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The future of agriculture and society in Iowa: four scenarios

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Iowa is a leader in crop and livestock production, but its high productivity has had concomitant negative environmental and societal impacts and large requirements for fossil-fuel-derived inputs. Maintaining agricultural productivity, economic prosperity and environmental integrity will become ever more challenging as the global demand for agricultural products increases and the resources needed become increasingly limited. Here we present four scenarios for Iowa in 2100, based on combinations of differing goals for the economy and differing energy availability. In scenarios focused on high material throughput, environmental degradation and social unrest will increase. In scenarios with a focus on human and environmental welfare, environmental damage will be ameliorated and societal happiness will increase. Movement towards a society focused on human and environmental welfare will require changes in the goals of the economy, whereas no major changes will be needed to maintain focus on high throughput. When energy sources are readily available and inexpensive, the goals of the economy will be more easily met, whereas energy limitations will restrict the options available to agriculture and society. Our scenarios can be used as tools to inform people about choices that must be made to reach more desirable futures for Iowa and similar agricultural regions.

Keywords: agricultural productivity; ecosystem services; energy availability; genuine progress indicator; scenario planning; systems thinking

Introduction

A major challenge for agriculture in the 21st century is the need to produce adequate amounts food while protecting environmental quality and the health of rural communities (NRC 2010). This challenge is especially apparent in Iowa – the heart of the United States Corn Belt. With

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fertile soils, adequate rainfall, abundant agricultural technology and 85% of the state's land area devoted to farming, Iowa leads the USA in the production of corn, soybean, ethanol, eggs and hogs; farm revenues exceeded $25 billion within the state in 2008 (NASS 2009). However, conventional farming in the Corn Belt is heavily reliant on fossil-fuel inputs embodied in synthetic fertilizer, machinery fuel and natural gas for grain drying (Miranowski 2005, Cruse *et al*. 2010). As such, in the coming decades the challenge of maintaining high levels of agricultural productivity is likely to become more difficult in Iowa, with increased volatility in price and supply of fossil fuels.

Concomitantly, Iowa ranks high nationally in the number of surface waters impaired by agricultural nutrients, pathogens, pesticides and soil sediment, and its croplands are major contributors to the hypoxic zone in the Gulf of Mexico (Gilliom *et al*. 2006, Alexander *et al*. 2008). Iowa ranks last among the 50 states in the amount of native vegetation still remaining; a historically rich diversity of native flora and fauna has been greatly reduced (Samson and Knopf 1994). Despite abundant production of crops and livestock, Iowa farmers received $3.8 billion in federal commodity programme payments during 2003–2005 (EWG 2009). Seventy-five of Iowa's 99 counties lost population between 2000 and 2008 (IDC 2009), and 42 of its counties have per capita income levels $<$80% of the national average (CIRS 2009).

Methods

Scenario planning was used to examine interactions among agriculture, the environment and society (Razak 1996). Scenarios are 'plausible, challenging, and relevant stories about how the future might unfold. . . . Scenarios are not forecasts, projections, predictions, or recommendations. They are about envisioning future pathways and accounting for critical uncertainties' (Raskin *et al*. 2005). Scenarios are best suited to exploring situations where uncertainty is high and controllability is low (Peterson *et al*. 2003). For example, energy prices and economic framing are largely beyond the control of a region such as Iowa. Here, scenarios can help us to illuminate the consequences of these global drivers of change and to formulate robust local responses. Importantly, scenarios can help us to reveal key branching points in the future (Gallopín 2002), and policy and value changes that may be required to achieve a particular future outcome. Thus, scenarios can facilitate transition processes.

Scenario development

Four scenarios were developed by a team of biophysical and social scientists in consultation with farmers, governmental officials, administrators and citizens to better understand key uncertainties about the future: potential trade-offs in the quantity, quality and flows of ecosystem services; and implications for human well-being. The opportunity to develop scenarios for three counties in central Iowa emerged during a course conducted during the fall of 2009.

We began by speaking with agricultural stakeholders around the state. These included conventional and organic crop farmers, dairy and pork farmers, public waterworks employees, private investors, farm advocacy employees, researchers, ethanol plant employees and wind farm employees. Each person was asked three questions:

(1) What is the current status of agriculture in Iowa?
(2) Where is agriculture going?
(3) What is your vision for a better food system in Iowa?

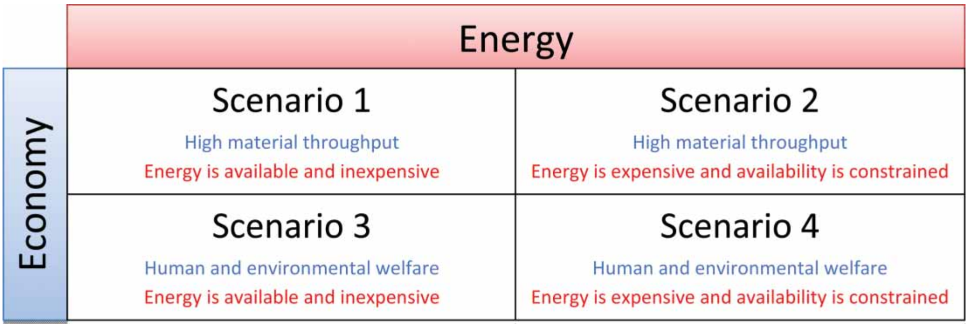

Figure 1. Scenario descriptions based on differing economic goals and energy availability/cost. Economic goals are high material throughput versus increased human and environmental welfare. Energy availability and cost are readily available and inexpensive energy versus expensive energy that has constrained availability.

