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Toward an Integrated GIScience and Energy Research Agenda

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The growing evidence indicating that climate change is real and accelerating, coupled with a host of interrelated energy sustainability questions, has fostered increased interdisciplinary research on improving energy efficiency and reducing per capita energy consumption, as well as better understanding the sources of pollution emissions and possible policy options for limiting permanent environmental damage. Increasingly, geographic information systems, remote sensing, and other spatial technologies are being leveraged by researchers when analyzing these problems. There is, however, limited discourse regarding the possible synergies that could result from sustained engagement between those interested in geographic information science (GIScience) and researchers tackling energy issues. In this article, we outline an integrated research agenda for GIScience and energy studies that focuses on the prospects for making new contributions to the growing literature on energy sustainability. We identify three critical issues that offer substantial opportunities for new synergistic research at the nexus of GIScience and energy sustainability, including (1) the problem of carbon estimation and inventory, (2) questions of new energy infrastructure placement and transition, and (3) household energy conservation and efficiency. We lay out substantive energy considerations within each problem area and discuss possible new contributions involving GIScience. Our analysis suggests that issues of scale, representation, complexity, and several other core GIScience themes underpin these energy research needs. This article is intended to foster new dialogue between GIScience and energy studies. Key Words: carbon, energy, GIScience, household consumption, sustainability.

La creciente evidencia de que el cambio climático es real y que se está acelerando, junto a un buen número de cuestiones interrelacionadas de sustentabilidad energética, ha fomentado un mayor volumen de investigación interdisciplinaria para mejorar la eficiencia en el uso de la energía y reducir el consumo energético per cápita, al igual que para entender mejor las fuentes de emisiones de polución y posibles opciones de políticas para limitar el daño ambiental permanente. De manera creciente, los sistemas de información geográfica, la percepción remota y otras tecnologías espaciales están siendo aprestigias por los investigadores al analizar estos problemas. Sin embargo, poco se ha discutido en lo que concierne a las posibles sinergias que podrían resultar de un continuado compromiso entre quienes se interesan en información geográfica científica (IGSciencia) y los investigadores empeñados en asuntos energéticos. En este artículo, bosquejamos una agenda de investigación integrada para IGSciencia y estudios energéticos, que centra su atención en la posibilidad de hacer nuevas contribuciones a la creciente literatura sobre sustentabilidad de la energía. Identificamos tres asuntos críticos que ofrecen sustanciales...
opportunities de nueva investigación sinergística en el nexo de la IGciencia y la sustentabilidad de la energía, a saber: (1) el problema del cálculo del carbono y su inventario, (2) cuestiones relacionadas con los nuevos emplazamientos de infraestructura energética y transición, y (3) conservación y eficiencia de la energía para uso familiar. Presentamos sustanciales consideraciones sobre energía en cada uno de esos problemas y discutimos posibles nuevas contribuciones que impliquen IGciencia. Nuestro análisis sugiere que asuntos relacionados con escala, representación, complejidad y varios otros temas centrales de IGciencia apoyan estas necesidades de investigación energética. Palabras clave: carbono, energía, IGciencia, consumo doméstico, sustentabilidad.

Because much of the world’s energy supplies are derived from limited fossil fuels, there are pressing questions about the long-term environmental, social, and economic sustainability of the current global energy regime (InterAcademy Council 2007). There is a growing sense in the scientific community (Intergovernmental Panel on Climate Change [IPCC] 2007), which also has been documented in popular outlets (Friedman 2008), that humanity is on the cusp of damaging and potentially irreversible environmental changes. The adverse impacts of these changes have been linked to energy consumption and the negative externalities of the primary energy sources used (Woodcock et al. 2007). Among these, the continued release of carbon and other greenhouse gases (GHGs) is thought to be at odds with the sustainability of Earth’s physical and human systems (Willsion and Brown 2008).

The convergence of scientific evidence strongly points to the need to explore and pursue new ways of meeting our current and future energy needs, as well as to mitigate the impacts of our energy consumption on the environment (IPCC 2007; National Academy of Sciences 2010). In the coming years, geographic information systems (GIS) are poised to play an essential role in the design and implementation of new energy infrastructure systems (Prest, Daniell, and Stendorf 2007), as well as to help us understand the impacts of new energy policies aimed at both the macro (Stone 2008) and microscales (Gidell 2009). Many basic research issues must be confronted if we are to successfully adopt a more sustainable energy system and minimize the associated long-term environmental impacts.

