



ALLEGHENY COLLEGE

Faculty Scholarship Collection

The faculty at Allegheny College has made this scholarly article openly available through the Faculty Scholarship Collection (FSC).

Article Title	Climate-adaptive technological change in a small region: A resource-based scenario approach
Author(s)	Don Goldstein
Journal Title	<i>Technological Forecasting and Social Change</i>
Citation	Goldstein, Don. 2015. "Climate-adaptive technological change in a small region: A resource-based scenario approach." <i>Technological Forecasting and Social Change</i> 99: 168-180.
Link to article on publisher's website	http://dx.doi.org/10.1016/j.techfore.2015.04.014
Version of article in FSC	Published version
Link to this article through FSC	https://dspace.allegheny.edu/handle/10456/40126
Date article added to FSC	November 5, 2015
Terms of Use	© 2015 The Author. Published by Elsevier Inc. This is an open access article under the CC BY-NC-ND license



Climate-adaptive technological change in a small region: A resource-based scenario approach



Don Goldstein

Economics, Allegheny College, Meadville, PA 16335, USA

ARTICLE INFO

Article history:

Received 2 June 2014

Received in revised form 19 February 2015

Accepted 7 April 2015

Available online 16 July 2015

Keywords:

Climate adaptation

Technology pathways

Scenario planning

Clusters

Organizational resources

Stakeholder engagement

ABSTRACT

Society at large must find technological pathways capable of mitigating climate change. But small regions – where private and public sector decision makers take actions whose aggregated effects shape those broader pathways – are faced with the need to adapt to climate impacts over which they have little control. Such impacts already include not only direct climatological ones, but also related systemic shifts in technologies, markets, and policies. Firms and policymakers can widen the range of adaptation opportunities by exploring regional resources applicable to emergent clusters, through which technologically related inter-organizational dynamics may permit more effective climate responses. As in the resource-based view of the firm underlying cluster theory, key decision fields are chosen based on existing capabilities internal to the region in relation to the threats and opportunities transmitted by external climate change impacts. Adaptive strategy options at the regional level can be identified and assessed using a scenario-building methodology that incorporates the interactions among multiple variables and decision-makers' actions over time. Stakeholder input and engagement during the research process can facilitate realism and traction. This methodology is applied to northwestern Pennsylvania, on Lake Erie, projecting a scenario based on a set of complementary, lower-carbon energy and transportation technologies.

© 2015 The Author. Published by Elsevier Inc. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

"Transformations in economic, social, technological, and political decisions and actions can enable climate-resilient pathways (...sustainable-development trajectories that combine adaptation and mitigation to reduce climate change and its impacts)...Strategies and actions can be pursued now that will move towards climate-resilient pathways for sustainable development, while at the same time helping to improve livelihoods, social and economic well-being, and responsible environmental management....[B]ut tools to understand and manage these interactions remain limited" (IPCC Working Group II, 2014, pp. 24–5).

1. Introduction

Society at large must transition to lower-carbon energy, transportation, and other technologies that are capable of mitigating climate change. But movement toward these technology shifts, and mitigation efforts generally, have been slow and fragmented (Kriegler et al., 2012). Because the effects of climate change are growing and nearly certain to accelerate (Bierbaum et al., 2014), private and public sector decision makers at sub-national levels are increasingly faced with the need to adapt to climate impacts over which they have little control. It is at the regional level that the impacts, exposures and vulnerabilities relevant to climate adaptation are constituted (Seitz, 2014).

In thinking about adaptation to climate change, this logic suggests the usefulness of much smaller regional definitions

E-mail address: dgoldste@allegheny.edu.

than the continental breakdowns often employed (for example, in *IPCC Working Group II*, 2014; Kriegler et al., 2014). The specific geophysical and socioeconomic characteristics of smaller regions, often missed by more macro-level analyses (Rosen and Guenther, 2014), can be highly salient. In turn, the aggregated effects of local actions over time will play a role in shaping the broader technological changes that emerge (Moss et al., 2010). Thus it is critical to develop analytical tools to assist firms and policy makers in small regions in projecting potential adaptive pathways that are locally viable and globally consistent with climate change-mitigative technological shifts.

This is all the more true in that adaptation at all levels has been uneven and has rarely progressed beyond the planning stages (Berrang-Ford et al., 2011; Bierbaum et al., 2014). The likely direct impacts of climate change itself are complex and uncertain, compounded by the fact that a myriad of wider public and private sector responses will increasingly transform the macroenvironment within which regional firms compete, governments operate, and economies evolve (Moss et al., 2010). Old technologies, products, and capabilities will lose traction, and both the need and the opportunity for new ones will emerge. Realizing such opportunities will require technological innovation – not only for individual companies, but also in related supply chains, other intra- and inter-sector relationships, and policy frameworks (*IPCC Working Group II*, 2014, p. 24). This in turn will require that decision making by private and public entities go forward in the presence of multiple variables that will co-evolve along uncertain trajectories. Individual actors must make adaptive choices whose eventual viability will depend in part on choices made by others. In the face of such complexity, often the resulting choice is to take no action at all.

Many researchers and practitioners are dealing with these problems – region-specificity, uncertainty and complexity, and stakeholder (dis-)engagement – in terms of adaptation “pathways”: “...an analytical approach for exploring and sequencing a set of possible actions based on alternative external changes over time” (Wise et al., 2014, Section 2.2 paragraph 2; see also Moss et al., 2010; Kriegler et al., 2012; Haasnoot et al., 2013). The present study reports preliminary results of ongoing research on potential climate-adaptive technology pathways in a small region: the northwestern part of Pennsylvania (NW-PA), adjacent to Lake Erie.

The aim is to contribute to our understanding of adaptation pathways in several respects:

- “Region” is defined in geographically delimited terms relevant to the kinds of place-specific characteristics and decision processes that must underpin adaptive change.
- Related, the project is framed in terms of regional economic opportunities (a “livelihood” perspective – Wise et al., 2014) rather than primarily risk management and vulnerability reduction (Berrang-Ford et al., 2011). It poses “the question ‘What are we adapting for?’ ... [which] is as significant, if not more, as the question ‘What are we adapting to?’” (PROVIA, 2013, p. 46).
- This implies a widened focus to include the regional implications of external technology and market changes induced by climate change – not just direct climate impacts themselves. The exercise begins from a normative position of seeking adaptation scenarios that are consistent with climate change

mitigation, recognizing that many of the broader parameters that can shape regional adaptation will be driven by mitigative policy and market pressures.

- The attendant uncertainty and complexity are approached through a set of tools from the strategic management literature: scenario-building (Bishop et al., 2007), regional clusters (Porter, 1998), and the resource-based view of the firm (Collis and Montgomery, 1995). These theories are well suited to the fine-grained exploration required by the small-region focus: identification of competitive resources capable of supporting adaptive development and consideration of key interactions among these resources in projecting internally and externally consistent technological pathways over time.
- Practitioner-experts’ views of evolving scenario projections are a key feature of the research design. Stakeholder views were used to draw attention to complex interactions among potential adaptive responses arising in disparate economic sectors and to generate technology predictions that are empirically plausible, stakeholder-relevant, and capable of testing and reworking over time. Thus a goal of this research is to increase stakeholder support for climate adaptation at the local level.

The next section develops a theoretical framework using the literatures on climate adaptation and the three strategic management concepts. The scenario methodology requires detailed attention to mutually relevant regional resources and external climate change-induced impacts transmitted to the region. This is provided in subsequent sections on the region’s economy and changing climate (Section 3); the impacts it is likely to experience as the climate changes (Section 4); and how technological innovation based on relevant resources might create an adaptive regional technological pathway (Section 5). The projected scenario describing such a pathway is described in Section 6, and a discussion concludes.

2. Literature review and theoretical framework

Wise et al. (2014)) provide an extensive and insightful review of recent developments in climate adaptation research. While the regional adaptation literature itself pays considerable attention to the risks and vulnerabilities arising from the direct impacts of climate change (IPCC, 2007; NRC, 2010; Bierbaum et al., 2014), less has been done on the salience of indirect impacts. Broad climate change-induced shifts – especially in technological alternatives, but also in markets, policies, and more – will act as powerful systemic parameters shaping the adaptation constraints and possibilities that smaller regions face (Moss et al., 2010; *IPCC Working Group II*, 2014). Some studies have begun to explore this dimension. Easterling et al. (2004, p. 5) stress that “... anticipatory ... adaptive reorganization” facilitates systemic resilience by “altering existing relationships or establishing new relationships and components.” The NRC (2010, p. 27) argues that by identifying the most salient among the system of likely climate change-induced shifts, adaptation efforts can “minimize harm and take advantage of opportunities that may result from a changing environment.” Bolton and Foxon (2014) and Wise et al. (2014)) go further in developing theoretical frameworks for understanding these relationships. Adaptation is seen as highly place-specific, but occurs in the context of external parameters – both

climatic and societal – that change over time in unpredictable ways. Ongoing stakeholder engagement emerges as critical to increasing the resiliency and traction of adaptation processes. Jackson et al. (2011) present a relevant case study of agricultural climate adaptation in California's Yolo County: IPCC and state climatic/socioeconomic scenarios are used to project alternative futures for Yolo County agriculture – based on existing economic assets, likely climate impacts and possible adaptations, and potential indirect impacts from changing agricultural markets, population, and land use patterns.

