Spatiotemporal considerations in energy decisions

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The importance of time and space for energy decisions

- Technology assessments typically focus on inputs and outputs.
  - Energy projects occur across regions, scales and with differing lifetimes.

- Assessments of impacts often focus on snapshots in time in a particular region.
  - The outside environment evolves: economics, politics, and the natural environment.

- Technology assessments over time that include regional variability are not well developed.

- These gaps pose a challenge for decision-makers: how can the environmental costs and benefits of energy projects be evaluated across regions, scales, and time?

- We now have software tools and datasets which can be combined and utilized with novel methods to address some of these questions – and our ability to do so will only improve.

Three impact categories: water, land, climate

Water consumption

Policies and technology assessments at the federal and state-levels do not account for regional impacts and vice versa. Methods are needed to translate the governance decisions to local/regional effects and constraints (e.g. scarcity) which may create limits to operations.

Land: spatial requirements of energy technologies

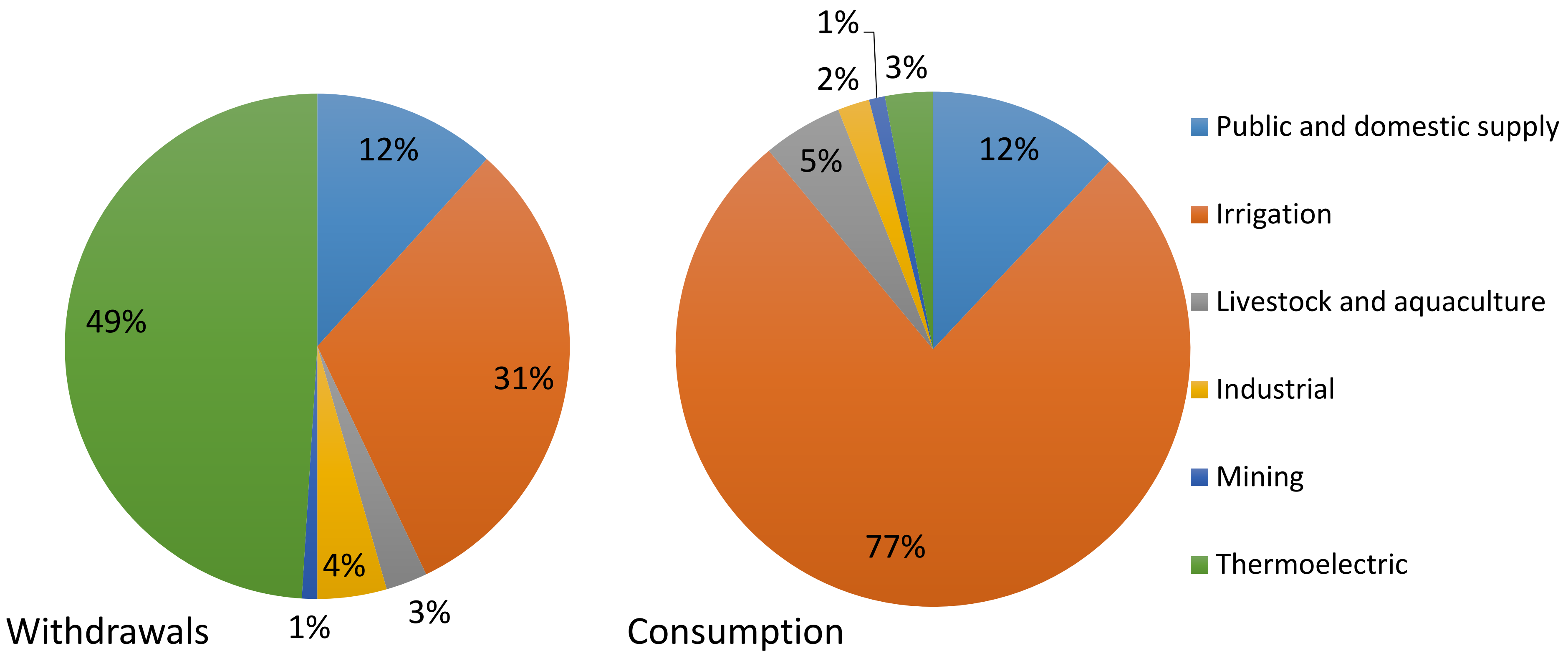
Comparisons of the land required for energy development across regions is not well addressed in present methodology, which is further confounded by challenges in comparing renewables and non-renewables over time.

Climate: emissions and policies

With the expansion of trade and growth in global greenhouse gas (GHG) emissions, decision-support tools such as Life Cycle Assessment (LCA) need to better recognize inter-regional variability of GHG emissions from energy technologies, but also the influence of regional policies on GHG reduction.

Water use in the United States

What is the difference between water consumption and withdrawal?



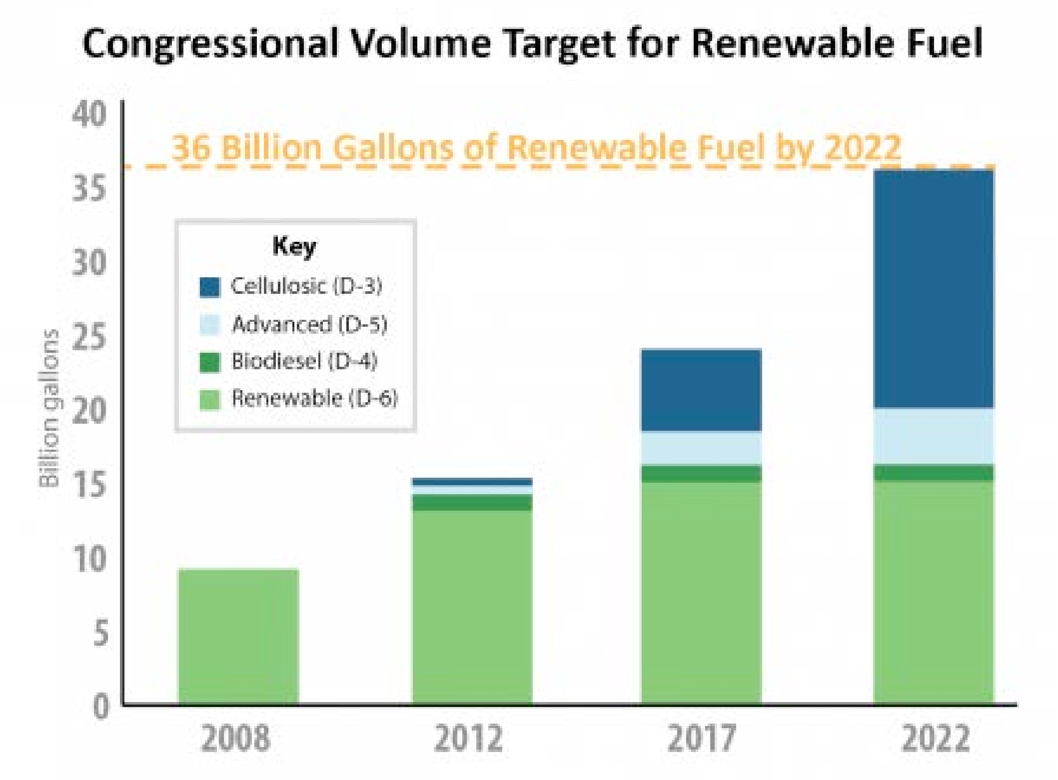
Total: 410 billion gallons per day (Bgal/d)

