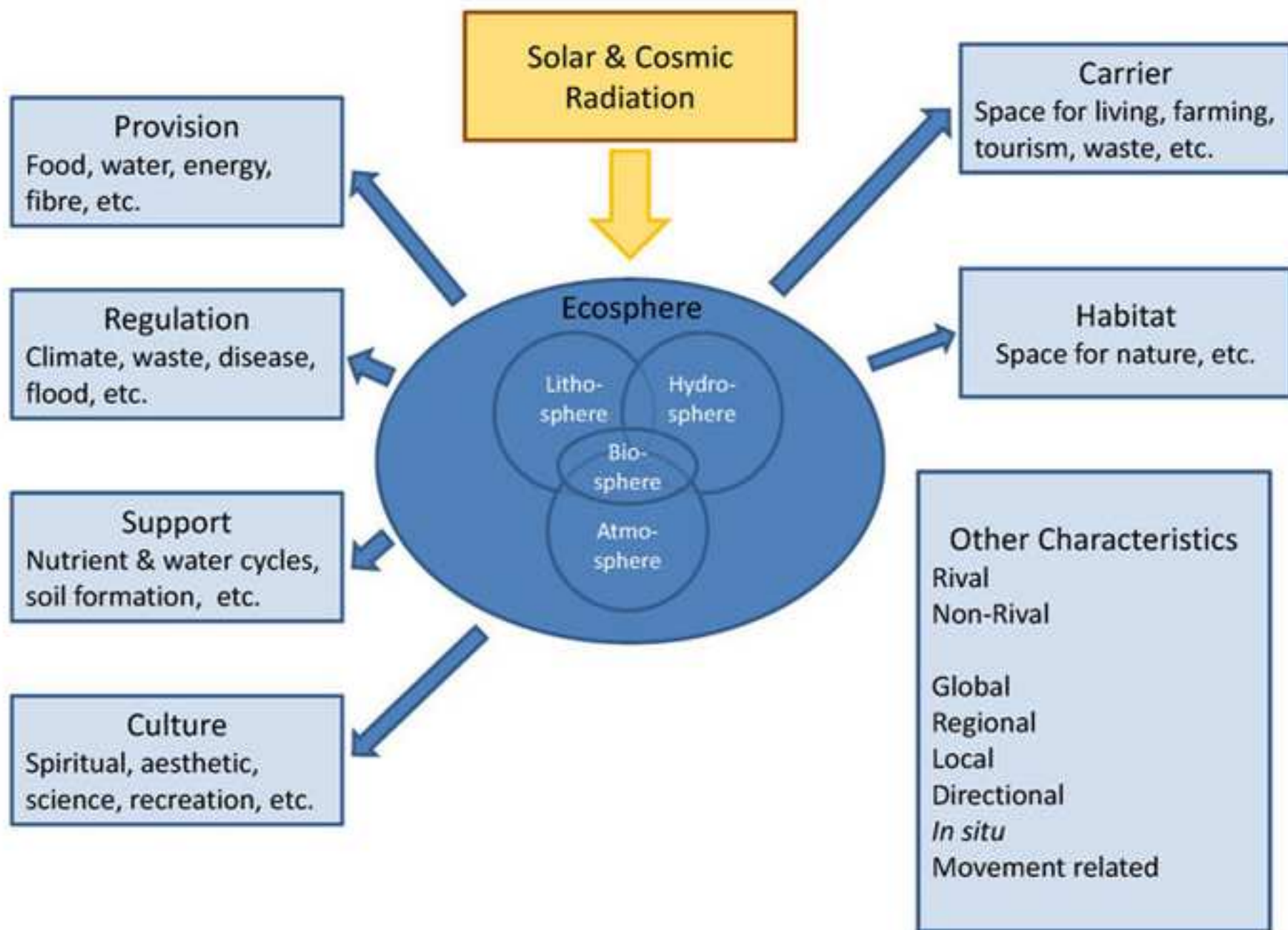
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