Focusing on strategic adaptation by firms and other institutions in a changing, place-specific, competitive environment, involving modification of existing know-how in conjunction with related changes by other regional actors, makes it useful to apply the following strategic management concepts. Together, they are useful for thinking about adaptive responses to uncertain external change and how individual decision makers' responses interact at a regional level of complexity:

Scenario-building, a set of planning methods for situations with multiple, cascading uncertainties (Bishop et al., 2007). Originally developed for military and corporate planning (Kahn, 1962; Enzer, 1981), it is well suited to exploring adaptive processes where climate projections and possible market, regulatory, and technological shifts are each uncertain and interact with one another. A range of potentially important influences is considered in developing plausible outcomes or scenarios. Structured as story lines, scenarios consider the possible paths of each critical, uncertain variable as well as the implications of interactions among these variable paths (Schultz, 1993; Ringland, 1998).

Resource-based view, a theory of the firm that can help point to likely directions for regional technology-pathway scenarios. Organizations compete on the strength of resources – distinctive capabilities and assets, built over time – that are valuable in relation to the threats and opportunities arising in changing external environments (Barney, 1991; Collis and Montgomery, 1995). Organizational capability, “the ability...to perform a coordinated set of tasks, utilizing organizational resources, for the purpose of achieving a particular end result” (Helfat and Peteraf, 2003, p. 999), involves what firms can do well relative to both one another (the industry or cluster) and the broader market setting (demand, technology, regulation). Organizational change is path dependent, with adaptive responses both conditioned and constrained by inherited operational capabilities (Teece et al., 1997). Adaptation paths are seen as influenced by the broader institutional environment as well (Lazonick, 1994). Regions' options for creating livelihood-enhancing technological pathways as they adapt to climate change will be shaped by their existing economic capabilities and assets, in relation both to external change and to their potential complementarities with one another.

Clusters, “...geographic concentrations of interconnected companies and institutions in a particular field” (Porter, 1998, p. 77). Regional opportunities for climate adaptation may depend not only on the resources firms deploy, but also on their inter-relationships – among competitors, specialized suppliers, customers and/or distributors, makers of related products, and governments and universities providing knowledge and other critical supports (Bradshaw and Blakely, 1999). Clusters promote innovation through competition, attracting specialized labor and suppliers, showcasing new ideas, encouraging new businesses,

and stimulating supportive programs in non-business institutions. Not every region will have the opportunity to extend existing clusters or generate new ones in the course of climate adaptation, but the place-specific, inter-organizational complementarity dynamics to which cluster theory draws attention are likely to be important in any event.

An emerging research stream applies these concepts to climate adaptation. Linnenluecke et al. (2013) provide a recent review of business-related climate adaptation research, which has focused mainly on climatic risks to industries like agriculture, tourism, and insurance, or on the need to reduce carbon emissions (Hoffman, 2006; Porter and Reinhardt, 2007). Linnenluecke and Griffiths (2010) examine “the development of new organizational capabilities” to increase firms' resilience regarding weather extremes (479). “(A)daptive capacity” with respect to climate is explored in an African development context by Tschakert and Dietrich (2010), who link stakeholder-driven scenario construction to “the capability for innovation” (2). Lade (2009) examines “social learning” at the regional level in Australian tourism clusters. Some studies argue the importance for businesses of broader, societal climate-related changes (Schwartz, 2007). Moser and Ekstrom (2010) emphasize the role of institutional structures as potential barriers to climate adaptation and of “interacting nonclimatic changes” in affecting the feasibility of specific climate responses (22027–22028). The Northwest2050 project (2012) addresses adaptation in northwestern Germany's agriculture, energy, and transportation industries; Karlstetter (2012) describes its agriculture component, modeling scenarios through which actors might approach adaptive ecological viability based on existing economic capabilities.

The present study applies elements of a “normative” scenario approach in creating an initial story line consistent *a priori* with climate change mitigation. It then uses an “explorative” approach in testing and modifying these preliminary hypotheses (Borjeson et al., 2006; Vervoort et al., 2014). Key prerequisites for scenario formation are identified; as in the Jackson et al. (2011) and Karlstetter (2012) studies, this targets arenas for stakeholder engagement. Thus the strategy is designed for iteration through a series of interactions between researchers and other stakeholders moving through time (Kriegler et al., 2012; Vervoort et al., 2014; Wise et al., 2014). Initial goals (technologies consistent with ecologically sustainable atmospheric carbon levels) shape the process, then the exercise suggests possible regional terrains in which these goals might become congruent with organizational strategies and an emergent technology pathway.

The region's adaptive resources and the external parameters are defined in terms of one another. Like in the resource-based view of the firm (Collis and Montgomery, 1995), those external impacts are important which may be capable of stimulating significant local responses, and those local resources are key which might effectively respond to direct or indirect impacts. A mitigation-consistent adaptive regional scenario emerges from this interplay – as a research outcome and, potentially, a practical pathway.

Fig. 1 charts this scenario methodology. Readings of other regional climate adaptation work and NW-PA climate and economic data led to a set of hypotheses about scenarios in which mitigation-consistent adaptation might emerge. Informed by these preliminary steps, a finer-grained analysis mapped the

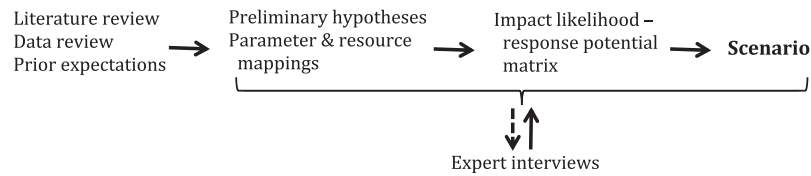


Fig. 1. Scenario-building: Methodological sequence.

climate change-induced external shifts that might act as parameters within which regional adaptation would occur, and the potential for clusters of regional assets and capabilities to respond. These mappings were overlaid into a matrix of impact likelihoods by resource response potentials. The matrix identified elements of a potential technology pathway, highlighted which of those links were likely to be stronger and weaker, and suggested developments that might be required for such a scenario actually to emerge.

A key input from the preliminary steps onward was a series of interviews with regional experts – stakeholders and scholars – in relevant sectors. Much of the exploratory phase's work involved testing researcher ideas against these experts' perspectives and eliciting their suggestions. The 31 interviews began early in the research. They were semi-structured conversations with participants and researchers in industry and public sectors targeted as important: metal-working, rail freight, forestry, deep shale natural gas, wind power, municipal water management, and economic development. The research was explained, and respondents were asked context-specific versions of the following:

- what they see as key drivers of change and important developments in their areas;
- how their organizations might relate to the preliminary adaptation-scenario ideas under consideration;
- how they might interact with other sectors in that scenario;
- what additional relevant issues were not being considered by the researchers.

This format allowed exposure of respondents to the current state of the research projections (the dashed arrow in Fig. 1) and channeled their feedback into further scenario development (the solid arrow). In the later stages of the project, this permitted a kind of “back-casting” (Robinson, 1990): working back from the projected scenario to identify what would have to happen, relevant to the interviewee's sector, to make that outcome possible. The expressed prerequisites involved both the sectors themselves (“Our shop would have to re-tool heavily to handle wind turbine components”) and complementary ones (“Better rail-service proximity to the shop would make us more competitive in outbound shipping of wind turbine components”). These important inputs to the research process grew out of the author's long-term involvement with related stakeholder activities and pointed toward continued researcher-stakeholder engagement going forward.

Subsequent sections detail this process: initial scoping of other regional climate adaptation work and NW-PA climate and economic information (3.1 and 3.2); preliminary scenario hypotheses to help structure the next research stages (3.3); deeper analysis of climate change-induced external shifts (Section 4) and the potential for responses based on regional assets and capabilities (Section 5); construction of a matrix

interacting the likelihood of external parameter impacts with the potential of relevant regional responses (6.1); and scenario projection (6.2).