A review of the recent scientific literature involving applications of GIS to energy issues, however, suggests limited participation by geographers and spatial scientists. Moreover, scholars interested in the basic science supporting GIS, GIScience, have yet to develop substantial linkages with researchers interested in energy issues. This lack of interaction represents a missed opportunity for the energy community to benefit from some of the foundational insights that could come from GIScience. From issues of spatial scale and representation (Miller and Wentz 2003; Goodchild, Yuan, and Cova 2007), to computational limits and advances with spatial data (Armstrong 2000; Xie, Batty, and Zhaoz 2007; Wang and Liu 2009), there are multiple GIScience knowledge areas underpinning potentially innovative energy research. At the same time, the diverse realm of energy studies offers GIScientists new venues in which to contemplate the boundaries of spatio-temporal analysis (Peuquet 2004; Yu and Shaw 2008), explore theories of complex systems (Evans, Sun, and Kelley 2006; Manson 2006), and advance other core research aims. More broadly, the benefits accrued from new exchanges between these areas have real potential to contribute to fostering long-term energy sustainability and aid in international efforts to mitigate climate change.

This article lays out possibilities for new interactions between GIScience and energy researchers within the context of selected ongoing research streams focused on energy sustainability issues. We first provide a brief background on GIScience and energy studies, highlighting their respective interdisciplinary foci. From there we identify three broad energy problems to which new research could contribute and provide examples of how these integrated contributions might proceed. We then close with summary statements and suggestions for further work. In short, our goal is to reflect on the opportunities for new GIScience–energy synergies and to outline a new research agenda that would support energy sustainability.

GIScience and Energy Studies

Although the term GIScience was coined early in the 1990s (Goodchild 2010), the field to which this term refers began decades prior, having core interests in issues such as spatial data handling, modeling, geographical representation, and so on (Mark 2003; Caron et al. 2008). It remains a vibrant interdisciplinary field drawing from computer science and engineering as well as the cognitive, physical, policy, and social sciences. Presently, there are well-attended conferences featuring GIScience research (e.g., GIScience, GeoComputation) as well as several journals devoted to GIScience.
content (e.g., International Journal of Geographic Information Science, GeoInformatica; Caron et al. 2008). For a fuller treatment of the history and research scope of GIScience, readers are referred to Goodchild (2010).

There have been successful efforts to integrate GIScience with other substantive domains to examine research synergies and explore specific societal issues. Some of these include emergency management (Cutter 2003), human rights (Madden and Ross 2009), and environmental justice assessment (Higgs and Langford 2009). With respect to emergency management and GIScience, synthesis has occurred with respect to topics such as human evacuation behavior (Chen, Meaker, and Zhan 2006), data dissemination during extreme events (Mills et al. 2008), and crisis management systems (MacEachren and Cai 2006). Extending this line of thought to GIScience and energy matters could yield productive new interactions.

The study of energy issues similarly draws from a diverse suite of researchers. Naturally, there are those scientists focused on understanding the physical and chemical properties of energy sources or how energy is used by biotic organisms and machines. Researchers have addressed topics ranging from where new forms of energy might be produced (Agugliaro 2007), to the viability of these alternative energy sources (Akinci et al. 2008). The implications of energy usage are increasingly important, especially in the area of GHG emissions (Andrews 2008) and policies for their management (Ze-gras 2007; Ewing and Rong 2008; Mack and Endemann 2010). Within this nexus, there are ample cases of GIS technology being used to address energy issues (Simao, Dennisham, and Haklay 2009; Velazquez-Marti and Annevelink 2009), largely because many energy problems are effectively informed by geospatial concepts. Geospatial analysis techniques and supporting theories can be brought to bear on their inherent spatial (and related temporal) dimensions.

Synthesizing Energy Issues, GIS, and GIScience

In making the case for increasing synergies with energy and GIScience, we focus our discussion on three areas within the energy sphere that seem to offer the greatest opportunities for integrated geospatial research. These areas are not only fertile ground for making new intellectual contributions to GIScience and energy studies but they also figure prominently in societal efforts to become more energy sustainable and to minimize the impacts of climate change on natural environments. These areas are (1) carbon estimation and inventory, (2) energy infrastructure placement and transition, and (3) household energy conservation and efficiency. There are two points that preface this discussion. First, we again acknowledge that GIS technology and applications are not new to any of these research areas (Saunders and da Silva 2009; Velazquez-Marti and Annevelink 2009). What is generally missing from this literature, however, is a more systematic engagement between energy and GIScience principles, including widespread participation from geographers and GIScientists. Second, we note that our focus is on research possibilities in GIScience and broader energy matters, which include but are not limited to issues related to climate change (Skole 2004). Although our motivation stems from the interactive linkages between energy and climate change (Hepburn and Stern 2008; McDonald et al. 2009), our emphasis is on examining the generation and use of energy and its impacts on climate change through GHG emissions.