Responses to these questions were compiled as a guide to developing the scenarios. We followed a commonly used scenario–axes method and developed four scenarios (Figure 1) around two axes of uncertainty (MEA 2005). The year 2100 was chosen as the endpoint for our scenarios. Axis one was based on the assumption that agriculture relies heavily on inexpensive and readily available energy, and that major disruptions in energy supplies can have dramatic effects (Smil 2008). Axis two relied on understanding the way the economy is framed, including understanding both the explicit goals and implicit assumptions of the economy. It was based on an assumption that the explicit goal of the US economy is continuous economic growth, as measured by the gross domestic product (GDP). An alternative goal for the economy is to increase human well-being through enhanced development without exceeding the resource base (Daly and Farley 2004).

Four plausible scenarios were thus developed for Iowa 2100, based on combinations of differing economic goals and energy availability and cost (Figure 1). In Scenarios 1 and 2, the goals and structure of the economy are organized to emphasize and facilitate high material throughput – the extraction of natural resources, their transformation into market goods by production and their disposal as waste. In Scenario 1, energy is available and low-cost; in Scenario 2, the energy supply is constrained and high-cost. In Scenarios 3 and 4, the goals and structure of the economy are renovated to emphasize and facilitate human and environmental welfare. Again, we envision the effect of energy availability and cost by contrasting the third scenario, where energy is readily obtainable and inexpensive, with the fourth scenario, where energy is limited and expensive. Details within each of the four scenarios were based on ideas revealed by stakeholders.

Focal area of analysis

The scenarios focus on Hamilton, Story and Polk Counties in central Iowa (41–42°N and 93°W) (Figure 2). These counties are representative of Iowa more broadly and contain a range of land uses from agricultural to urban. Approximately 1,500 km^2 each, all are nearly equal in size (US Census Bureau 2009). Virtually all of Hamilton and Story Counties are dedicated to agriculture, 94 and 96%, respectively, whereas 66% of Polk County is used for agriculture (Otto and Parkinson 2008a, b, c). Hamilton County is rural with 15,000 residents. Story County has a population of 87,000, with most of the residents living in the Ames metropolitan area. Polk County is the most populated county in Iowa with 425,000 residents, most of whom live in the Des Moines metropolitan area (US Census Bureau 2009).