3. The region, its changing climate, and adaptive scenario possibilities

The location of NW-PA, and the six counties of which it consists, are indicated in Fig. 2. The climates, topographies, economies, demographics, and histories of these counties are similarly distinctive in relation to the state as a whole, and thus it is reasonable to group them as a region. At the same time, these features of NW-PA tend to be similar to those characterizing a broader swath of the southern Great Lakes region, from roughly Milwaukee, Wisconsin to Rochester, New York. Thus the results of this study may be more widely applicable in varying degrees.

3.1. NW-PA's economy

Geography made both manufacturing and freight transportation important in NW-PA for over a century. Due to proximity to Pittsburgh's iron and steel and Titusville's oil fields and their position between New York and Chicago, cities like Erie and Meadville became home to a wide range of manufacturing and to major rail yards and Lake ports by the late 19th Century. But by the mid-20th Century, manufacturing and both rail and Great Lakes-St. Lawrence Seaway (GL-SLS) freight transport were in decline (Higginson and Dumitrascu, 2007). Three long-haul Class I rail lines through the region became two, rail yards shrank or closed, and numerous short-haul carriers closed or consolidated; Port Erie declined due to broad steel industry shifts.

But a nationally prominent cluster of smaller tool and die and precision machining firms remains (Onyeiwu, 2009; CSW, 2011), a legacy of the deep metal-working supply chain and workforce created by once-dominant large firms. And Port Erie retains advanced deep-draft dock, crane, shipbuilding, dry-dock, and warehousing facilities (World Port Source, 2012). Although NW-PA is older and poorer than the state overall, due to industrial decline, the region is still more manufacturing-based and equally transportation-intensive, reflecting its economic legacy. These features of the NW-PA economy were identified by preliminary research as potentially relevant in responding to the projected impacts of climate change. The next section begins to consider these effects.

3.2. NW-PA's changing climate

Proximity to Lake Erie makes the region cooler and more moist than the state overall. Average summer temperatures approach only 70 degrees, typically including few days with

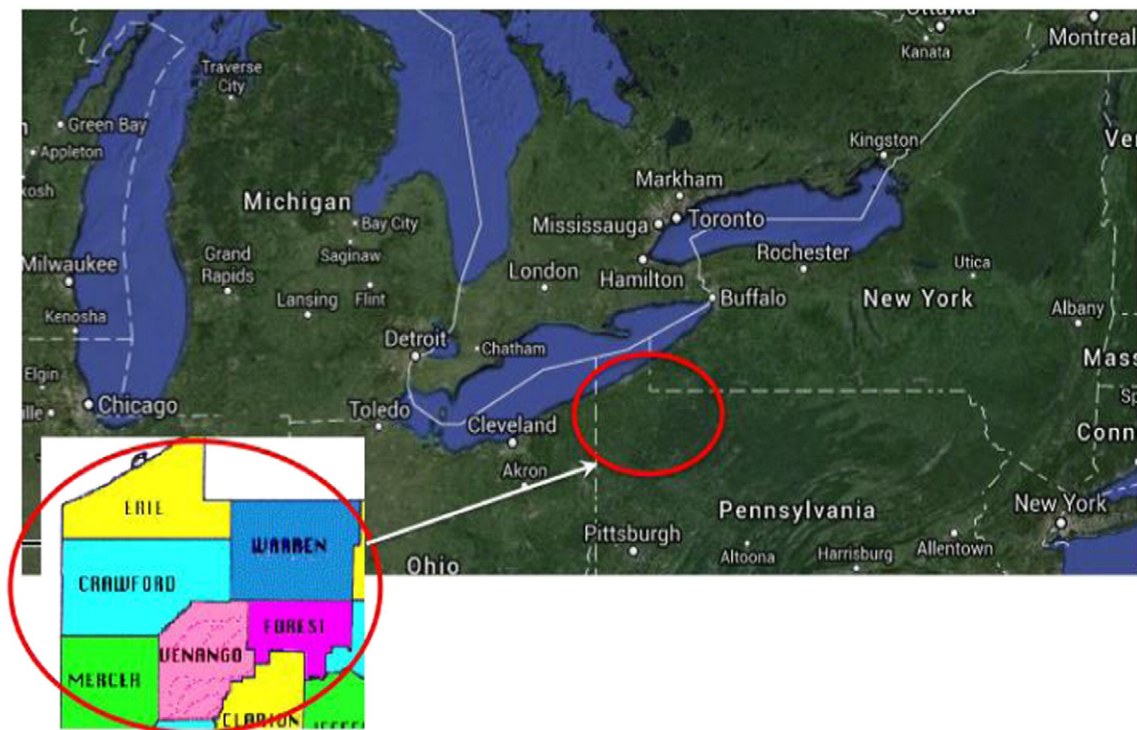


Fig. 2. NW-PA region.

highs at or above 90 degrees (Pennsylvania State Climatologist, 2012). Precipitation is approximately 40 inches annually, historically more frequent and less intense than elsewhere in the state, with the exception of heavy “lake snow” events in the winter. Along the lake shore, home to orchards and Pennsylvania’s chief vineyards, moderated temperature extremes permit a long growing season.

Maps of projected global climate changes show that the southern Great Lakes are part of a zone that will likely get wetter and warmer overall (IPCC, 2007, pp. 46–47). Much of the U.S. research on downscaling global circulation models has been done in the context of the larger Northeastern and Great Lakes regions at whose intersection NW-PA lies. Three key studies suggest the direct regional impacts of climate change shown in Table 1.

Of potential relevance for the adaptation scenario presented below, by mid-century average annual precipitation is projected to increase on the order of 10%, more of it as rain and less as snow. Land snow cover and Lake Erie ice cover are likely to diminish in amount and duration. Recent research suggests that despite elevated evapotranspiration, surface energy flows will be such that Great Lakes water levels are not expected to fall (Lofgren et al., 2011; Milly and Dunne, 2011).

The frequency and severity of heavy precipitation events in NW-PA are likely to increase, as has occurred in the broader northeastern U.S. throughout the second half of the 20th Century (Karl et al., 2009). Based on monthly precipitation records from the Pennsylvania State Climatologist (2012), Fig. 3a and b show that in the ten-county area that includes the six in NW-PA, average annual precipitation and both within-year and across-year precipitation variability increased

from the early 1900s onward. The upshot is that the region’s storm water infrastructure is being stressed already, and this will almost certainly worsen over time (Kessler, 2011).

3.3. Scenario possibilities

Consideration of NW-PA’s location, economic legacies, and changing climate suggested that an adaptive technology-pathway scenario might revolve around metal-working firms’ supply responses to new stormwater management, renewable energy, and lower-carbon transportation activities. This preliminary research informed a subsequent, deeper analysis of the projected climate-related impacts affecting the region and the potential for corresponding technology-pathway responses, with stakeholder feedback via expert interviews playing a key role.

Table 1
Mid-century climate projections for NW-PA.

	Temperature (F)	Precipitation
GLRA (2000) ^a	+5°	+12%
NECIA (Frumhoff et al., 2007) ^b	+4°	+9%
ClimAID (2011) ^c	+5°	+18% (win.), –10% (sum.)

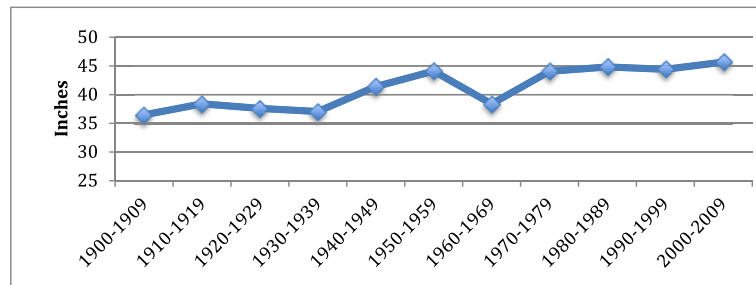
Notes:

^a Averaged: winter and summer, two GCMs, and early-late century; NW-PA values approximated from Figs. 3.1 and 3.2, pp. 20–21.

^b Pp. 6, 10–11. Based on IPCC (2007) low (B1) and high (A1FI) carbon scenarios, averaged.

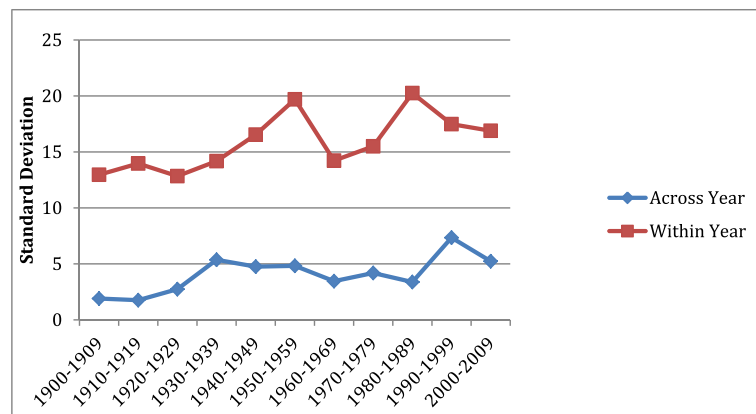
^c Both summer and winter, temperature; NW-PA values approximated from Fig. 1–10 – 1–13, pp. 46–47. Based on IPCC (2007) A2 scenario.

a) Average annual precipitation by decade, northwestern ten Pennsylvania counties.