Total: ~100 Bgal/d

BP 2013, USGS 2009

Renewable Fuel Standard

- Federal energy policies can impact water consumption nationally and regionally.
- The EPA is responsible for ensuring transportation fuel sold in U.S. contains a minimum volume of renewable fuel.
- The Renewable Fuel Standard mandates an increase in the use of biomass-based fuels from 9 billion gallons in 2008 to 36 billion gallons by 2022.
    - No more than 15 billion from corn grain.
    - The remaining 21 billion would be produced from advanced biofuels, biodiesel, and cellulosic.

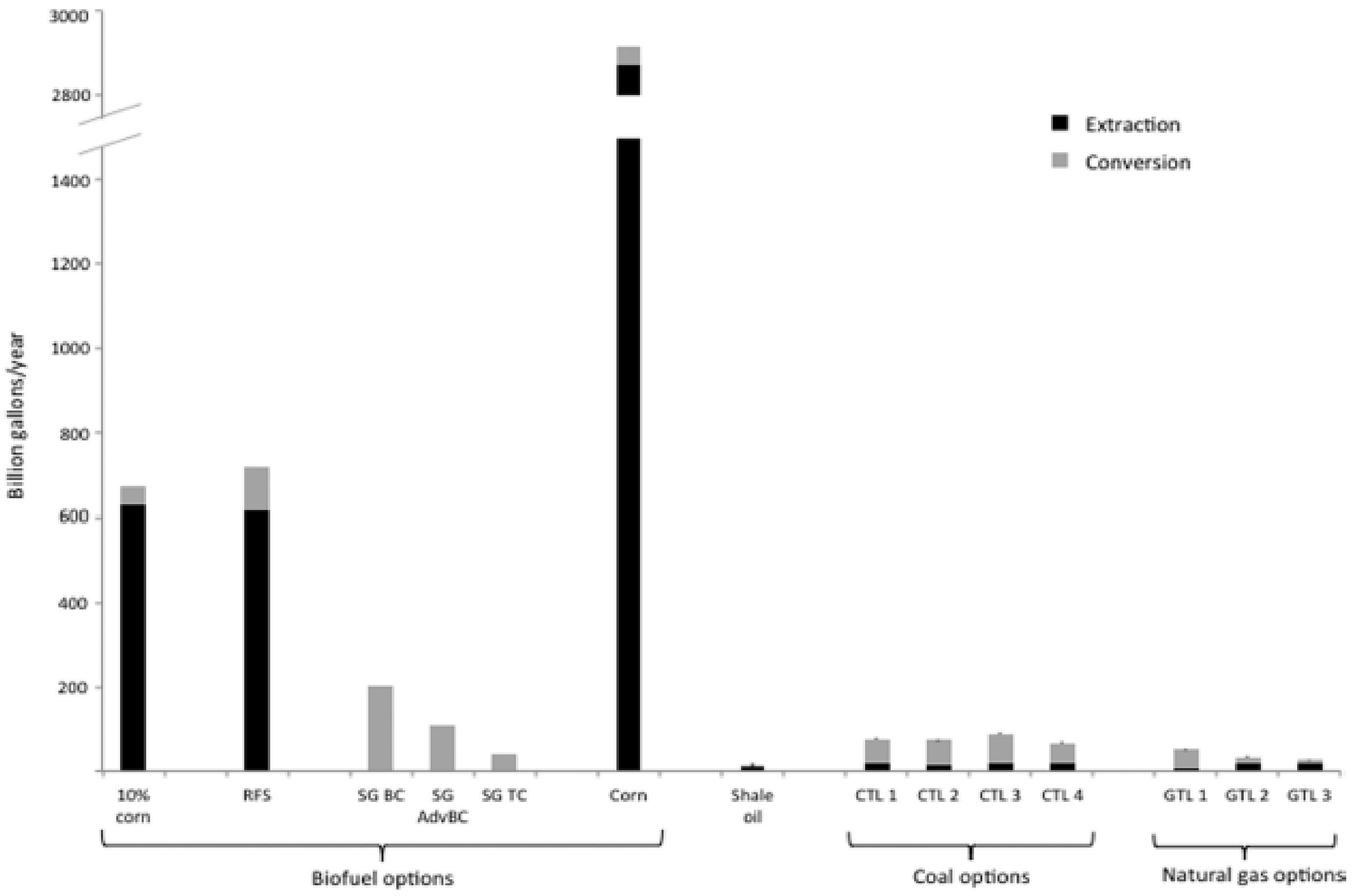


EPA 2016

Water consumption by scenario in 2022

We developed 7 scenarios for reducing oil imports to the United States. Water consumption was evaluated for each options. Consumption was then translated to state-level water requirements.