Carbon Estimation and Inventory

To stabilize GHG concentrations in the atmosphere due to petroleum-based energy consumption, international collaboration on emissions reductions will be required. Some current policy ideas under consideration involve complex and difficult questions, including setting future global emissions targets, distributing emissions target responsibilities among nations or to metropolitan areas within nations, and establishing emissions trading systems (Hepburn and Stern 2008). In the United States, the federal government has examined the feasibility of cap-and-trade programs to reduce GHGs (U.S. House of Representatives 2009). There are opportunities for GIScientists and energy researchers to work together to inform these emissions management programs through innovations in spatially explicit carbon source inventory methodologies.

Carbon emissions inventories require quantitative assessments of the sources and sinks of anthropogenic GHGs during a certain time period. Carbon sources are associated with anthropogenic activities such as burning fossil fuels and deforestation, whereas carbon sinks can be either natural vegetation or manmade such as croplands (IPCC 2007). Inventories of carbon sources and sinks provide the baseline information necessary to establish future emissions targets for a region. Emissions inventories also provide support for market-based emissions reduction programs. For example, some of
the economic models used to determine carbon credits require information on target GHG concentration levels that are calculated based on historical emissions (Metcalf and Weisbach 2009). This raises important questions regarding the functionality and availability of spatio-temporal databases for such applications, a long-standing concern in GIScience (Peuquet 2004; Stell and Worboys 2008). Previous work has pointed out the need for new spatio-temporal database capabilities in the context of managing climate change data (Abraham and Roddick 1999). New exchanges between energy researchers and GIScientists with respect to spatial data handling and database infrastructure issues, within the context of temporal dynamics, could lead to mutually beneficial developments.

Spatial and temporal scales are both considerations in carbon inventories. Depending on the necessary level of spatial detail, carbon estimates might be produced as finely as the household (Niemeier et al. 2008). Temporally, there is the possibility of mapping daily, monthly, or annual household carbon emissions associated with energy use. With recent advances in real-time data acquisition capacities based on environmental sensor networks, such as smart grid systems (Worboys and Duckham 2006), we are likely to see even greater temporal flexibility with respect to the availability of spatial data for carbon emissions inventories. Going forward, we will need new dialogue to address how complex spatial-temporal queries of such data are best constructed (Lopez, Snodgrass, and Bongki 2005).

Spatially disaggregated estimates can be aggregated to coarser geographic scales for the inventory of emissions over a residential neighborhood, Census geography, or municipality, which raises questions about appropriate aggregation strategies (Mu and Wang 2008). Further, highly spatially disaggregate estimation will require a large amount of data and processing effort for large study areas, which presents challenges when working at certain scales. As such, GIScience has great potential to contribute to large-scale emissions inventories through the development of new spatial interpolation and extrapolation approaches that can reduce sampling burdens and increase the spatial extensibility of results (Komarov et al. 2007; Andrews 2008). Commonly collected public spatial data sets are also likely to be of use in these large-scale efforts. For example, it is well known that the U.S. Census Bureau provides detailed data on households and housing unit characteristics at regular intervals. Also, the U.S. Department of Energy has conducted household energy and fuel consumption surveys every five years since 1993. Although these data represent a starting point for inventories, new techniques will be needed to ensure maximally accurate estimation procedures. Here, insights from the branches of GIScience related to spatial analysis and geostatistics (e.g., the use of spatial regression techniques) could be helpful, particularly given the propensity for spatial autocorrelation in the requisite socioeconomic data (Fotheringham 1997).

GIScience concepts also weigh on inventories of vegetation carbon sinks over large geographic extents with respect to scaling and remote sensing techniques. Ecosystem productivities, or measures of the carbon dioxide absorbed by plants through photosynthesis, have been mapped from stands to global levels based on ground measurements, ecological models, or both. For example, sampled crop harvest yields (kg carbon per acre) can be associated with cultivation areas to derive spatial rates of agricultural carbon assimilation (Prince et al. 2001). Advances in satellite sensors with large image swaths and rapid repeat cycles, such as the Terra Moderate Resolution Imaging Spectroradiometer (MODIS), allow the spatial heterogeneity of carbon fluxes to be captured at 1-km resolution for regional and global carbon accounting (Running et al. 2004; Zhao, Brown, and Bergen 2007).