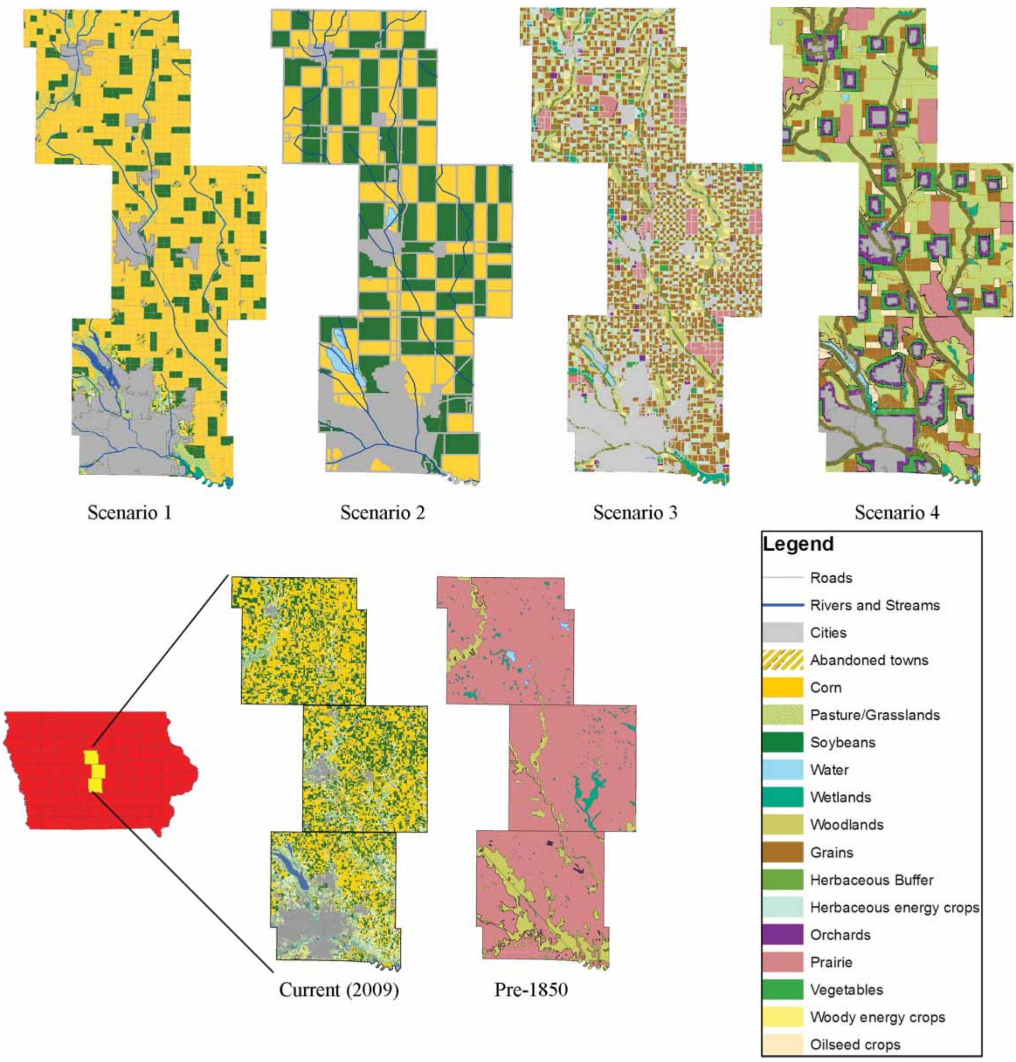

Figure 2. Land-use maps of Hamilton, Story and Polk Counties in Iowa for Scenarios 1–4 (top row), 2009 and pre-1850s (bottom row). In *Scenario 1* field sizes will increase (mean = 250 ha) and become dominated by corn production. Urban and suburban regions will expand, whereas small towns will become abandoned. In *Scenario 2* corn and soybean will be grown on dramatically larger fields (mean = 3,000 ha). Urban regions will contract and small towns will be converted to agricultural production. The landscape will be diversified in *Scenario 3* through the use of more crops and re-incorporating livestock into the land. Field sizes will be smaller (average field size will be less than 100 ha). Urban areas will have condensed, and small towns will be repopulated. In *Scenario 4*, most of the land will be in grasslands for livestock grazing or conservation. Agricultural production will be concentrated near urban area to minimize the distances that agricultural products must travel to reach consumers. The data source for the 2009 land-use map was Iowa NRGIS Library (www.igsb.uiowa.edu/webapps/nrgislibx/). The pre-1850 map was derived from the General Land Office surveyor field notes and township plat maps.

The importance of agriculture to the economies of Hamilton, Story and Polk Counties also differs greatly. One indicator of the importance of agriculture to the counties is livestock density. The livestock populations in these three counties – primarily hogs and cattle – are inversely related to the population densities. More than 1.12 million livestock were sold in Hamilton

County in 2007, making the livestock to person ratio 73:1 (Otto and Parkinson 2008a). In Story County there were twice as many livestock sold in 2007 as county residents (Otto and Parkinson 2008b), whereas in Polk County there were 7.6 times more people than livestock (Otto and Parkinson 2008c). In Hamilton County, 20% of the jobs are related to agriculture (Otto and Parkinson 2008a), whereas in Story and Polk Counties, agricultural jobs comprise 11 and 3% of the total workforce, respectively (Otto and Parkinson 2008b, c).

Scenario evaluation methods

Land-use maps and photorealistic visualizations of farm landscapes were constructed to aid in the evaluation of the scenarios (Figures 2 and 3). The maps compare major land uses among the scenarios as well as historical land-use patterns. The photorealistic visualizations are based on a central Iowa landscape and are bounded by its biophysical attributes. In the forefront of each is a farmstead whose structure and function illustrate how the adjacent agricultural systems are organized. Waterways and wetlands are present to indicate the role of water in each scenario. In addition to using visualizations to compare the scenarios, we compare the specific agricultural and social characteristics of each scenario as it relates to agricultural productivity, ecosystem services, socioeconomic outcomes and policy.

Results and discussion

Agricultural productivity

The definition of what is considered 'productive' differs among scenarios. When more than the provisioning ecosystem services (i.e. saleable goods) provided by agricultural systems are valued – as they are in Scenarios 3 and 4 – the concept of productivity includes a broad suite of ecosystem services provided by the system. In this section, however, we restrict the definition of productivity to include only saleable agricultural goods to make comparisons among all scenarios. These goods primarily include grains, livestock, fruits and vegetables, and energy crops.

In Scenarios 1 and 2, commodity grain production will increase, whereas the converse will occur in Scenarios 3 and 4. Due to intense investment in corn and soybean breeding technology in Scenario 1, yields will increase at 3.4 and 2.4% annually, respectively – double historic increases in yields (Egli 2008). Large annual harvests will provide sufficient grains for livestock feed, energy production and human food. Corn and soybean will be grown in Scenario 2, but crop breeding programmes will focus on developing crops that use resources more efficiently, such as increased nitrogen-use efficiency, increased pest resistance and increased performance under no-till conditions, which will maintain yields at levels similar to 2010. In Scenarios 3 and 4, multiple crops will be grown and cropping systems will be designed to enhance ecosystem services and system resilience. For example, perennial species and cover crops will be integrated into grain production systems (Boody *et al*. 2005). In Scenario 4, grain production will be further integrated into diversified systems designed to persist with low external inputs and environmental variability.

In Scenario 1, demand for animal products will steadily increase. Concentrated animal feeding operations (CAFOs) will continue to grow in size and number (Figure 3). In Scenario 2, there will be a general decrease in demand for animal products globally. What remains in this scenario of industrialized livestock production will be heavily subsidized. In Scenario 3, there will be sufficient energy to raise animals for meat. However, Iowans' meat consumption will decrease from current levels (over 100 kg meat/person · year) to the 1950s levels (65 kg meat/person · year) due to increased costs as animal welfare and environmental issues are internalized into the cost