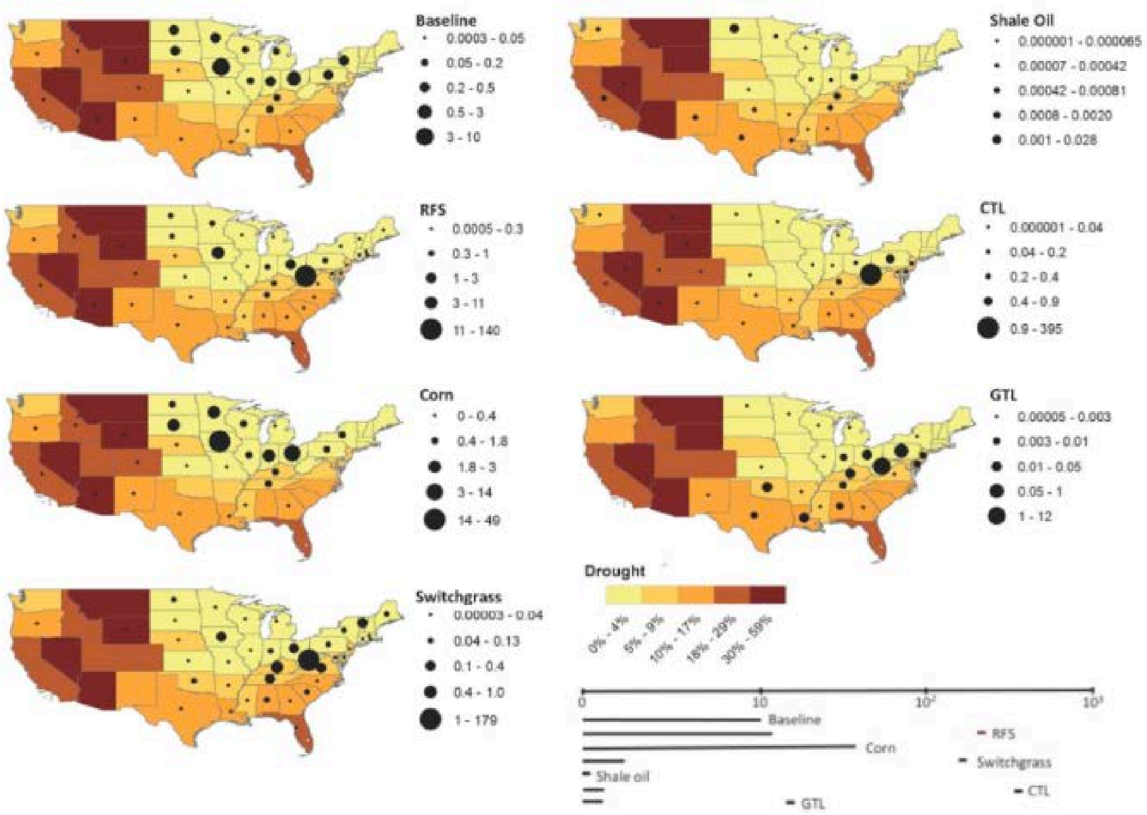
Scenario	Description
Baseline	Biofuels maintain10% of production and production increases proportionally to demand growth. Any additional growth in oil demand is met by imports.
Shale oil	Given the changes in domestic oil production, this could also be considered a business as usual case. Biofuel production stays constant compared to today and the amount of fuel required by the RFS by 2022 is produced with shale oil rather than biofuels.
RFS	In this scenario, the RFS is met with the same proportions expected under the current policy.
Switchgrass	It is assumed that switchgrass becomes commercially available. No additional corn biofuel is produced and the additional fuel quantity expected to be produced using the RFS is met only using switchgrass.
Corn	In this scenario, cellulosic ethanol is not commercially available and corn ethanol is ramped up to produce the same amount of fuel to be produced by the RFS.
CTL	Gasoline and diesel are produced from coal using Fischer Tropsch technology.
GTL	Gas to liquids are used here to produce an equivalent amount of fuel as that produced by the RFS.



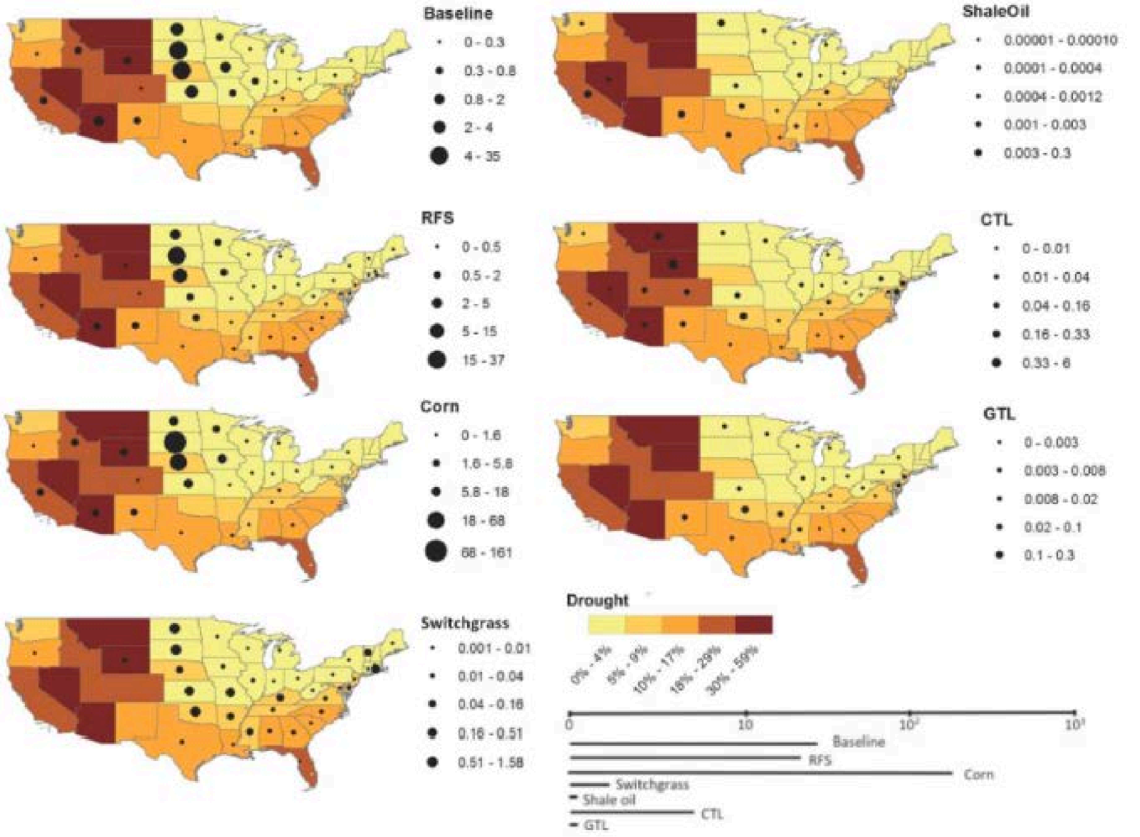
Jordaan, Anadon, Mielke, Schrag 2013

Consumption to withdrawal ratio and water availability

Water consumption 2022 to irrigation withdrawals in 2005



Water consumption 2022 to industrial withdrawals in 2005



Jordaan, Anadon, Mielke, Schrag 2013

Policy implications

- Fossil options and cellulosic ethanol require significantly less water and are weighted toward less drought-prone states.
- The first gen corn scenario is the most water intense option and is more weighted toward drought-prone states.
- Results provide coarse scale, first order estimate to assist with integrating federal policies with regional planning.

Federal-regional policy coherence

- There is a need to develop stronger strategic planning tools to understand water impacts of federal policies.
- Emphasizes need for coordination among agencies.
  - Water implications for US energy policy can be significant and heterogeneous.
  - Areas where more fine-grain analysis is warranted can be identified.