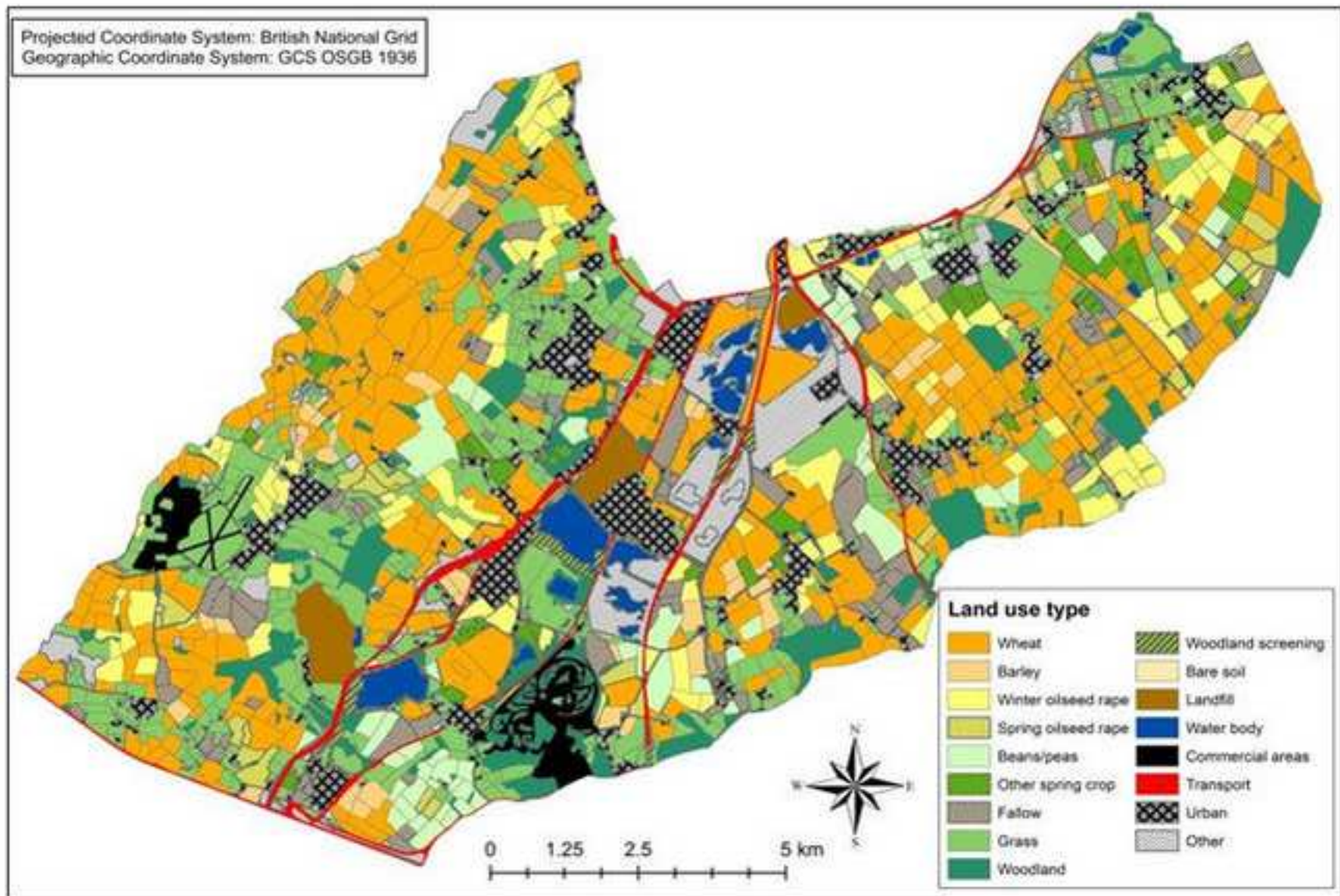
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