Source: Author's calculation from data at Pennsylvania State Climatologist (2012).

b) Precipitation variability by decade, northwestern ten Pennsylvania counties.



Source: Author's calculation from data at Pennsylvania State Climatologist (2012).

Note: Within-year standard deviations have been scaled up by a factor of 12 for comparability, because their underlying data is monthly versus annual precipitation.

Fig. 3. a. Average annual precipitation by decade, northwestern ten Pennsylvania counties. Source: Author's calculation from data at Pennsylvania State Climatologist (2012). b. Precipitation variability by decade, northwestern ten Pennsylvania counties. Source: Author's calculation from data at Pennsylvania State Climatologist (2012). Note: Within-year standard deviations have been scaled up by a factor of 12 for comparability, because their underlying data is monthly versus annual precipitation.

4. Likelihood of projected climate change impacts

This section examines the likelihood that each possible external climate-driven impact will transmit a strong impulse to which regional adaptation might respond. The choice of possible impacts is motivated by the region's economic and climatic trajectories, as well as the perceived broader shifts toward renewable energy and alternative freight transportation technologies. The logic is “intuitive” rather than “probabilistic” (Bradfield et al., 2005): The likelihood of a strong impulse is designated as high, medium, or low with an effort toward transparency of assumptions and information sources.

4.1. Direct effects of climate change

4.1.1. Increased incidence and severity of heavy precipitation events

Documented in Section 3.2. The relevance for regional resource potential is the probable need to source and construct storm water infrastructure upgrades. *High likelihood.*

4.1.2. Longer shipping season on the Great Lakes

Downscaled climate projections uniformly suggest that rising temperatures will be sufficient to continue reducing the annual period during which ice cover halts GL-SLS shipping (Miller, 2007). It is assumed that recent years' record low Lakes levels (Schwartz, 2013) are transient, and that climate change will not lower water level trends (Lofgren et al., 2011; Milly and Dunne, 2011). A longer shipping season will affect the potential for increased activity at Port Erie and adjacent Lake Erie facilities. *High likelihood.*

4.2. Indirect effects of climate change

4.2.1. Growth in demand for biomass sources

NW-PA's large areas of hardwood forest have attracted attention from the EU, where 20% of energy is mandated to come from renewable technologies by 2020 (European Commission, 2010). Biomass for power generation, heating, and fuel is expected to play a significant role. Amsterdam port managers have been examining NW-PA as a potential source of wood pellets for import to Europe; Amsterdam offers strong

capabilities for the wood pellet trade because it is a traditional import hub for cocoa, whose handling requirements (consistency, temperature and moisture control) are quite similar (Hallworth, 2012). *High likelihood.*

4.2.2. Increasing opportunities for domestic wind power

There has been considerable, climate-related interest in development of Great Lakes wind energy (Loomis, 2013). Despite inconsistent policy incentives at the Federal level, U.S. wind power capacity has grown rapidly throughout the last decade. Regulatory pressures on fossil-fuel power continue to rise – for example, recent EPA decisions on coal-fired power plants and allowable soot limits. Pennsylvania, like many states, has in place a variety of supports that have exerted a moderate push toward renewables expansion. But fracking-driven lower gas prices, along with policy uncertainty, cloud the future of renewable energy investments (Doran and Reed, 2012). *Medium likelihood.*

4.2.3. Growing rail freight shipping

Freight system expansion has been tilted away from trucking by highway congestion (Federal Highway Administration, 2008), environmental regulation (ICF et al., 2011), and world oil prices (TEMS, 2008). Climate pressures are congruent; possible future U.S. carbon policy helps make rail investment a low-regret strategy (C2ES, 2010). During the 2000s rail freight ton-miles recovered the ground lost to trucking since the early 1980s (U.S. Department of Transportation N.D.). Rail container-system infrastructure expansion has included port intermodal investment (TEMS, 2008) and several long-haul corridors, including two near NW-PA: CSX's National Gateway and Norfolk Southern's Crescent Corridor (Heerwagen, 2009). Completion of a Panama Canal enlargement in 2014 will increase East Coast container arrivals (Burnson, 2011), movement inland via rail, and handling of regions' goods at intermodal nodes. *Medium likelihood.*

4.2.4. Increase in Lakes system freight shipping

GL-SLS shipping continues to lose bulk market share to rail and trucking (Transportation Research Board, 2003). Most of the growing East Coast container volume will involve boats too large for the GL-SLS, and transloading to compatible craft will be costly. But even a small portion of this business could be highly significant for southern Great Lakes ports. And industry sources report plans to ship frack sand into Pennsylvania via Lakes freighter. In addition, existing regional trade with northern Europe could expand if improved port and intermodal facilities in the southern Lakes manufacturing zone created better "backhaul" options for European ships, or if technologies like smaller, multi-purpose vessels and container-on-barge shipping were diffused in the GL-SLS (Vickerman, 2012). But none of this international growth is imminent. *Low likelihood.*

4.2.5. Deep-shale natural gas development

While expansion of unconventional natural gas extraction is not a climate-induced shift, fracking may mediate the opportunity for technology responses in regional rail, shipping and metal-working. The Marcellus locally is not exploitable, but exploration is underway for the region's Utica shale (which in nearby eastern Ohio yields the more valuable "wet" gas). The

shale gas supply chain already extends deep into NW-PA, including a major "completions" contractor based in Meadville. Movement of frack sand to well sites is reversing the longtime decay of short-haul rail statewide, stimulating upgrades to intermodal and Class I – short-haul linkages; in addition, industry sources report plans to move frack sand into the region via the Great Lakes. Finally, shale gas capital investment may generate significant components demand for regional metal-working companies, whose significance is discussed below. *High likelihood.*

The next section examines the potential for NW-PA business and other decision makers to respond to these systemic parameter shifts, on the basis of relevant resources and capabilities, as suggested by preliminary research.

5. Adaptive potential of regional resources

Each resource is analyzed individually and assigned a high, medium or low potential for a strong, scenario-consistent response to the relevant climate change-related shift(s). Response potential can be thought of as adaptive "capacity" with respect to a particular impact or set of impacts (PROVIA, 2013, p. 13). Possible complementarities among responses are discussed in Section 6.

5.1. Biomass supply

(Relevant systemic impacts: EU renewable energy policy; longer GL-SLS shipping season.) There are an estimated 3.4 million acres of high-quality hardwood forest within 75 miles of Erie. Hardwood waste cuttings and pulpwood, once in demand at International Paper's recently-closed Erie mill, could support at least 1 million tons of pelletized wood annually while meeting EU sustainable-forestry certification criteria. Rail transport to East Coast ports is costly, but sufficient economies could be achieved by direct waterway shipping from Erie and nearby ports and out the GL-SLS (GFR, 2011). Scalable supporting resources include upstream infrastructure and labor force for raw material sourcing; sustainable-forestry capabilities in academia and the private sector; and the public-private Erie Development Corporation, which is working to match European buyers with regional supply-chain actors. *High potential.*

5.2. Wind power development

(Relevant systemic impact: policy-driven wind industry growth.) Lake Erie and its southern shores have a commercially viable wind resource, estimated offshore at 18 mph at 90 meters above water level and onshore at 15 mph at 80 meters high (U.S. Department of Energy N.D.). But although the lake's shallow depth makes its offshore wind highly construction-accessible, Pennsylvania lacks a clear legal framework for underwater development rights, and bills to clarify and streamline these rights have languished in the Pennsylvania legislature. In addition, initiatives by offshore developers have gotten little support, and a proposed utility-scale onshore project near the New York border has elicited organized local opposition (Myers, 2013). *Low potential.*