Jordaan, Anadon, Mielke, Schrag 2013

Water consumption changes of the coal-to-gas transition

- Natural gas is a cleaner burning fuel then coal and results in fewer GHG emissions at the stack.

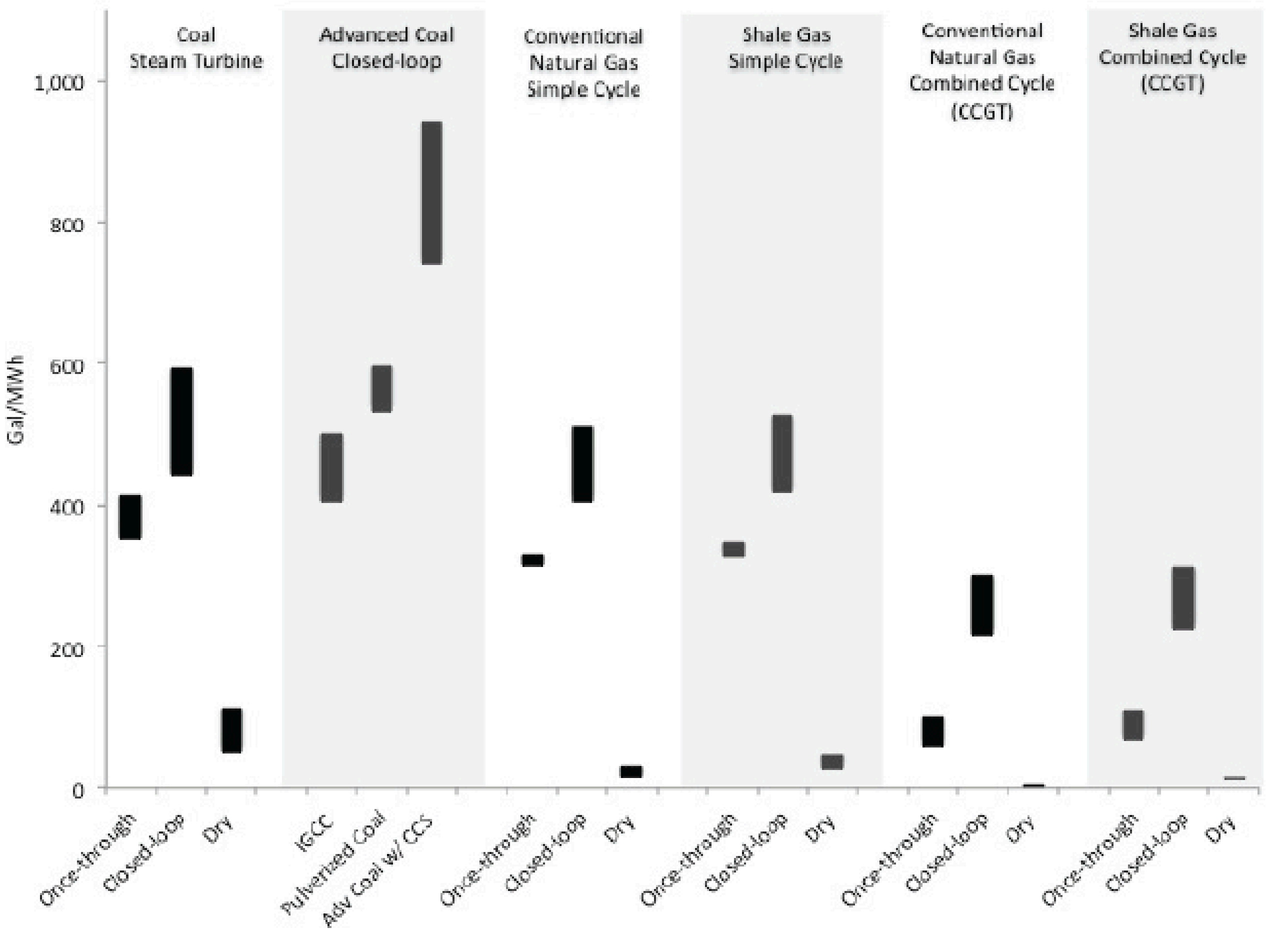
- Water implications of the coal-to-gas transition are complex spatially and temporally.

- Two different views:

    - Switching from coal to natural gas for power reduces the amount of water consumption by as much as 65% (Diehl and Harris 2014).

    - Expansion of hydraulic fracturing increases water consumption, which may stress local water supplies (Gilmore et al. 2014).

Figure 1. Influence of technical and fuel characteristics on water consumption for electricity generation.



Patterson, Jordaan, Anadon 2016

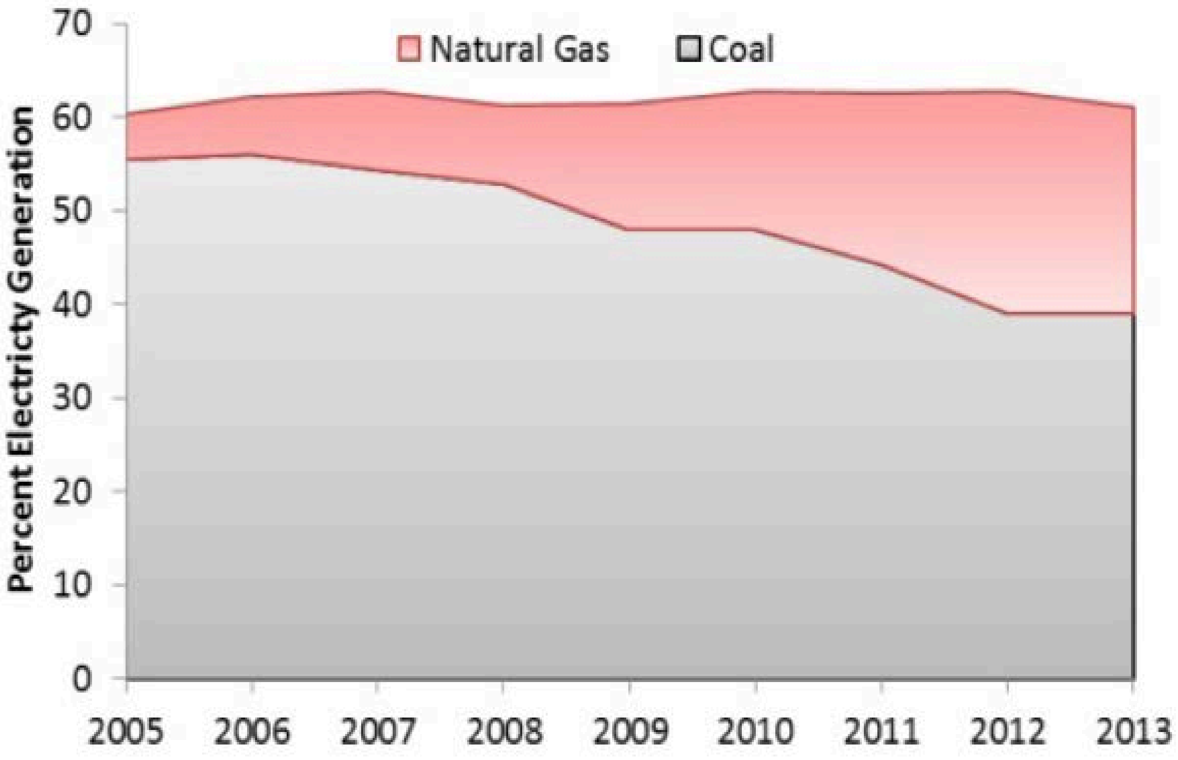
Study area and contribution

This study makes two main contributions:

1. A method to estimate water consumption associated with fuel extraction and power generation at a higher spatial and temporal resolution.

2. A comprehensive picture of the changing water consumption patterns in the coal-to-gas transition.

Changes in coal and natural gas power generation in Pennsylvania, 2005–2012.



Pennsylvania was selected as the study area due to: (1) the distinct coal to gas transition in the electric sector and (2) the reported water limits placed on operators despite being a water-rich state.

Time period: 2009-2012.

Data: Shale gas (Fracfocus, PA-DEP); coal (MSHA, Mielke et al(2010)); power generation (EIA, Macknick et al, Mielke et al (2010), UCS).

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Results

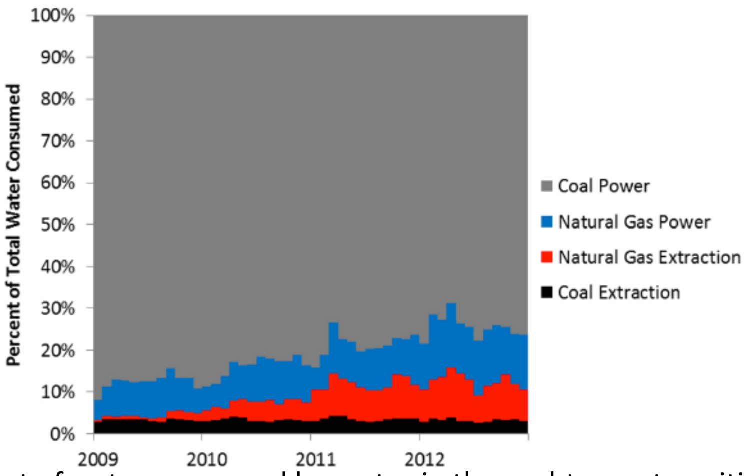

Figure 1: Percent of water consumed by sector in the coal-to-gas transition.

Table 1. Annual water consumed (Mgal) by sector, 2009–2012.

	Gas Extraction	Coal	Coal Power	Natural Gas Power	Total
2009	857	2,614	70,212	6,381	**80,064**
2010	3,529	2,831	72,787	7,622	**86,768**
2011	7,149	2,983	67,810	8,011	**85,953**
2012	7,542	2,578	61,411	10,682	**82,212**

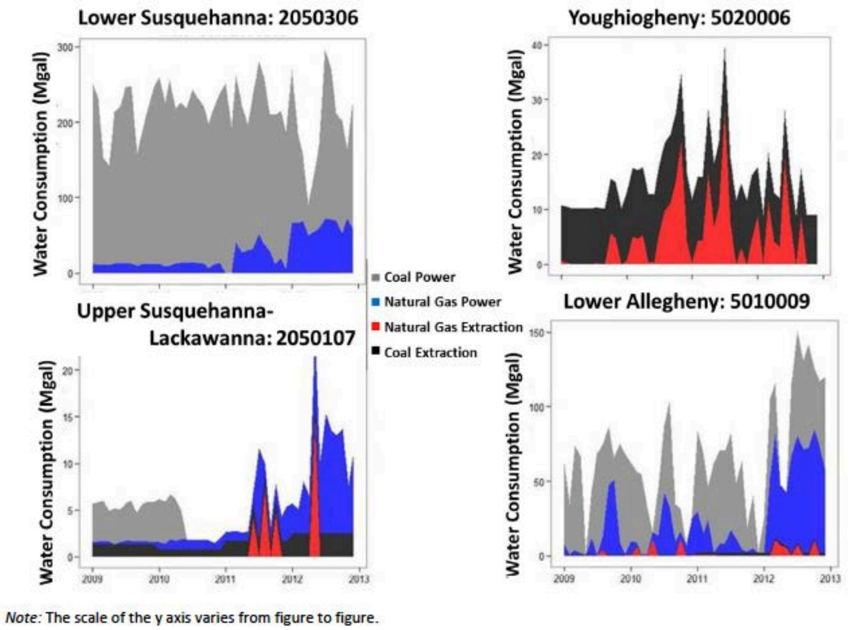

Figure 2: Water consumption over time in specific basins.