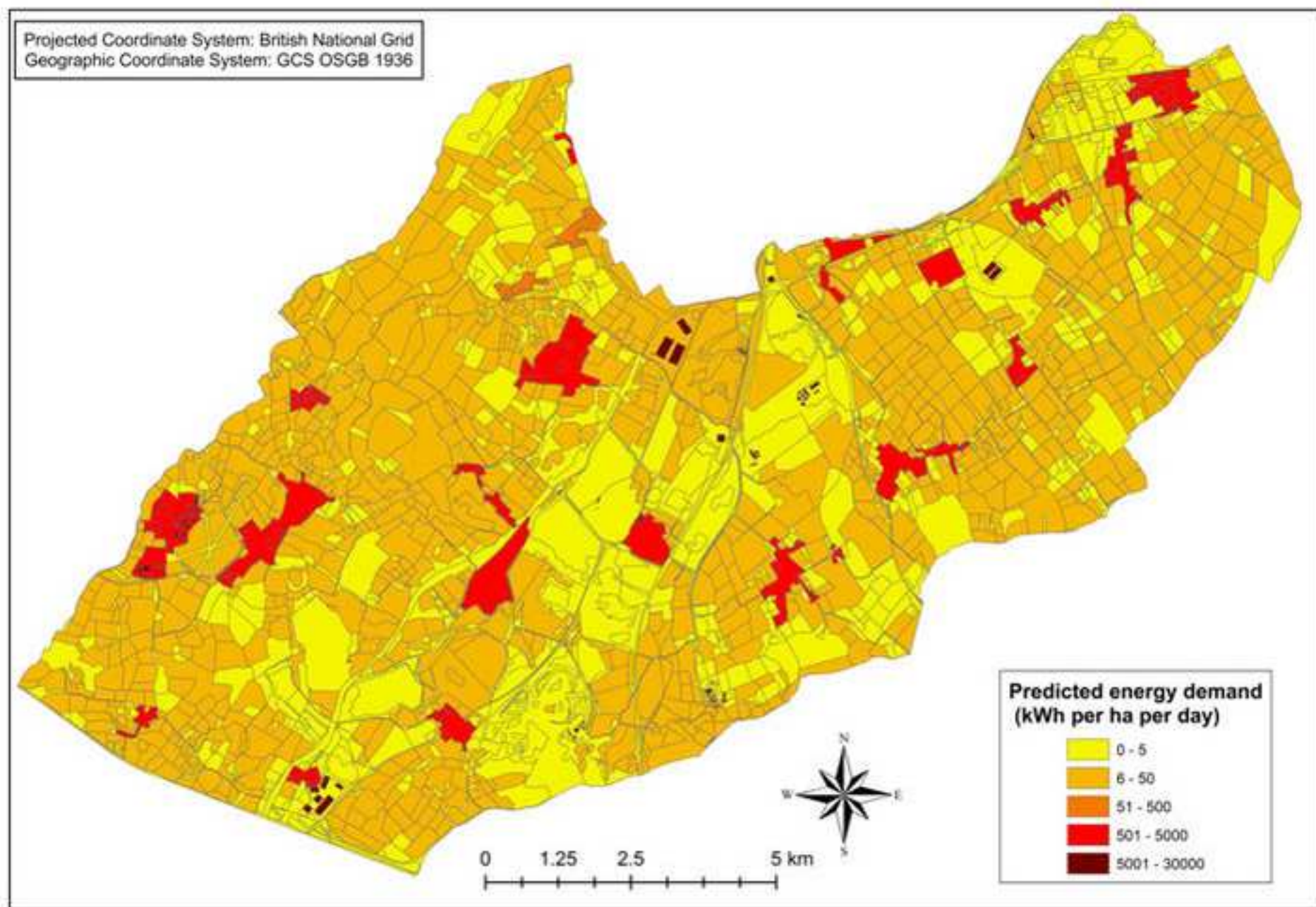
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Recursive representation