5.3. Rail freight

(Relevant systemic impacts: logistics for Marcellus and Utica extraction; growing national rail freight flows.) Eastward frack sand movement from the west has led Class I lines like CSX to boost staffing and operations in western Pennsylvania and add rail-truck transload and railcar storage capacities. Short-haul lines have done likewise between east–west Class I corridors through Pittsburgh and Erie. All of this is likely to intensify as gas prices recover and the NW-PA Utica is developed. In addition, intermodal container movement involving the region has grown (EDC, 2011). Cost comparisons and proximity to eastern ports (Fig. 4) suggest that more containers will find their way to western Pennsylvania by rail as a Panama Canal upgrade increases east coast arrivals: At distances much above 300 miles, rail will be cheaper than truck (TEMS, 2008); Erie is 420 miles from Newark-New York, 820 miles from Savannah, and 520 miles from Norfolk, the three biggest East Coast ports (Burnson, 2011). But the main new container corridors pass through major nodes in north-central Ohio and southwestern Pennsylvania. Whether terminals in NW-PA could be attractive inter-connectors will depend partly on whether regional rail and intermodal enhancements from other indirect impacts have leveraged additional infrastructure investment. *Medium potential.*

5.4. Waterway shipping

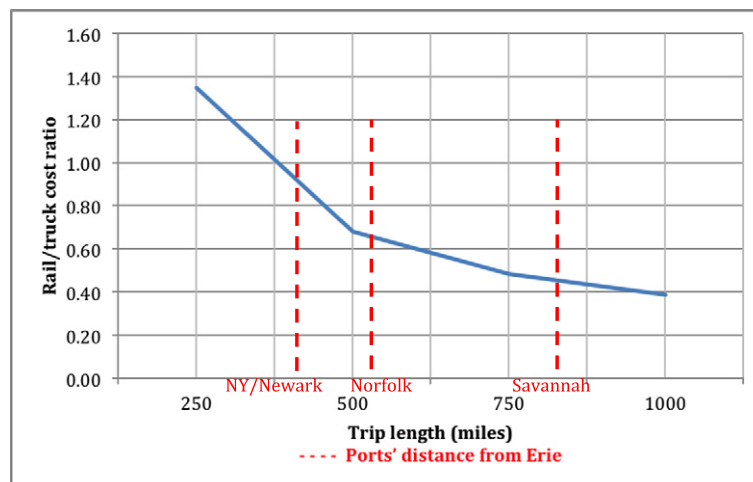
(Relevant systemic impacts: growth in GL-SLS shipping, extended Lakes shipping season, and GL-SLS biomass export.) Unlike for rail, any NW-PA-specific boosts to GL-SLS shipping would be cutting against the industry's national trend. But the

loading, storage, dockage, drydock, and ship-building capabilities around Port Erie are important resources that could be strengthened by shipping firms in response to anticipated inbound frack sand and outbound biomass exports to Europe. The expected payoff from such investments is increased by the likelihood that regional warming will continue to reduce the wintertime Lakes shipping shutdown. But without enhanced port-to-rail and rail-to-truck facilities, existing capabilities are less sufficient for major new inbound and outbound GL-SLS shipping activities; and lacking firm commitments for the latter activities to expand, the investment case for enhanced intermodal infrastructure is weakened. The Erie Development Corporation is working to overcome this coordination problem (EDC, 2013), but many uncertain pieces must fall into place. *Medium potential.*

5.5. Metalworking industries

(Relevant systemic impacts: storm water infrastructure overhaul, shale gas development, and wind power and rail freight expansion.) NW-PA's important metalworking cluster (Onyeiwu, 2009) is concentrated in precision machining and structural or fabricated iron and steel. Aggressively responding to these impacts would require extending firms' existing capabilities toward larger-scale work. Storm water management and transportation and wind power responses would generate demand in structural iron and steel for similar infrastructural products like stanchions, culverts, under- and overpasses, bridgework, gratings, and weirs – and for related components (gauges, gears, controls, fasteners) in precision machining as well. Additionally, wind energy build-out could create opportunities for precision-machining firms to enter the

Per-container cost comparison: Rail vs. truck.



Source: Derived from TEMS 2008. Exhibit 31, page 34.

Notes:

1. Underlying data is total cost of shipping one container (FEU) the indicated distance, including long and short/final haul segments.
2. Cost data is projected for 2020 based on diesel fuel price of \$3.99/gallon (2008 dollars).

Fig. 4. Per-container cost comparison: Rail vs truck. Source: Derived from TEMS, 2008. Exhibit 31, page 34. Notes: 1. Underlying data is total cost of shipping one container (FEU) the indicated distance, including long and short/final haul segments. 2. Cost data is projected for 2020 based on diesel fuel price of \$3.99/gallon (2008 dollars).

wind turbine supply chain. Because many wind turbine parts are very similar to deep-shale capital goods components (Sterzinger and Svercek, 2004), any required investment could be leveraged. However, this does not necessarily imply a no-regrets strategy; wind turbine makers in the U.S. do much of their sourcing abroad (Uchitelle, 2010), and interviewees report that shale-gas equipment producers buy mostly from suppliers centered around Texas. Interview results suggest little appetite among most NW-PA metals companies for the risk of new strategic capital and capability investments toward renewable energy. *Low potential.*

6. Scenario projection

6.1. Systemic impacts and regional responses

The foregoing assessments of climate-driven shifts (direct and indirect), in tandem with possible regional responses, are summarized in Fig. 5 in an impact likelihood – response potential matrix. (This construct borrows from the “likelihood matrix” approach in Sutherland, 2006).

The systemic impacts suggested by preliminary research appear in the left column, ranked via subsequent analysis according to the likelihood of their transmitting strong impulses to which regional adaptation might respond. The hypothesized responses appear across the top row, ranked according to the potential or capacity for effective action by regional decision makers. Shaded cells in Fig. 5 match these responses with the hypothetically triggering impacts. The climate change-causal logic runs from left to right: each of the proposed climate-related impacts can act as stimuli to regional responses, more strongly the higher is the impact likelihood thought to be. The adaptive scenario logic runs from the top down; each regional resource can pick up on the relevant systemic impacts, more strongly the higher are the response potential and the impact likelihoods thought to be.

The group of cells labeled “1” indicates the strongest set of relationships: a highly likely biomass demand stimulates a high-potential resource response, given a sufficient response from a medium-potential Lake port/shipping resource. (Short-haul rail could also come into play, if sufficient volume were generated.) Circled group 2 suggests the strong complementarities that could emerge as distinct regional rail and port responses interact to make critical intermodal infrastructure and capabilities investments more viable. Circle 3 highlights a weaker part of the preliminary scenario: There is little likelihood that systemic freight patterns or new NW-PA coastal wind development will provide much additional encouragement to the regional GL-SLS port activity involved in cell groupings 1 and 2. Finally, the circled area 4 suggests that counter to initial expectations, the region’s metal working cluster is likely to be unresponsive to the multiple but disparate impacts arriving from broader shale gas, rail, renewable energy, and storm water management developments. In turn, the region’s climate response will at least initially lack the complementary boosts that precision and structural components production could provide to infrastructure and equipment development in these areas.

6.2. Scenario

Nevertheless, a coherent scenario story line, capable of guiding strategic technology planning by alert regional businesses and planners, emerges from the methodology. Direct and indirect climate impacts – a longer Lakes shipping season, and continuing shifts toward renewable energy and away from trucking – stimulate innovation and growth in the corresponding industries in the NW-PA region:

- biomass sourcing;
- intermodal rail and shipping capacity; and, perhaps later,
- lake shore wind production.

Systemic impact - regional response matrix

Systemic impact likelihoods		Regional response potentials				
		High	Medium		Low	
		Biomass supply	Rail expansion	Port, shipping development	Coastal wind development	Metal components supply
High	Storm severity	1				
	GL-SLS season					
	Biomass demand					4
Medium	Deep-shale gas					
	Rail freight volume					
	Wind power growth	2				
Low	GL-SLS volume		3			
Notes: a. The expected impacts from each climate-related systemic shift are read from left to right. b. Each potential regional response to expected systemic impacts is read from the top down. c. The circles isolate groups of cells for in-text analysis as subsets of the theorized scenario.						

Fig. 5. Systemic impact – regional response matrix. Notes: a. The expected impacts from each climate-related systemic shift are read from left to right. b. Each potential regional response to expected systemic impacts is read from the top down. c. The circles isolate groups of cells for in-text analysis as subsets of the theorized scenario.

Along with these individual elements, the scenario would create and be supported by cluster-type complementarities. One kind would be a set of interlocking demand relationships. Biomass export requires shipping and potentially rail services; inbound shipping needs intermodal connections; and offshore wind farms use shipping firms for construction and ongoing operations. In addition, combinations of scenario elements would share very similar kinds of mutually supportive activities, labor skills, supply chains, and customer bases. These complementarities would include the following:

- Facilities and infrastructure construction – sourcing, staging, and implementing large-scale shale gas, biomass, wind farm, port, and intermodal projects.
- Maintenance and supply – ensuring functionality of dispersed infrastructure in a rural environment (structural integrity and operational fitness for bridges, culverts, towers, drainage systems, monitoring and control devices).
- Logistics – getting equipment and crews in and out of remote locations; coordinating in and outflows of supplies, transport services, and product.
- Intermodal operations – choosing and scheduling optimal combinations of rail, ship, and trucking for bulk (biomass, frack sand, other) and container freight.