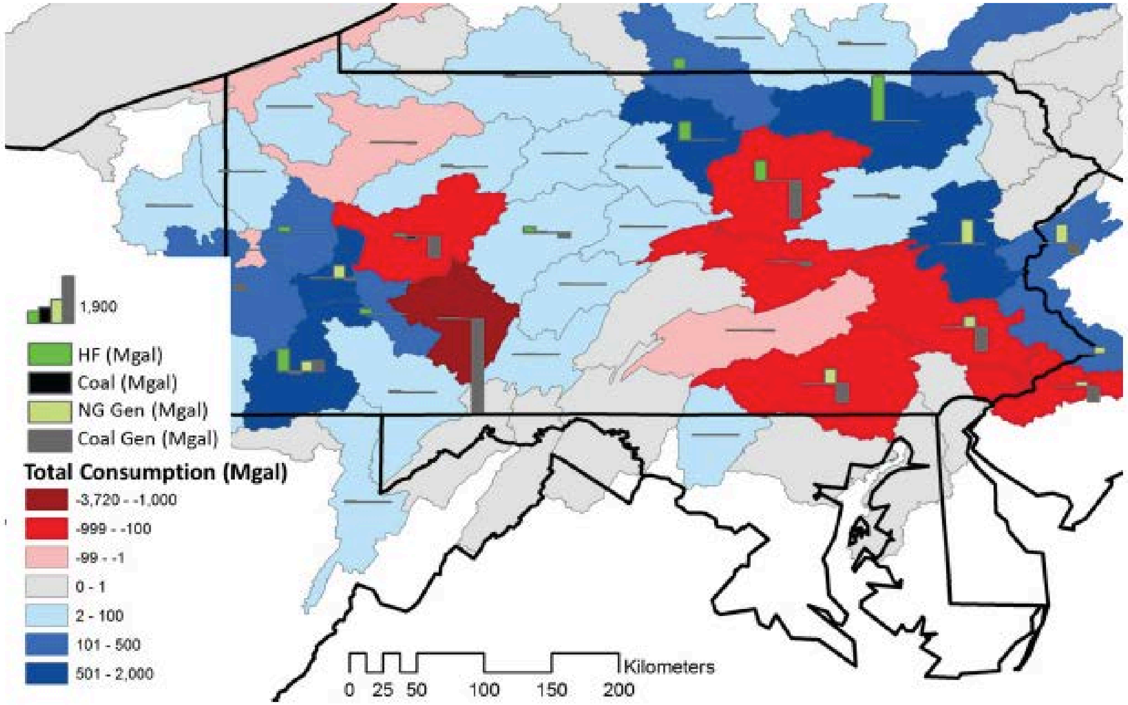

Figure 3: 2009-2012 change in water consumption.

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Key findings

- Shale gas extraction (2009-2012):
  - Water consumption for fuel increased within each sub-basin with hydraulic fracturing activity.

- Power generation (2009-2012):
  - Water consumed by coal power decreased by 13%.
  - Natural gas power increased by 67%.
  - Net decrease of 6% for total water consumed for electricity generation.

- Overall (2009-2012):
  - The change in water consumption patterns varies by sub-basin.
  - Basins with hydraulic fracturing increase their water consumption if no opportunities to transition from coal to natural gas-fired plants.
  - Basins where coal-fired plants transition to natural gas may decrease their overall water consumption.

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Policy implications

- National level: understanding broad sectorial transitions.
- Local level: decision-makers approving permits and crafting policies to manage environmental impacts.

Governments:

- Watershed-level management.
- Water markets (pricing).
- Regulations requiring new technologies or performance.
- Withdrawal and consumption restrictions.
- Protection of sensitive ecosystems.

Utilities:

- Best-in-class cooling technology.
- Technology innovation.
- Alternative water sources (e.g. industrial ecology).

Shale operators:

- Water reuse.
- Technology innovation.
- Use of water sources other than surface water.
- Timing of consumption/withdrawal.

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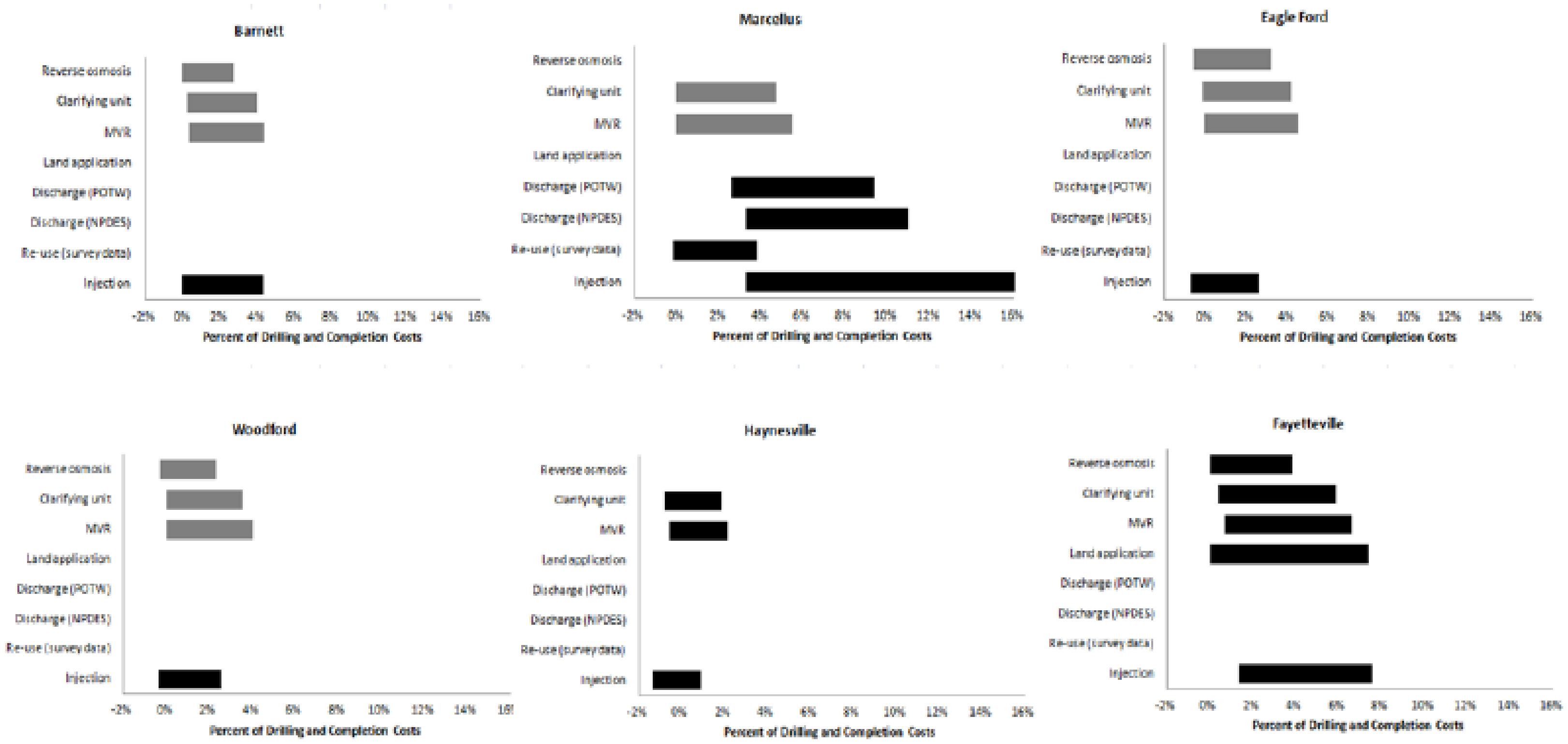
Similar questions can be applied to costs…

Combined incremental costs of produced water treatment and well completion



- The costs associated with environmental mitigation can and often do differ by region as well as over time.
- Solutions may be more cost effective in some regions when compared to others.
- Results highlight the importance of better understanding regional variability for costs/solutions as well as impacts.

Land-energy nexus

Two key areas where space and time matters for the land-energy nexus will be covered:

Comparisons of renewable energy and non-renewable energy are often criticized due to the lack of systematic methodology and data. The choice of metric and assumptions about time have a large impact on the results.

Few methods have been developed to compare systematically the inter-regional variability of specific energy types. The land requirements for energy technologies varies based on geology, operator practice, regulation, and existing infrastructure.