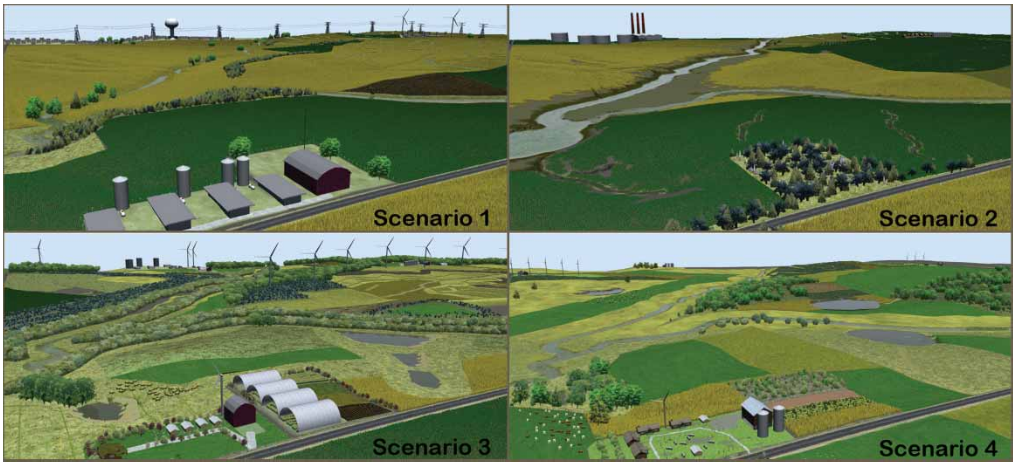

Figure 3. Photorealistic depiction of the Iowa countryside for each scenario. *Scenario 1* is a countryside dedicated to agricultural productivity; fields of annual row crops dominate although suburbia is encroaching on the horizon. A CAFO and a large machine shed have replaced a previous homestead. Conservation practices are used only where it is economically beneficial. In *Scenario 2* soybeans must be grown for their nitrogen fixation, and deep gullies result from soil erosion on even moderate grades. The crops in low-lying areas have been lost to flash flooding, abetted by extensive subsurface drainage. The farmstead has been abandoned. In the distance a refinery produces biodiesel for local distribution. In *Scenario 3* field crop production consists of a variety of annual and perennial grain and biomass crops as well as a mosaic of warm- and cool-season grasses used for forage and biomass. Vegetable crops are grown outside in the summer and year round inside large greenhouses. Native prairies, interspersed with hybrid tree plantations, form a riparian buffer network. Reconstructed wetlands and associated upland habitat are managed as part of the commons sector for multiple benefits including human recreation, wildlife habitat, flood mitigation and nutrient transformation. On-farm energy generation facilitates a large single-family dwelling and a technologically advanced farm operation. On the horizon there is a densely populated city centre. In *Scenario 4* much of the countryside has been replanted or reverted to perennial vegetation. Integrated crop-livestock systems rely heavily on human ingenuity and labour. The farmstead is home to multiple families living in modest sized dwellings and acts as the hub for numerous farm enterprises (including cattle, hog, sheep and poultry production; fruit, nut and fuel-tree production; and vegetable and fibre production). Riparian buffers and wetlands protect the water supply as well as serve as a forage reserve in the case of drought. Images created with Visual Nature Studio 3 (3D Nature) by Larsen, Landscape Ecology and Sustainable Ecosystem Modeling Lab, Iowa State University.

of production (IAPC 2008). In Scenario 4, livestock will be managed as tools to maintain ecosystem health, including recycling nutrients, maintaining desired ground cover and wildlife habitat, as well as sources of human food (Figure 3) (Holechek *et al*. 1982).

In 2007, fruit and vegetable farms covered less than 5,000 ha in Iowa – 0.04% of the state's total land area (NASS 2007) – and approximately 10% of the fruits and vegetables that Iowans consumed came from within the state (CTRE 2009). In Scenarios 1 and 2, the production of fruits and vegetables in Iowa will decline to less than 1% of the food consumed in Iowa because of the continued focus on commodity grain crop production. In contrast, fruit and vegetable production will increase in Scenarios 3 and 4. In Scenario 3, approximately 50% of the fruits and vegetables consumed by Iowans will be produced in Iowa on 3–7 ha farms, which rely heavily on both outdoor and greenhouse production (Figure 3). In Scenario 4, fruit and vegetable production will occur primarily in urban areas in home, rooftop and neighbourhood gardens, and more than 90% of the population will participate in some form of food production (Figure 2).

In 2010, the USA produced more than 51 GL of biofuels. Ninety-eight per cent of these fuels were corn grain ethanol (EIA 2011), which required 55% of Iowa's corn crop (ICGA 2011). In each scenario, bioenergy will be produced from plant biomass, but the form of biomass and energy produced will differ. Biofuels will be the primary bioenergy produced in Scenarios 1 and 2. Corn grain and stover will continue to be the primary biofuel feedstock in Scenario 1, whereas soybean will be the primary feedstock in Scenario 2. Multiple forms of bioenergy, such as heat, electricity and biofuels, will be produced from biomass in Scenarios 3 and 4. High-yielding perennial plants that are environmentally beneficial, such as prairie plants, will be grown for biomass in Scenario 3 (Figure 3) (Tilman *et al*. 2009). In Scenario 4, 'waste' materials, such as crop residues, municipal waste and tree thinnings, will be the primary feedstock for bioenergy production (Tilman *et al*. 2009).

Ecosystem services

Ecosystem services refer to the natural processes by which ecosystems support and sustain human life (MEA 2005). How agricultural systems and the broader landscape are managed greatly affect the quantity and quality of the ecosystem services. Because natural resources will be viewed as unlimited and readily interchangeable in Scenarios 1 and 2, most ecosystem services will not be economically valued. Conversely, in Scenarios 3 and 4 natural resources will be viewed as finite and not interchangeable and most ecosystem services will be valued (Daly and Farley 2004). In Scenario 3, many environmental resources and services become part of an expanding commons sector that is collectively managed but not owned (Figure 3). In Scenario 4, all urban and agricultural land will be managed for multifunctionality, including ecosystem services (Boody *et al*. 2005). We compare the provisioning of these ecosystem services related to water, biota, soil, air and culture among the four scenarios.