These commonalities would stimulate creation of competitive capabilities and assets across the board in ways greater than might be expected for each of the elements in isolation. For example, attention and pressure from biomass buyers would hone the capabilities of and attract new customers to regional intermodal shippers. Port-related capabilities and intermodal connectivity would be pushed to improve. Forging inland transportation networks (woodlot-chipping facility-pellet mill-dock) would entail both significant investment and a complementary stimulus to waterway shipping and intermodal facilities and capabilities, potentially involving short-haul rail as well. And infrastructure construction in rail is already increasing the region's capacity for building new port facilities.

Thus development in any of the scenario sectors would make each dollar invested in the others more profitable. In line with the predictions of cluster theory, the proximity and interactivity of these related activities would foster innovation, productivity, and new business creation. Specialized labor would move across firms and sectors. Performance standards set in leading companies would raise the bar for others. Innovation processes would cross-fertilize both within and among sectors. New business formation would be stimulated by the availability of customers across multiple activities.

The projected scenario response to climate change would be based on the region's substantial set of relevant resources in terms of location, infrastructure, skill base, and organizational capability. It is also a function of powerful impulses being transmitted through the region by the shale gas industry, unexpectedly pushing in the same directions as climate-related transportation shifts. Finally, as described in Section 2, it emerges as a research outcome from practical interaction with key stakeholder groups. The implications are discussed below.

7. Conclusion

This research began with the goal of applying concepts from the literatures on scenario-building, organizational resources,

and clusters to constructing a plausible technology pathway along which a small region's businesses, policymakers, and other stakeholders might strategically adapt to climate change. The intent has been to widen the opportunity set beyond risk management and cost reduction by considering not only direct climate impacts, but also the indirect effects transmitted from climate-related changes in broader technologies, markets, and policies.

Although it retained the climate-mitigative direction established by its normative starting point (Borjeson et al., 2006), the scenario methodology did not simply give back the story it was expected to tell. During the explorative stage (Vervoort et al., 2014), the machining-based cluster expected to anchor a regional climate response faded into the background, and alternative energy and transportation activities – originally seen chiefly as machining demand sources – emerged as the main drivers. Applying this methodology to a small, coherent region allows the economic and policy landscape to resolve at a sharp enough focus for key real-world dynamics to come to the fore in scenario projection.

The methodology suggests that indirect effects of climate change are likely to be the critical impacts to which this particular region must adapt. While the constellation of energy and transport activities highlighted in the scenario do not share as compact a set of technologies, products, and customers as a traditional cluster (Porter, 1998), there would be sufficient *relatedness* in those dimensions to create complementarities – in demand creation, organizational learning and capability formation, and resource attraction. This web of interactions could act as a growing gravitational influence around which an adaptive pathway might emerge.

The direction this takes would be determined by an iterative process involving interaction among key stakeholders (Kriegler et al., 2012; Wise et al., 2014). Vervoort et al. (2014) have pointed to the problem of scenario-projection that remains separate from the real decision processes of regional stakeholders. Tying the scenario-building process to feedback from regional experts has been a step toward addressing this problem. In addition to the interviews with industry executives reported above, the researcher has worked to locate relevant practitioner initiatives: capturing their implications for scenario possibilities, actively projecting those conjectures into practitioner discourse, and in the process testing research conclusions against the responses of stakeholders whose actions would be critical for the theorized pathways to be realized. This has involved working with leaders and participants in, for example, the Erie Development Corporation (its Erie Shippers Conference and Biomass Stakeholders Workshop), the Northwest Pennsylvania Coalition for a Green Economy, and the Clean Air Council (its Offshore Wind Committee and Renewable Energy Accelerator grant process). In the future, deeper relevance and traction can be encouraged via the kinds of ongoing stakeholder linkages reported by Jackson et al. (2011) and Karlstetter (2012). Extension of this research is planned to help establish and fund, where necessary, formal structures through which regional leaders' continued input and engagement can be secured.

Unpredictable external developments will shift the parameters within which this process occurs. Decision makers will need to recognize the changing boundaries of the "adaptive space" for regional responses to climate change and make

mutually-reinforcing technological choices within its evolving limits (Wise et al., 2014). The scenario results reported here suggest particular sensitivity points for such unanticipated shifts – for example, in EU renewable-energy targets, regional impacts from rising east-coast container trade, and climate effects on GL-SLS navigability. Ongoing research can assist stakeholders in recognizing the implications of such changes and in widening the range of adaptive opportunities by approaching them within a regional, complementarities-based process.

Central policy aspects of the institutional framework would have to be gotten right for something like the scenario presented here to unfold. Critical transportation and energy infrastructure investments can have public good dimensions, which may be strengthened by the public interest in supporting the scenario's lower-carbon options (Tompkins and Eakin, 2012). Policy incentives must be designed to align private actors' interests with societal ones at key scenario points, such as the need for stronger state law on underwater development rights. State action influences private decision makers' expectations, which can be key to such a scenario process (Budde et al., 2012). The public-private initiatives of the Erie Development Corporation (in biomass, port development, and intermodal architecture) can serve as a model for how to get enough of the parts moving so that firms can have enough confidence for strategic investment (EDC, 2011, 2013).

The projected scenario thus identifies potential opportunities to assist regional decision makers in thinking about how to build upon existing assets, capabilities, and initiatives that can interact in complementary ways, combining analysis of what is and structured conjecture about what might be. It sketches the potential outlines of a pathway for livelihood-enhancing technological adaptation to climate change.

Because the climate is changing, and regions must adapt, the creation and refinement of workable tools to aid the process will be an ongoing research priority. The framework proposed here aims to contribute in a way that can help build support for climate adaptation and mitigation at the local level where decision makers both respond to and collectively shape the opportunities and costs of adaptive technological pathways.

Acknowledgements

Christopher Brennan, Tyler Danzey, Dan Eiben, Jacob Ford, Cory Rectenwald, and Thuc Vu provided excellent research assistance, and Eric Pallant offered invaluable insights. Participants in the "expert interviews" gave generously of their time and knowledge. Two reviewers for this journal made many useful suggestions. All interpretations, errors, and omissions are my own. Financial support from Allegheny College's Christian Allison and Jane France Endowment Fund and the Andrew Wells Robertson Chair in Economics is gratefully acknowledged.