The integrated spatial assessment of carbon balance that connects carbon sinks estimated using biophysical remote sensing to emissions accounting based on socioeconomic data is still at an early stage of development. GIScience can help support these activities, as there are opportunities for comprehensive analyses leading to detailed profiles of human-related carbon activities (Wise et al. 2009), including identifying source and sink hotspots and examining relationships between landscape dynamics and carbon sustainability. In this context, one of the most prominent trends is the rapid growth of urban populations and settlement areas (Theobald 2001). Although the impacts of these changes on carbon emissions and sinks are still inconclusive, it is widely held that the ongoing growth in urban populations will have profound impacts on global energy consumption and emissions. The vast urban modeling expertise within the GIScience literature is relevant (Batty 2005; Zhang and Guindon 2006; Horner 2010), as ongoing work seeking to measure urban morphology (Herold, Scepan, and Clarke 2003; Ji et al. 2006), for example, can inform the development of new carbon balance estimation methods. In sum, several GIScience knowledge areas underpin key aspects of the emerging area of spatially coupled carbon balance estimation and landscape evaluation.
Energy Infrastructure Placement and Transition

As the world moves toward adopting alternative means of producing energy, new infrastructure systems will likely need to be integrated into existing landscapes (Zimmerer 2011). The placement of production, transmission, and distribution facilities is subject to a variety of complex considerations ranging from minimizing possible impacts on the environment and biological habitats, particularly when converting undeveloped land (McDonald et al. 2009), to addressing population equity concerns (Marsh and Schilling 1994). There are examples in the literature where GIS and spatial modeling approaches are being applied to problems involving energy infrastructure, including the placement of wind farms for electricity production (Rodman and Meentemeyer 2006; Simao, Densham, and Haklay 2009) and siting alternative fuel refueling stations for vehicles (Nicholas, Handy, and Sperling 2004; Kuby and Lim 2007). In this context, spatial modeling implies using quantitative methodologies including spatial optimization techniques to address various location-oriented questions in the face of scarce resources or conflicting interests (ReVelle and Eiselt 2005).

Spatial modeling has an important role in research aimed at designing the energy infrastructures of tomorrow. Beyond the nominal questions of where infrastructures should be placed, subject to resource and financial constraints (DeVerteuil 2000), there are inherent social and environmental questions underlying such decisions (Talen 2001; Horner and Downs 2008). These considerations will be paramount in future infrastructure location projects as planners simultaneously seek to minimize impacts to disadvantaged population groups, sensitive habitats, water systems, and the like (McDonald et al. 2009). Moreover, residents often protest new energy infrastructure projects due to NIMBY (not in my backyard) concerns that usually involve perceived negative impacts on property values, community health, or both. These efforts can derail or slow the development of new energy facilities, particularly in the cases of wind farms, where there is a clear visual impact (Rodman and Meentemeyer 2006), or biomass plants, where residents might object to these facilities being proximal to their neighborhoods (Upreti 2004).

Given that the siting of infrastructure elements is informed by spatial analyses, GIScience is particularly well suited to contribute to research and policymaking in these areas. There will be opportunities for designing new model structures that better capture the many competing needs in infrastructure siting. In this way, researchers will not only have to think critically about representation and characterizations of “space” in model constructs (Miller and Wentz 2003; Goodchild, Yuan, and Cova 2007), but they will also need to push the envelope in terms of developing policy-applicable methodologies.

Focusing on representation in GIScience and spatial models, there has been substantial effort devoted to this issue. From relaxing the binaries inherent to discrete space (Murray 2005), to producing detailed assessments of the impacts of aggregate spatial data on model solutions (Francis et al. 2004), there are several representational issues that bear on future energy model development. As these models are typically expected to reinforce positive societal outcomes (e.g., maximizing equal access to a facility), their results are potentially compromised by poorly chosen spatial inputs. Going forward, productive synthesis could entail more discussion about how space manifests itself in spatial models of energy facility location.