Water regulation

Precipitation in Iowa is expected to increase in the coming century with an increased frequency of high-intensity rainfall events (US GCRP 2000; Gutowski *et al*. 2007) such as the catastrophic flooding that occurred in Iowa in 2008. Interactions between precipitation and landscape management will have dramatic impacts on both water quantity and quality. More of Iowa's landscape will be devoted to row-crop production in Scenarios 1 and 2, which will increase the amount and rate of water leaving the landscape (Figure 2). The amount of water stored in the soil is lower under row-crop systems versus perennial systems (Brye *et al*. 2000), and water infiltration rates are five times lower under row-crop systems than under multi-species perennial systems (Bharati *et al*. 2002), which means that more water will leave the field as surface runoff. This will be exacerbated in Scenario 2 because nearly all perennial vegetation will be removed to increase field sizes (Figure 3). Because the landscape in Scenarios 3 and 4 will have large amounts of perennial vegetation, surface-water runoff will be greatly reduced.

Subsurface water flow will also differ among the scenarios. Iowa is part of the prairie pothole region that is characterized by numerous, small, depressional wetlands (Blann *et al*. 2009). While wetlands perform critical ecosystem services such as slowing water movement across the landscape, mitigating floods and droughts, purifying water and providing wildlife habitat, approximately 99% of Iowa's wetlands have been eliminated through drainage ditches and subsurface drainage (Mitsch *et al*. 2005, Sugg 2007). Subsurface drainage accounts for 85% of the drainage in the state and has been installed under approximately 32% of the cropland statewide (Sugg 2007), allowing water to move more quickly from uplands into waterways (Skaggs *et al*. 1994). In order to accommodate the increased row-crop production in Scenarios 1 and 2, more subsurface drainage will be installed, and Iowa's prairie potholes will be eliminated (Figure 3). This will result in increased subsurface water flow and increased flooding frequency and severity in Scenarios 1 and 2 (Kunkel *et al*. 1999). Wetlands will be reincorporated into the landscape in Scenarios 3 and 4 by breaking subsurface drains and allowing natural hydrologic patterns to reestablish (Figure 3). This will reduce the volume of subsurface water flow and reduce the frequency and severity of flooding (Mitsch and Gosselink 2000).

In addition to changes in the quantity of water moving across the landscape, water quality is affected by how the landscape is managed. Section 303 of the Clean Water Act sets standards for water quality, and those water bodies that have substandard water quality are classified as 'impaired' (EPA 2009). Less than 20% of Iowa's water bodies are classified as not impaired and more than 25% are classified as impaired (the remaining water bodies have not been sufficiently tested) (Iowa DNR 2009). The main causes of impairment are bacterial contamination, excess nutrients and increased turbidity (Iowa DNR 2009). Increases in row-crop production and CAFOs in Scenario 1 will increase water quality impairment (Blann *et al*. 2009). Water quality in Scenario 2 will be similar to water quality in 2010 due to offsetting changes in agricultural production: reductions in tillage, nutrient applications and the number of CAFOs juxtaposed with elimination of wetlands and riparian buffers (Figure 3). Water quality will improve in Scenarios 3 and 4 because more of the landscape will be in perennial vegetation and animal production will not occur in CAFOs. A major factor in increasing water quality, however, will be the reestablishment of wetlands. One effect of reestablishing small, depressional wetlands is that water flow will become more localized around individual wetlands with fewer large linear networks, which reduces the sphere of influence for any polluting activity (Blann *et al*. 2009).

Biotic resources

Pest regulation, pollination and wildlife habitat are three important biotic ecosystem services that will differ among the scenarios. Scenarios 1 and 2 will rely heavily on therapeutic measures for pest regulation, whereas agricultural systems will be designed to intrinsically limit major pest outbreaks in Scenarios 3 and 4 through the use of longer rotations, more complex landscape structure, polycultures and planned refugia for natural pest enemies (Lewis *et al*. 1997). Scenario 2 will be especially susceptible to crop failures because no-till cropping systems often require higher rates of herbicide use (Liebman *et al*. 2001), but high costs of herbicides and the evolution of herbicide resistance in weeds will limit their availability and efficacy. Synthetic biocides will be used sparingly in Scenario 3 as an occasional supplement to the multiple biological forms of pest control methods used (Lewis *et al*. 1997). Pest control in Scenario 4 will rely almost exclusively on ecologically based pest management strategies due to the limited availability of synthetic biocides.

Pollinators require sufficient food resources and habitat throughout the year in order to thrive. Wind-pollinated plants, such as corn, do not provide abundant food resources and annually harvested plants generally do not provide sufficient pollinator habitat. Many native prairie forbs are excellent food sources for pollinators in addition to some non-native forbs, and standing vegetation throughout the year provides sufficient habitat (Landis *et al*. 2000, Fiedler and Landis 2007). Pollinator populations will decline in Scenarios 1 and 2 because of the expansion of annual row crops and reductions in area of native vegetation, whereas pollinator populations will increase in Scenarios 3 and 4 because the landscape will become more heterogeneous and native vegetation will be reestablished (Figure 2).

Wildlife habitat is loosely included under the ecosystem services umbrella because wildlife benefit from this service more than humans – and ecosystem services are generally defined based on the benefits to humans. Wildlife habitat will decrease in Scenarios 1 and 2, but some habitat will remain in Scenario 1 because wealthy individuals will pay to conserve game-animal habitat for use in hunting (Herkert 1994). In Scenario 2, hunting as a recreational activity will decline due to insufficient money available for recreational activities and for taking land out of production. In Scenarios 3 and 4, people will intrinsically value maintaining wildlife on the landscape. In Scenario 3, wildlife habitat will be actively managed. For example, every county will have at least one large prairie restoration in addition to multiple satellite prairie patches (Figure 2). In Scenario 4, wildlife habitat will primarily occur in the land that is farthest from cities and towns because this landscape will not be heavily managed by people due to the lack of resources needed to manage the land (Figure 2).