References

- Barney, J.B., 1991. Firm resources and sustained competitive advantage. *J. Manag.* 17, 99–120.
- Berrang-Ford, Lea, Ford, James D., Paterson, Jaclyn, 2011. Are we adapting to climate change? *Glob. Environ. Chang.* 21 (1), 25–33 (Accessed April 10, 2014: <http://dx.doi.org/10.1016/j.gloenvcha.2010.09.012>).
- Bierbaum, R., Lee, A., Smith, J., Blair, M., Carter, L.M., Chapin, F.S., III, P. Fleming, Ruffo, S., McNeeley, S., Stults, M., Verdusco, L., Seyller, E., 2014. Ch. 28: Adaptation. *Climate Change Impacts in the United States: The Third National Climate Assessment*. In: Melillo, J.M., Richmond, Terese (T.C.), Yohe, G.W. (Eds.), U.S. Global Change Research Program, pp. 670–706 <http://dx.doi.org/10.7930/J07H1GGT> (Accessed May 10, 2014: <http://nca.2014.globalchange.gov/report/response-strategies/adaptation>).
- Bishop, Peter, Hines, Andy, Collins, Terry, 2007. The current state of scenario development: an overview of techniques. *Foresight* 9 (1), 5–25.
- Board, Transportation Research, 2003. *Freight Capacity for the 21st Century. Special Report 271*. National Academy of Sciences, Washington, DC.
- Bolton, R., Foxon, T.J., 2014. Infrastructure transformation as a socio-technical process – Implications for the governance of energy distribution networks in the UK". *Technol. Forecast. Soc. Chang.* 90 (Part B), 538–550 (Accessed April 25, 2014: <http://dx.doi.org/10.1016/j.techfore.2014.02.017>).
- Borjeson, Lena, et al., 2006. Scenario types and techniques: towards a user's guide. *Futures* 38 (7), 723 + (Academic OneFile, Web. 8 Feb. 2013. Accessed July 22, 2013: http://go.galegroup.com.ezproxy1.allegheny.edu:2048/ps/i.do?id=GALE%7CA151764179&v=2.1&u=alleg_main&it=r&p=AONE&sw=w).
- Bradfield, R., Wright, G., Burt, G., Cairns, G., Van Der Heijden, K., 2005. The origins and evolution of scenario techniques in long range business planning. *Futures* 37, 795–812.
- Bradshaw, T.K., Blakely, E.J., 1999. What are "third-wave" state economic development efforts? From incentives to industrial policy. *Econ. Dev. Q.* 13 (3), 229–244.
- Budde, B., Alkemade, F., Weber, K.M., 2012. Expectations as a key to understanding actor strategies in the field of fuel cell and hydrogen vehicles". *Technol. Forecast. Soc. Chang.* 79 (6), 1072–1083 (Accessed August 15, 2013: <http://dx.doi.org/10.1016/j.techfore.2011.12.012>).
- Burnson, Patrick, 2011. Top 20 U.S. Ports: Where's the money? *Logist. Manag.* (May 1. Accessed May 23, 2012: http://www.logisticsmgmt.com/article/special_report_top_20_u.s._ports_wheres_the_money).
- Center for Climate and Energy Solutions, 2010. "Freight transportation". (Accessed July 30, 2013: <http://www.c2es.org/technology/factsheet/FreightTransportation>).
- ClimAID, 2011. Responding to climate change in New York state: the ClimAID integrated assessment for effective climate change adaptation in New York state. In: Rosenzweig, Cynthia, Solecki, William, DeGaetano, Arthur, O'Grady, Megan, Hassol, Susan, Grabhorn, Paul (Eds.), Prepared for the New York State Energy Research and Development Authority, Albany, NY (Available at <http://www.nyserda.ny.gov>).
- Collis, David J., Montgomery, Cynthia A., 1995. Competing on resources: strategy in the 1990s. *Harvard Business Review* (July–August).
- CSW (Corporation for a Skilled Workforce), 2011. *Revitalizing a tradition of excellence: a strategic plan*. Ann Arbor, Michigan.
- U.S. Department of Energy. N.D. "Wind Powering America." Energy Efficiency and Renewable Energy Program. Accessed July 18, 2013: http://www.windpoweringamerica.gov/wind_resource_maps.asp?stateab=pa.
- U.S. Department of Transportation. N.D. Research and Innovative Technology Administration, Bureau of Transportation Statistics, special tabulation. Accessed April 27, 2012: http://www.bts.gov/publications/national_transportation_statistics/html/table_01_50.html.
- Doran, Kevin, Reed, Adam, 2012. Natural Gas and its role in the U.S. energy endgame. *Environment* 360 (13 Aug http://e360.yale.edu/feature/natural_gas_role_in_us_energy_endgame/2561/).
- Easterling, W.E., Hurd, B.H., Smith, J.B., 2004. Coping with Global Climate Change: The Role of Adaptation in the United States. Pew Center on Global Climate Change, Arlington, Virginia 40 pp.
- EDC (Economic Development Corporation), 2011. Market assessment & analysis for an intermodal container transfer facility serving the East Lake Erie Region. Proprietary; references used by permission.
- EDC (Economic Development Corporation), 2013. Erie inland port initiative spurs global trade". E-Newsletter of the U.S. Economic Development Administration, Philadelphia region, February 14 (Accessed July 18, 2013: <http://edaphiladelphiaaregionaloffice.createsend5.com/t/ViewEmail/r/43E9D8424A392E40/5FE15CE311007DD34936C359EC0425C0>).
- Enzer, S., 1981. Exploring long-term business climates and strategies with Interax". *Futures* 13 (6), 469.
- European Commission, 2010. The EU's Climate and Energy Package. http://ec.europa.eu/clima/policies/package/index_en.htm (Accessed May 23, 2012).
- Federal Highway Administration, 2008. Freight story 2008. http://ops.fhwa.dot.gov/freight/freight_analysis/freight_story/index.htm Accessed July 31, 2013.
- Frumhoff, P.C., McCarthy, J.J., Melillo, J.M., Moser, S.C., Wuebbles, D.J., 2007. Confronting climate change in the U.S. Northeast: science, impacts, and solutions. Synthesis report of the Northeast Climate Impacts Assessment (NECIA). Union of Concerned Scientists (UCS), Cambridge, MA.
- GFR (Gelbert, Fullbright & Randolph Forestry Consultants), 2011. Regional analysis of woody biomass resources: Erie, PA. Prepared for the Erie Development Corporation Proprietary; references used by permission.