Future energy work involving spatial modeling also offers GIScience a new venue in which to tackle traditional theory–practice divides in terms of getting meaningful information to practitioners and people who need it (Ligmann-Zielinska and Jankowski 2007). There is a role for GIScientists interested in facilitating public participation and collaboration through geospatial technologies (Elwood 2008; Sidlar and Rinner 2009). Many new energy facilities and infrastructures are perceived as noxious or undesirable (Berman and Huang 2008), so the challenge for modeling efforts will be to propose solutions that can be implemented given social and environmental justice concerns (Mennis and Jordan 2005). This process will involve incorporating stakeholder involvement as well as communicating key geospatial issues (Elwood 2008). The potential interface between spatial modeling efforts, geospatial collaboration, and participatory GIS in the context of energy studies can be mutually beneficial. This could spur new model developments that are more attuned to issues of representation, social and environmental context, real-world implementation, and so on, as well as offer new territory for theory and application with regard to participatory GIS. So, too, would energy facility location studies gain from the availability of more holistic and representative modeling methodologies.

Household Energy Conservation and Efficiency

We previously mentioned prospective large-scale policy efforts intended to curb and regulate GHG
energy decision making is ripe for such analysis. More
themselves (Monclar et al. 2009), and household en-
abling reexamination of information diffusion processes
digital social media technologies portends a continu-
(Zahran et al. 2008). Moreover, the pervasiveness of
why households make certain energy-saving adoptions
berg 2009) in terms of the factors that might explain
(2008; Cantono and Silver-
) have bearing on these energy issues
(McEachern and Hanson 2008; Cantono and Silver-
problems, including industrial sites and large corporations.
Although households are typically not targeted directly,
they would bear some burden as private entities pass
along some of their compliance costs to them. As such,
questions about how to encourage more sustainable en-
energy use at the household level are likely gain traction in
coming years. This raises two interrelated possibilities
for future research involving GIScience. One emanates
from attempts to model household behavior given vari-
ous energy conservation and efficiency policy proposals,
whereas the second examines household energy con-
sumption behavior specifically related to transportation
expenditures.
Taxes, user charges, fees, and other pricing mech-
isms are among the most common policy tools for
affecting individual behavior, but owing to the polit-
ical challenges faced when pursuing these strategies,
pricing mechanisms have been employed sparingly to
reduce carbon emissions and promote energy conserva-
tion. For example, in North America, there was only
one case of carbon taxes being paid by households, as
a tax was established in 2008 in British Columbia on
virtually all household fuels consumed, including those
used in transportation (Litman 2009). In the United
States, policy remedies for encouraging more sustain-
able household energy consumption have largely con-
isted of incentives or “carrots” (Coad, de Haan, and
Woersdorfer 2009), such as reductions in taxes for pur-
chasing a more energy-efficient or alternative fuel ve-
cicle, upgrading household appliances to more energy-
efficient models, or pursuing energy-sustainable housing
improvements, including better insulation, multipane
windows, or solar panels on rooftops. Assuming that fu-
ture household-level policy instruments will take a sim-
ilar incentive-based form, more research will be needed
to understand behavioral responses to these policy pre-
scriptions and the subgroups that choose to adopt (or
ignore) incentives.
Long-standing geographical research foci in inno-
vation and information diffusion (Hagerstrand 1967;
Brown 1999) have bearing on these energy issues
(McEachern and Hanson 2008; Cantono and Silver-
berg 2009) in terms of the factors that might explain
why households make certain energy-saving adoptions
(Zahran et al. 2008). Moreover, the pervasiveness of
digital social media technologies portends a contin-
ing reexamination of information diffusion processes
themselves (Monclar et al. 2009), and household en-
ergy decision making is ripe for such analysis. More
broadly, within the span of factors affecting house-
hold efficiency decisions, understanding the influence
of social networks is a potential area for increased re-
search. It is recognized that social networks play an
important role in consumer choices, such as how peo-
ple choose a travel mode (Dugundji and Walker 2005)
or structure their daily activities (Carrasco and Miller
2009). When viewed in this fashion, households be-
come agents within complex systems shaped by both
interactions with top-down policies as well as inter-
nal interactions and lateral connections to other indi-
viduals, households, and system actors. Thus, behav-
ioral responses to energy policies are contingent on
emergent elements of the system including outcomes of
information diffusion through social networks. Dur-
ing the last several years there have been significant
advances in the modeling of complex spatial systems
using agent-based models (Torrens 2006; Xie, Battty,
models to explore household reactions to energy poli-
cies (Nannen and van den Bergh 2010), such as incen-
tives to purchase a fuel-efficient vehicle (Mueller and
de Haan 2009), is an area for future syntheses. Oppor-
tunity for even deeper engagements could also come in
the form of exchanges between energy researchers and
those with interests in complex systems theories (Man-
son 2001; Ligmann-Zielinska and Jankowski 2007). As
discussions of geographic complexity have been situ-
ated within the literature on land-use and land-cover
change processes (Evans, Sun, and Kelley 2006; Man-
son 2006), prospects exist for new extensions such as
examining the urban form dynamics associated with
energy issues.
Household transportation behavior is another area
for increased attention. Approximately 25 percent of
energy consumed in the United States in 2006 was from
motor vehicles (Akinci et al. 2008). Moreover as much
as 33 percent of CO₂ emissions in the United
States are from the transport sector (Ewing et al. 2008).
One set of ideas proposed to reduce household travel looks
at whether it is possible to save transportation energy
through changes to land use (Horner 2008). Although
there is inherently a question of choice in terms of where
people live and where they choose to partake in activ-
ities (Levine 1998), “smart growth” advocates argue
that the mixing of desirable destinations across a het-
erogeneous urban landscape can yield shorter trips and
energy savings (Ewing et al. 2008; Stone 2008). Con-
versely, more segregated land-use patterns are thought
to yield more energy-intensive travel because there is an
inherent “built-in” distance that must be overcome to
link people to destinations. Transportation specialists have sought to develop more theoretically sound models of transportation behavior to better address such questions (Miller and Shaw 2001). Moving forward, increasingly detailed simulations of human activities could allow researchers to examine how well particular land-use changes would produce improvements in transportation resource consumption (Waddell et al. 2007). Historically, there have been strong links between the GIScience and transport fields (Thill 2000). These should be expanded to explore new computational approaches that investigate the energy-saving benefits of development patterns.