Soil quality and nutrient cycling

Soil quality will decrease in Scenarios 1 and 2 due to increases in soil erosion, whereas soil quality will increase in Scenarios 3 and 4 due to decreased soil erosion rates. In Scenario 1 soil erosion rates will increase as soil conservation practices are abandoned. Although no-till crop production will be adopted in Scenario 2, soil erosion rates will increase because marginal and highly erodible land will be put into row-crop production (Pimentel 2006). Scenarios 3 and 4 will include more perennial vegetation and cover crops that will reduce erosion rates (Kennedy and Smith 1995, McLauchlan *et al*. 2006).

Nutrient cycling and waste treatment greatly affect soil and water quality. In Scenarios 1 and 2 there will not be a focus on enhancing soil and water quality. Because surface and subsurface runoff will increase in Scenarios 1 and 2, high concentrations of nutrients will continue to be transported out of Iowa and will be deposited into large water bodies such as the Mississippi River and eventually the Gulf of Mexico (Blann *et al*. 2009). These lost nutrients will have to be replaced. In Scenario 1, nitrogen fertilizers will continue to be derived from petroleum-based sources, whereas those sources will be too expensive in Scenario 2, and farmers will rely heavily upon biological sources, such as microbial nitrogen fixation. Re-incorporation of perennial vegetation, biotic diversity and wetlands into the landscape in Scenarios 3 and 4 will improve soil quality and water retention, which will reduce the long-distance transport of nutrients (Figure 3) (Kennedy and Smith 1995; Hooper and Vitousek 1998). In Scenario 4, there will be a heavy emphasis on cycling nutrients. Diverse plant populations will be selected to fill multiple niches necessary to capture resources at different times of the year and at different levels of the soil profile. Animal and human wastes will be composted and otherwise transformed into nutrient-rich soil amendments.

Atmospheric gas regulation

The structure and functioning of a landscape affect the global climate. In Iowa, the management of agricultural landscapes is a major source of greenhouse gas emissions (Larsen *et al*. 2007). Scenario 1 will have extensive subsurface drainage, tillage, application of fertilizer and CAFOs, which will result in increased emissions of carbon dioxide, methane and nitrous oxide (Phelteplace *et al*. 2001, Lal 2007, Lassey 2007). There will be fewer emissions in Scenario 2 than in Scenario 1 because tillage, fertilizer and animal agriculture will become too expensive to use extensively. Scenarios 3 and 4 will both offer opportunities to sequester carbon through increased perennial vegetation (Post and Kwon 2000, Lal 2007). Decreased greenhouse gas emissions will also result from decreases in the overall consumption of animal products. In Scenario 3, greenhouse gas emissions from animals will be further reduced because ruminants will be bred to reduce the amount of methane they emit (Hegarty *et al*. 2007).

Cultural resources

Ecosystems provide numerous cultural resources such as aesthetic, spiritual and recreational benefits. The cultural resources provided by ecosystems will not be heavily valued in Scenarios

1 and 2 because these resources do not contribute to the overarching goal of high material throughput. Cultural resources will be valued in both Scenarios 3 and 4. In Scenario 3, people will have large amounts of leisure time and will have money to spend on the cultural resources that are of value to them. For example, ecotourism to the large prairie reserves will be common (Figure 2). In Scenario 4, people will have less leisure time and less money to spend on cultural resources, but because they will be directly involved in obtaining their resources, people will develop stronger affective connections to the land such as the 'land ethic' described by Aldo Leopold (1949).

Socioeconomic outcomes

For each of the scenarios, we analysed the impact on society using two metrics: GDP and the genuine progress indicator (GPI). GDP uses only economic measures without regard for issues of equity or quality of life. GPI measures both economic and social progress, and the degree to which benefits are dispersed throughout society. GPI is used as a means of quantifying human well-being in terms of health, environmental integrity and access to basic services, such as housing, education, clean water and health care (Anielski 2002, Costanza *et al*. 2009).

GPI is a constructed number based on value judgments. Although this makes the measurement dependent upon the analysts' values, most values are derived from known data and predicted trends (Neumayer 1999, Clarke and Lawn 2008). As a means of comparing among the scenarios, we constructed relative GPIs for the four scenarios (Table 1) (Redefining Progress 2009). Using the current social, economic and physical environment as our baseline (a score of 0), each measurement was scored on a scale of -2 to 2, with negative numbers representing a decrease in GPI and positive numbers representing an increase. Final scores provide a relative ranking in changes in GPI across the scenarios.

In Scenario 1, health and environmental costs will continue to be externalized (↑GDP, ↓GPI). Labour will continue to become less skilled and more mechanized until it is completely replaced with computerized or remote technology. The trend towards vertical integration of agricultural production will continue. Downward pressures on wages will drive people to urban centres which will continue to expand into agricultural areas (↑GDP, ↓GPI) (Figure 2) (Gordon and Richardson 1997).