- GLRA (Great Lakes Regional Assessment), 2000. Preparing for a changing climate. University of Michigan, U.S. Global Change Research Program.
- Haasnoot, M., Kwakkel, J.H., Walker, W.E., ter Maat, J., 2013. Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world. *Glob. Environ. Chang.* 23, 2 Accessed April 13, 2014: <http://dx.doi.org/10.1016/j.gloenvcha.2012.12.006>.
- Hallworth, James, 2012. The Port of Amsterdam – Green Gateway to Europe. Erie Shippers Conference, May 24. (Courtesy of Erie, Development Corporation.).
- Heerwagen, Peter, 2009. Railroads pull for public-private partnerships. *North Valley Bus. J.* (Accessed July 30, 2013: <http://www.nationalgateway.org/railroads-pull-public-private-partnerships>).
- Helfat, C.E., Peteraf, M.A., 2003. The dynamic resource-based view: capability lifecycles. *Strateg. Manag. J.* 24, 991–995.
- Higginson, James, Dumitrascu, Tudorita, 2007. Great lakes short Sea shipping and the domestic cargo-carrying fleet. *Transp. J.* 46 (1), 38 (Winter).
- Hoffman, A.J., 2006. Getting ahead of the curve: corporate strategies that address climate change. Pew center on global climate change (Accessed July 15, 2013: http://www.c2es.org/docUploads/PEW_CorpStrategies.pdf).
- ICF International, Delcan Corporation, Cheval Research, 2011. Impacts of public policy on the freight transportation system. Transportation Research Board, National Research Council (Accessed July 31, 2013: http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_006.pdf).
- IPCC (Intergovernmental Panel on Climate Change, 2007. *Synthesis report* (Geneva).
- IPCC Working Group II, 2014. Climate change 2014: impacts, adaptation and vulnerability: a summary for policymakers. Fifth assessment report (31 March, Geneva).
- Jackson, L.E., Wheeler, S.M., Hollander, A.D., O'Geen, A.T., Orlove, B.S., Six, J., Sumner, D.A., Santos-Martin, F., Kramer, J.B., Horwath, W.R., Howitt, R.K., Tomich, T.P., 2011. Case study on potential agricultural responses to climate change in a California landscape. *Clim. Chang.* 109 (Supplement 1), S407–S427.
- Kahn, Herman, 1962. *Thinking about the unthinkable*. Avon Books, New York, NY.
- Karl, Thomas R., Melillo, Jerry M., Peterson, Thomas C. (Eds.), 2009. *Global climate change impacts in the United States*. Cambridge University Press.
- Karlstetter, Nana, 2012. Developing viability conditions – Transition to climate adapted land use as an example. Paper presented at the AFEP/AHE/IIPPE Conference "Political Economy and the Outlook for Capitalism", July 5–7. Panthéon-Sorbonne University, Paris.
- Kessler, Rebecca, 2011. Stormwater strategies: Cities prepare aging infrastructure for climate change. *Environ. Health Perspect.* 119, a514–a519 (Accessed March 24, 2012: <http://dx.doi.org/10.1289/ehp.119-a514>).
- Kriegler, E., O'Neill, B.C., Hallegatte, S., Kram, T., Lempert, R.J., Moss, R.H., Wilbanks, T., 2012. The need for and use of socio-economic scenarios for climate change analysis: a new approach based on shared socio-economic pathways. *Glob. Environ. Chang.* 22, 807–822 (Accessed May 9, 2014: <http://dx.doi.org/10.1016/j.techfore.2013.09.021>).
- Kriegler, E., Riahi, K., Bauer, N., Schwanitz, V.J., Petermann, N., Bosetti, V., Marcucci, A., Otto, S., Paroussos, L., Rao, S., Currás, T.A., Ashina, S., Bollen, J., Eom, J., Hamdi-Cherif, M., Longden, T., Kitous, A., Méjean, A., Sano, F.I., Schaeffer, M., Wada, K., Capros, P., van Vuuren, D.P., Edenhofer, O., 2014. Making or breaking climate targets: The AMPERE study on staged accession scenarios for climate policy." 2014. *Technol. Forecast. Soc. Chang.* 90 (Part A), 24–44 (Accessed April 13, 2014: <http://dx.doi.org/10.1016/j.techfore.2013.09.021>).
- Lade, Clare, 2009. Tourism business clusters: Winners and losers along Australia's Murray River. In: Martin, John, Rogers, Maureen, Winter, Caroline (Eds.), *Climate change in regional Australia: Social learning and adaptation*. Victorian Universities Regional Research Network Press, Ballarat, Australia, pp. 394–422.
- Lazonick, W., 1994. Social organization and technological leadership. In: Baumol, W.J., Nelson, R.R., Wolff, E.N. (Eds.), *Convergence of productivity: Cross national studies and historical evidence*. Oxford University Press, pp. 164–193.
- Linnenluecke, M.K., Griffiths, A., 2010. Beyond adaptation: Resilience for business in light of climate change and weather extremes. *Bus. Soc.* 49 (3), 477–511.
- Linnenluecke, M.K., Griffiths, A., Winn, M.I., 2013. Firm and industry adaptation to climate change: a review of climate adaptation studies in the business and management field. *WIREs Clim. Change* 4, 397–416. <http://dx.doi.org/10.1002/wcc.214>.
- Lofgren, B.M., Hunter, T.S., Wilbarger, J., 2011. Effects of using air temperature as a proxy for potential evapotranspiration in climate change scenarios of Great Lakes basin hydrology. *J. Great Lakes Res.* 37.
- Loomis, D.G., 2013. The Potential Economic Impact of Offshore Wind Energy in the Great Lakes. Great Lakes Commission: Great Lakes Wind Collaborative (Accessed January 15, 2014: <http://www.glc.org/files/docs/2013-potential-economic-impact-offshore-wind.pdf>).
- Millerd, Frank, 2007. Global climate change and great lakes international shipping. Transportation Research Board Special Report 291.
- Milly, P.C.D., Dunne, K.A., 2011. On the hydrologic adjustment of climate-model projections: The potential pitfall of potential evapotranspiration. *Earth Interact.* 15.
- Moser, Susanne C., Ekstrom, Julia A., 2010. A framework to diagnose barriers to climate change adaptation. *Proc. Natl. Acad. Sci.* 107 (51), 22026–22031. <http://dx.doi.org/10.1073/pnas.1007887107> (Available at: <http://www.pnas.org/content/suppl/2010/11/30/1007887107.DCSupplemental>).
- Moss, R.H., Edmonds, J.A., Hibbard, K.A., Manning, M.R., Rose, S.K., Van Vuuren, D.P., Carter, T.R., Emori, S., Kainuma, M., Kram, T., Meehl, G.A., Mitchell, J.F.B., Nakicenovic, N., Riahi, K., Smith, S.J., Stouffer, R.J., Thomson, A.M., Weyant, J.P., Wilbanks, T.J., 2010. The next generation of scenarios for climate change research and assessment. *Nature* 463, 747–756.
- Myers, Valerie, 2013. North East group wants tight restrictions on wind farms. *Erie Times-News* (April 23, Accessed July 18, 2013: <http://www.goerie.com/apps/pbcs.dll/article?AID=2013304139911>).
- Nordwest2050, 2012. Prospects for climate-adapted innovation processes in the model region Bremen-Oldenburg in North Western Germany. (Accessed July 15, 2012: http://www.nordwest2050.de/index_nw2050.php?obj=page&id=139&unid=7d715c6031d64e61856f0da3e65b9ae9).
- NRC (National Research Council), 2010. Adapting to the impacts of climate change. National Academies Press, Washington, DC Accessed May 18, 2012: http://www.nap.edu/catalog.php?record_id=12783.
- Onyeiwu, Steve, 2009. Identifying and leveraging growth drivers in the tooling and machining industry of Crawford and Erie counties, Pennsylvania. Center for Economic and Environmental Development, Allegheny College, Meadville, Pennsylvania.
- Pennsylvania State Climatologist, 2012. http://climate.met.psu.edu/www_prod/data/state/ Accessed May 4, 2012.
- Porter, Michael E., 1998. Clusters and the new economics of competition. *Harv. Bus. Rev.* 76, 77–90 (November–December).
- Porter, M.E., Reinhardt, F.L., 2007. A strategic approach to climate. *Harv. Bus. Rev.* 85, 22.
- PROVIA, 2013. PROVIA guidance on assessing vulnerability, impacts and adaptation to climate change. Consultation document. United Nations Environment Programme, Nairobi, Kenya (198 pp. Accessed May 21, 2014: <http://www.unep.org/provia>).
- Ringland, Gill, 1998. *Scenario planning: Managing for the future*. John Wiley & Sons, Hoboken, NJ.
- Robinson, J., 1990. Futures under glass: a recipe for people who hate to predict. *Futures* 22 (8), 820–823.
- Rosen, R.A., Guenther, E., 2014. The economics of mitigating climate change: What can we know? *Technol. Forecast. Soc. Chang.* 91, 93–106 Accessed April 30, 2014: <http://dx.doi.org/10.1016/j.techfore.2014.01.013>.
- Schultz, W., 1993. Scenario building: the Manoa approach. (Accessed July 22, 2013: www.infinitefutures.com/tools/sbmanoa.shtml).
- Schwartz, P., 2007. Investing in global security. *Harv. Bus. Rev.* 85, 26.
- Schwartz, John, 2013. Water levels fall in great lakes, taking a toll on shipping. *N.Y. Times* (June 10, Accessed August 1, 2013: <http://www.nytimes.com/2013/06/11/us/great-lakes-shipping-suffers-as-water-levels-fall.html?hp&r=0>).
- Seitz, Diana, 2014. Regionalisation of global insights into dryland vulnerability: Better reflecting smallholders' vulnerability in Northeast Brazil". *Glob. Environ. Chang.* 25, 173–185 (Accessed April 10, 2014: <http://dx.doi.org/10.1016/j.gloenvcha.2014.01.010>).
- Sterzinger, George, Svercek, Matt, 2004. Wind turbine development: Location of manufacturing activity. Renewable Energy Policy Project, Washington, DC.
- Sutherland, William, 2006. Predicting the ecological consequences of environmental change: A review of the methods. *J. Appl. Ecol.* 43 (4), 599–616.
- Teece, D.J., Pisano, G., Schuen, A., 1997. Dynamic capabilities and strategic management. *Strateg. Manag. J.* 18 (7), 509–530.
- TEMS (Transportation Economics and Management Systems, Inc.), 2008. Impact of high Oil prices on freight transportation: Modal shifts in five corridors. Maritime Administration, U.S. Department of Transportation, Washington, DC.
- Tompkins, E.L., Eakin, H., 2012. Managing private and public adaptation to climate change. *Glob. Environ. Chang.* 22 (1), 3–11 (Accessed August 24, 2013: <http://dx.doi.org/10.1016/j.gloenvcha.2011.09.010>).
- Tschakert, Petra, Dietrich, Kathleen Ann, 2010. Anticipatory learning for climate change adaptation and resilience. *Ecol. Soc.* 15 (2) (Available online at <http://www.ecologyandsociety.org/vol15/iss2/art11/>).
- Uchitelle, Louis, 2010. Green economy is not yet made in U.S.A. *N.Y. Times* (April 22 Accessed July 15, 2011: http://www.nytimes.com/2010/04/22/business/energy-environment/22PLANT.html?_r=1).
- Vervoot, J.M., Thornton, P.K., Kristjansson, P., Förch, W., Erickson, P.J., Kok, K., Ingram, J.S.I., Herrero, M., Palazzo, A., Helfgott, A.E.S., Wilkinson, A., Havlik, P., Mason-D'Croz, D., Jost, C., 2014. Challenges to scenario-guided adaptive action on food security under climate change. *Global Environmental Change* 28, 383–394 (Accessed May 5, 2014: <http://dx.doi.org/10.1016/j.gloenvcha.2014.03.001>).

- Vickerman, John, 2012. Presentation at Erie Shippers Association Conference. Erie, PA (May 24).
- Wise, R.M., Fazey, I., Stafford Smith, M., Park, S.E., Eakin, H.C., Archer Van Garderen, E.R.M., Campbell, B., 2014. Reconceptualising adaptation to climate change as part of pathways of change and response. *Glob. Environ. Chang.* 28, 325–336 (Accessed May 9, 2014: <http://dx.doi.org/10.1016/j.gloenvcha.2013.12.002>).
- World Port Source, 2012. Port of Erie Accessed May 3, 2012. http://www.worldportsource.com/ports/USA_PA_Port_of_Erie_1617.php.

Don Goldstein is the AW Robertson Professor of Economics at Allegheny College. His research on corporate change has addressed climate adaptation, environmental management, restructuring and downsizing, and the high performance workplace. Goldstein founded Allegheny's program in Managerial Economics. He has been a Fulbright Scholar in Ireland, Costa Rica, and Ethiopia, and a Brookings Dissertation Fellow in Washington, DC. Goldstein received his bachelor's degree from Harvard College and his doctorate from the University of Massachusetts at Amherst.