Methods aimed at exploring household energy consumption are data-hungry by nature. For example, agent-based models require empirical data for their construction and validation. Information on individuals is necessary to understand decisions such as solar energy adoption rates (Sidiras and Koukios 2004) and transportation choices (Boussauw and Witlox 2009). Also necessary are data on the availability of infrastructure and the physical environment (Beccali et al. 2009). As we suggested earlier, how these data are captured spatially has important implications for how they can be used and the questions energy researchers are able to ask. Researchers have lamented the difficulties of combining the diverse spatial data sets necessary to comprehensively analyze energy questions within GIS (Ewing, Pendall, and Chen 2003), particularly for large-scale analyses (Parshall et al. 2010). As such, mutual interests in matters of data fusion (Beccali et al. 2009) as well as the aforementioned areas of spatial interpolation (Goodchild, Anselin, and Deichmann 1993) and spatial representation issues (Miller and Wentz 2003) could generate new dialogue. There has been a trend in spatial analysis toward using more disaggregate, individualized information, especially with regard to households and transportation questions (Kwan and Weber 2003). How new individual-level disaggregate data sources can be incorporated into household energy studies to enhance their representativeness, while living within the limits of computational tools (Wang and Liu 2009), will be a critical issue for future work.

Toward Research Opportunities in Energy and GIScience

We have argued that although there are examples of researchers using GIS and other geospatial technologies to address energy issues, as well as many possible areas of shared research interest, to date there has been limited engagement between those interested in GIScience and those interested in energy research, broadly defined. Energy issues offer significant research challenges for GIScience, particularly within the context of spatio-temporal inventories and models of energy behavior and emissions production, decisions regarding the placement of facilities that are environmentally viable and socially equitable, and the assessment of energy savings and land-use policies’ efficacy and political feasibility. There are many potential opportunities for future synergies to develop, synergies that can both inform the knowledge base in energy systems and push the boundaries for GIScience research. Perhaps more important, work at the nexus of energy and GIScience can contribute to longer run efforts to become more energy sustainable.

We have identified three broad problems to which geospatial technologies are already contributing solutions, but where new interactions between energy researchers and those interested in GIScience seem particularly well-suited to yield deeper insights. Naturally, future GIScience contributions will not be limited to these topics. Within these subject areas we noted that good solutions are contingent on the basic science underlying GIS. From scale and representation in computational models to data fusion, interpolation, and extrapolation techniques, GIScience should be a more prominent part of new research efforts seeking to foster energy sustainability. No doubt as others contemplate future possible integration between energy and GIScience, they will see other opportunities we did not detail. Besides other energy problem areas on which we might have focused (e.g., the environmental impacts of certain types of energy uses), there are additional cross-cutting GIScience themes that could bear relevance in the future (e.g., spatial uncertainty). Our hope is that this work helps to propel further discussion and action regarding the opportunities that exist at the intersection of energy studies and GIScience.

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