The population will enter a situation where more work hours will be required to maintain a static quality of life (↓GPI). Longer commutes and telecommutes will be made possible by increased use of personal automobiles and communication devices, respectively (Anderson *et al*. 1996). The old city centres will not be redeveloped because people with capital will be free to flee them (Orfield 1997, Rusk 1999). Poorer populations will cluster in areas with insufficient amenities and deteriorating infrastructure (↓GPI). In sum, GDP will continue to increase while the quality of life will decrease, resulting in a relative GPI score of -7 (Table 1).

In Scenario 2**,** agricultural production will be one of society's highest priorities and will command a disproportionate amount of the available energy (↓GDP). This will make it possible for current agricultural practices to continue as in Scenario 1, despite burgeoning energy costs. Day-to-day work will be done by low-skilled labour and managed by a few highly paid supervisors overseeing large tracts of land (↓GPI) (Figure 2). The consolidation of economic power will increase inequity and will exacerbate the exploitation of labour (↓GPI). A reduction in environmental quality will result in poorer human health and quality of life (↓GPI).

As in Scenario 1, the migration from rural to urban areas will continue (Forrester 1969). Automobile usage, however, will nearly cease due to energy restrictions and be replaced largely by public transportation (↓GDP) (Anderson *et al*. 1996). In sum, GDP will decline due to increasing

Table 1. Relative quality-of-life scores for Scenarios 1–4 for selected categories from the GPI.

GPI indicators	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Income distribution	Differences in income maintained by profit motive and inexpensive energy	Disparity between rich and poor increases; those with access to energy profit more than those without	Democratic decision to adjust taxation minimizes income disparity	Incomes equalized due to high costs for basic needs; taxation redistributes wealth
Crime	Crime remains stable; the cost of living is maintained, most immediate needs met	Increased disparity between the wealthy and the poor creates social unrest, crime increases	Technology improves law enforcement; crime low, people have basic needs met	Increased support for social programmes reduces social tension and crime
Resource depletion	Resources depleted at little monetary cost to Iowa's population	Most valuable resources depleted, complete extraction of resources not economically feasible	Energy derived from renewable sources, little resource depletion	Resource depletion slowed by awareness of consequences
Long-term environmental damage	Focus on immediate short-term profit creates irreversible environmental damage	Prioritizing profits over environmental welfare results in irreversible environmental damage	Long-term environmental damage not tolerated, previous damage will be reversed	Long-term environmental damage not tolerated, some past damage will remain
Changes in leisure time	Leisure time limited by focus on money-making activities, labour-saving, high-energy devices make work more efficient	Leisure time rare; working hours increase, lower classes exploited to substitute for energy	Leisure time highly valued, technology eases work loads	Leisure time important, but limited by the need for manual labour

Colour key					
	−2	−1	0	1	2

Five of the 10 GPI categories are shown above to demonstrate how scores were determined. Scores were assigned from −2 to 2 for each scenario in each category to represent relative changes compared to 2010 conditions in Iowa. Negative values represent a decrease in GPI and positive values represent an increase. The text in the boxes describes the factors that most strongly affected the relative GPI score.

energy costs and limits on production, and the GPI will decline to a relative score of −9, due to the exploitation of resources and labour (Table 1).

In Scenario 3, higher levels of technology and innovation maintain low-energy prices and create new opportunities for rural areas (↑GDP, ↑GPI). The proliferation of renewable-energy technologies and new agricultural enterprises will create numerous career opportunities for both agriculturalists and engineers (↑GDP, ↑GPI). Technology will allow for the efficient use of natural resources, which will enhance economic development and quality of life (↑GPI), but enforceable governmental policies will prevent increased consumption as efficiencies increase (i.e. Jevons' paradox). Energy and resources will be successfully invested in technological advancements that benefit the whole of society and enhance environmental quality.

Access to information will be recognized as a necessity for equitable knowledge, and publicly funded broadband internet will be available to everyone. Many individuals will be able to work online, which will help drive an increase in the population of small Iowa towns (Figure 2). As rural towns are revitalized, schools, grocery stores, convenience stores and clinics are reestablished providing access to health care, goods and services, and economic opportunities (↑GDP, ↑GPI). Increased community vitality leads to increased societal participation in the political process and better urban planning (↑GPI). Politicians will become genuine public servants with vantage points longer than 2- to 4-year electoral cycles, and legislation will be passed to reform campaign finance to 100% public support. In sum, there will be an increase in both GDP and GPI, with a relative GPI score of +12 (Table 1).

In Scenario 4, expensive energy will make current energy-intensive cropping systems unfeasible. The optimal mix of labour, capital and energy will therefore change, leading to more farming and labour opportunities for the general population. These jobs will be characterized by higher skill levels and non-interchangeability (↑GPI). Workers will have control over both methods of production and the goods that they produce. Higher energy costs will lead to an overall decrease in production and consumption (↓GDP). Health care expenditures overall will be reduced as human health improves due to decreases in the consumption of industrial foods, decreases in toxins released into the environment, increases in human activity and greater emphasis placed on well-being (↓GDP, ↑GPI).

Urban and rural populations will organize around localized clusters, thus achieving significant reductions in energy use (Figure 3) (Carrol 1977). Small towns will grow or repopulate to meet the day-to-day consumption needs of the expanding rural labour force (↑GDP, ↑GPI). Throughout, smart growth plans will be implemented to lessen the monetary and energy costs of infrastructure maintenance (↑GPI) (Daniels 2001). Despite a stark reduction in GDP, a reallocation of resources with a priority on human and ecological well-being will result in an increase in GPI, a relative score of +8, due to reductions in income disparity, increased human health and improved environmental quality (Table 1).

Policy: how do we get there?