Challenges include: choice of metric (e.g. land intensity (m^2/MWh, m2/MJ), Power density (W/m^2)), time frames of the analysis, lifespans of the project, land quality, etc.

Comparing renewable energy and non-renewable energy

- Assumptions about lifetime remain a challenge.
- Power densities (W/m2) introduced as a metric by Vaclav Smil.
- **Equivalency time**: the time for a hectare of land to produce the equivalent amount of energy as a hectare producing a finite amount of fossil fuel.
- The proof-of-concept presented is based on Alberta data (Jordaan 2010); however, data and regional variability remain a challenge.
  - Natural gas values reflect conventional gas with a large contribution from shallow gas wells.

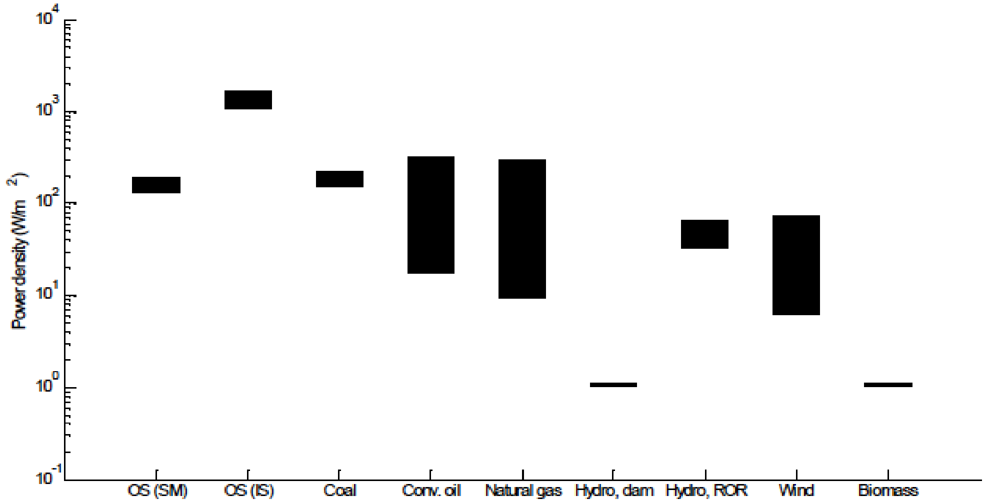


Figure 1. Power densities (W/m^2) of energy production in Alberta. OS, IS and OS, SM are in situ oil sands and surface mining of oil sands. ROR is run of the river hydropower (Jordaan, 2010).

Table 1: estimated restoration time for select ecosystem types (Koellner and Scholtz, 2007)

Ecosystems	Time (years)
Agricultural land, pioneer[6] vegetation	<5
Species-poor grasslands, mature pioneer vegetation	5-25
Oligotrophic[7] vegetation, species-rich marshland, grasslands	25-50
Species-rich forests, shrubs, hedgerows	50-200
Immature peatbogs, old dry grasslands	200-1000
Mature peat bogs, old growth forests	1,000-10,000

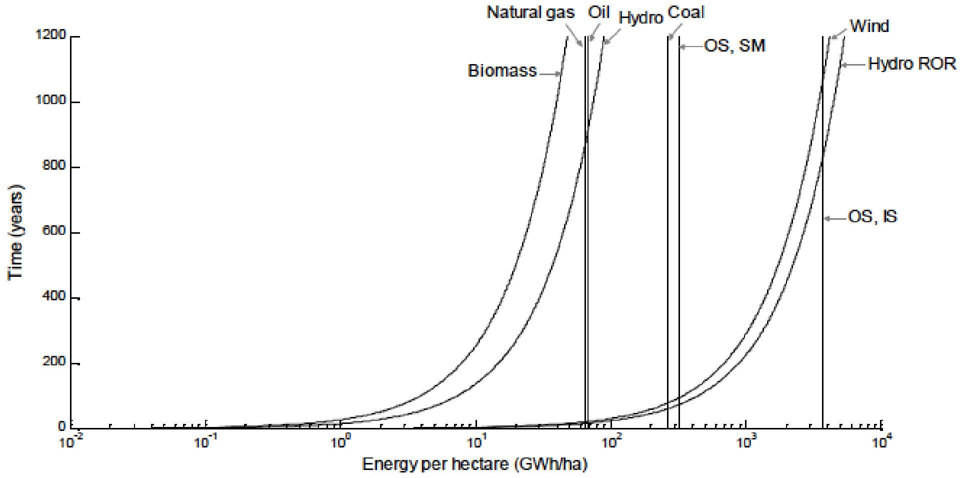


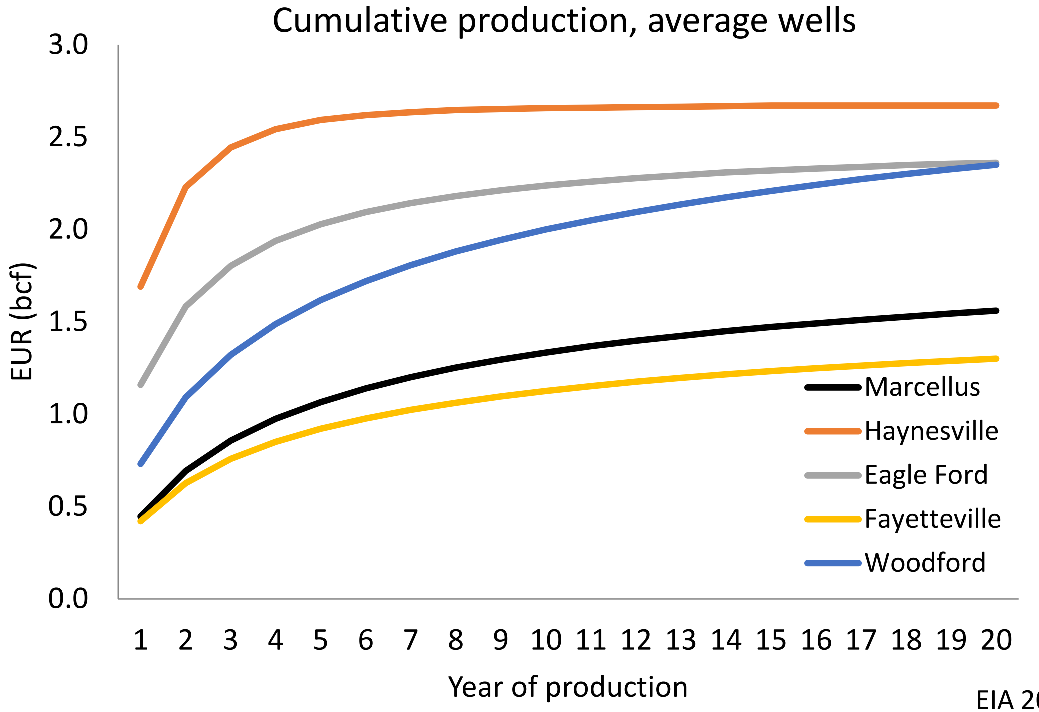
Figure 2. Equivalency times for different energy types. OS, IS and OS, SM are in situ oil sands and surface mining of oil sands. ROR is run of the river hydropower (Jordaan, 2010).