Policy at all levels of government will significantly influence the ways in which we meet the agricultural, environmental and quality-of-life challenges of the next 90 years. Policy drives changes in behaviour and the landscape, and it reflects the goals of the society and economy in which it is embedded (Brown and Schulte 2011; Reganold *et al*. 2011).

Our policy assessment starts by asking several basic questions: Who has the power to wield policy? Who are the main political actors? Who benefits from policy? Who pays? In Scenarios 1 and 2, the power to make policy will be held by entities with the financial and political means to influence the policy process. Often the resulting policies will reflect their economic interests, and this will often be with externalized expenses. In contrast, in Scenario 3 and 4 the public will be critically engaged in the political process because institutional roadblocks that inhibit citizen participation and democratic structures, which currently exist, will be removed. The resulting policies will be specifically targeted to positively enhance societal and environmental welfare.

Another key area where policy will differ dramatically between Scenarios 1–2 and 3–4 is in how the local and global ecological commons will be envisioned and valued. In the former, the commons will be an exploitable resource pool and sink, and will be managed best when it is privatized. In the latter, the commons will be assets to be protected in perpetuity, to be utilized sustainably by society (Raffensperger *et al*. 2009). This fundamental change will create the matrix for a coherent environmental policy, rather than a piecemeal approach that tends to oversimplify and opt for simpler 'silver bullet' solutions.

Policies that currently exist will continue in Scenario 1. These include heavy subsidization of commodity-crop production, marketing and export, and subsidization of energy including access to oil-producing lands, tax breaks for refiners and transportation, and infrastructure that will promote energy use such as the federal highway system and pipeline production. There will be continued disincentives for non-commodity crop and food production. Campaign finance policy will continue to allow for the concentration of undue political influence, wealth and power. Environmental laws seen as impeding and adding costs to production will continue to be weaker than in other developed countries and will be poorly enforced. In order to maintain material throughput, policies will continue to encourage high levels of consumption and short turnover of disposable goods. Lack of appropriate land-use policy will continue to fail to curb urban sprawl into agricultural land (Figure 2).

In Scenario 2, burgeoning energy costs will add energy subsidies to the commodity-crop subsidies to facilitate their continued production. This influx of funds to the agricultural sector will further focus policy on agricultural interests dominated by large commodity groups and consolidated agricultural/energy corporations. Commodity and energy markets will be battered by volatility in reaction to climatic and economic events, driving agricultural interests to demand policies that protect agriculture. Environmental policies will be viewed as adding additional costs without corresponding economic benefits. Regulatory bodies will be eliminated as budgets are downsized in response to increasing energy costs. Food prices will rise with increases in energy costs, and consumers will be vocal in their demands for policy relief as real incomes shrink.

In Scenario 3, a societal shift towards valuing human well-being and ecosystem functioning will significantly impact policy decisions. Environmental policy will come to the forefront of society's concern; it will be merged with economic and agricultural policy in an integrated framework. At the federal and state levels, policy will nurture the research and development of new technologies to support this new framework. Technologies will be developed and deployed within the constraints of the precautionary principle. Market and political power will be decentralized across the value chain of agricultural goods, which will result in the rise of stronger local and regional economies. Policies supporting ecosystem service markets will help farmers and landowners improve resilience while maintaining profitability. To help reduce overconsumption, goods will be taxed based on product durability and a greater proportion of the government's general revenues will be collected in the form of luxury sales taxes. Steep, progressive income taxation and incentives will prompt citizens to work less than 40 h of paid labour each week and to then turn their attention to social and community activities.

Given the reality of limited energy and its contracting effect on the economy and incomes, in Scenario 4 many issues tied to the consumption of inexpensive fossil fuels, from overfertilizing to overshopping, will be self-limiting and will perhaps not require policy to change behaviour. Policy will be more focused on the development of energy-efficient technologies, fostering innovation, communicating existing knowledge, conserving natural resources and restoring ecosystem functions. Current policies that hinder local-food processing and distribution will be amended to accommodate alternative methods and multiple scales of production (Figure 3). Groups of citizens with common interests will band together in cohesive voting blocs and will drive place-based policy initiatives. Reliance on adaptive solutions will create a positive feedback loop for resurgence in local and regional participation in policy making and in the political process (Jordan and Warner 2010).

Conclusion

Iowa is currently situated as a global leader in crop and livestock production. Achieving that high level of agricultural productivity has been subsidized by fossil-fuel-derived inputs and environmental degradation whose costs have been externalized. We examined four scenarios of possible futures for Iowa in 2100 based on combinations of differing goals for the economy (high material throughput versus improvement of human and environmental welfare) and differing energy availabilities and costs (high versus low). The scenarios are not predictions of the future; they are tools that highlight how specific changes can produce dramatically different outcomes for the future. Envisioning scenarios derived from situations that will plausibly occur in the future provide guidance on how to arrive at more desirable futures.

The availability and cost of energy are major factors affecting human actions in the early 21st century, and they are likely to remain important at the turn of the 22nd century. As a society we can choose to continue to consume large quantities of energy and rely on fossil-energy sources or we can choose to reduce our consumption through conservation and increased efficiency and transition to renewable sources of energy.

The current metric of a nation's health is the GDP. GDP is effective in measuring the growth in material wealth of a country, but it is relatively ineffective in measuring the welfare of its citizens and the environment. In order to move to a future where human and environmental welfare are valued above material wealth, such as in Scenarios 3 and 4, numerous changes will have to occur including individual choices and governmental policies and laws. Transitioning from a material-wealth-focused society to a well-being-focused society will require significant changes to how our society is organized and functions.

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