Jordaan 2010

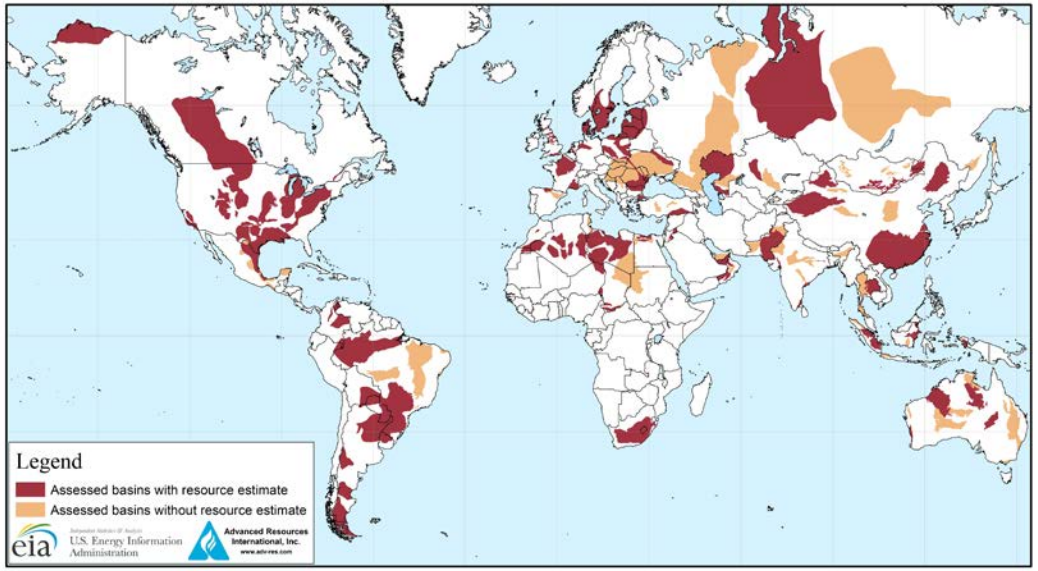
Natural gas: inter-regional variability

- Land requirements and intensity vary across regions for some energy categories: exactly how and how much is not well understood.

- Influencing factors: historical development patterns, current land use and population settlement patterns, land use laws and regulations, geology, operator practice, maturity of gas development in the region.



EIA 2013



- Variability in some factors is observed directly for across regions in the U.S. and will certainly apply to regions globally

- Of key importance to not only land, but water and emissions as well as solutions (mitigation and control).

- Methods are still in early in their development.

The Spatial Footprint of Natural Gas-Fired Electricity: A Case Study of the Barnett Shale region of Texas

A method is being developed using spatial analysis combined with commercial datasets. The goal is to provide a systematic way to better compare land requirements across regions and energy technologies.

** Figures to be released upon publication **

Jordaan, Heath, Macknick, Bush, Ben-Horin, Mohamadi, Marceau (in prep)

Policy implications

- How will such analyses assist decision-makers?
  - Developing meaningful ways to understand better the spatial requirements of renewable and non-renewable energy.
  - Improving our present inter-regional estimates to inform the impacts of future decisions and policies.

Firms:

- Better comparisons provide broad public knowledge on energy decisions (debunking myths).
- Spatial databases can inform other areas where infrastructure is related to impacts (e.g. methane emissions, pipeline risk assessment).
- More efficient land use plans can be developed with other land users in regions.

Governments:

- Broader agreements needed on what to measure and how (systematic methods).
- Meaningful metrics can lead towards better scenario modeling for multiple land uses in a region.
- Such assessments provide meaningful links between policy and impacts.
- Inter-regional variability can inform regional land policies.
- Understanding overall land requirements for infrastructure can support more efficient infrastructure planning.

Climate-energy nexus

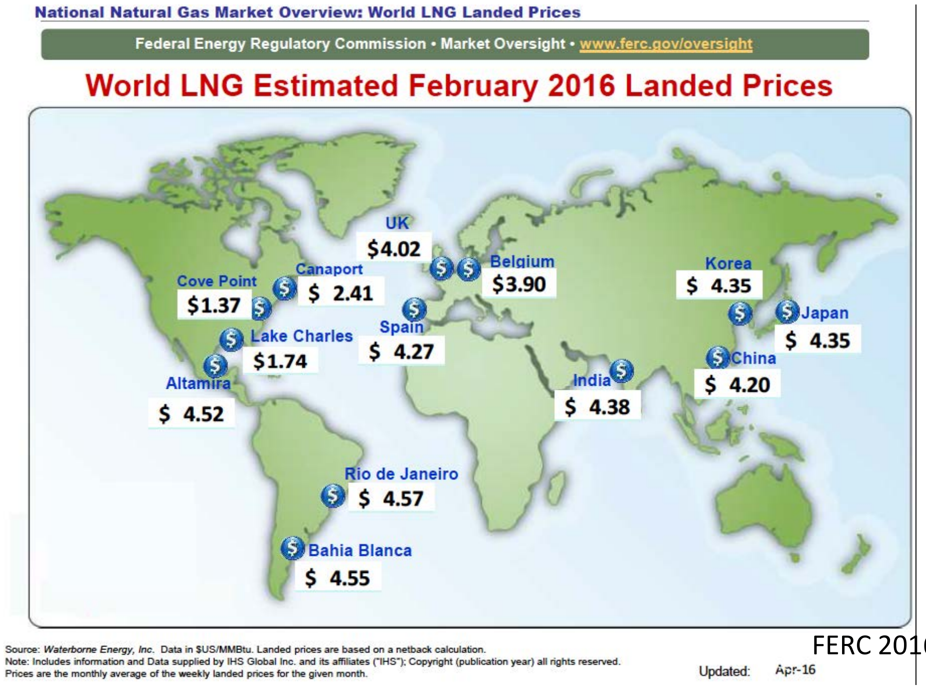
Two areas where regional variability matters for mitigation will be covered:

Greenhouse gas emissions vary geographically according to several factors, such as available resources, the technology in use, and the vintage of the existing infrastructure. Present LCA models need to be expanded to explicitly address such factors to support effective decisions and policies.

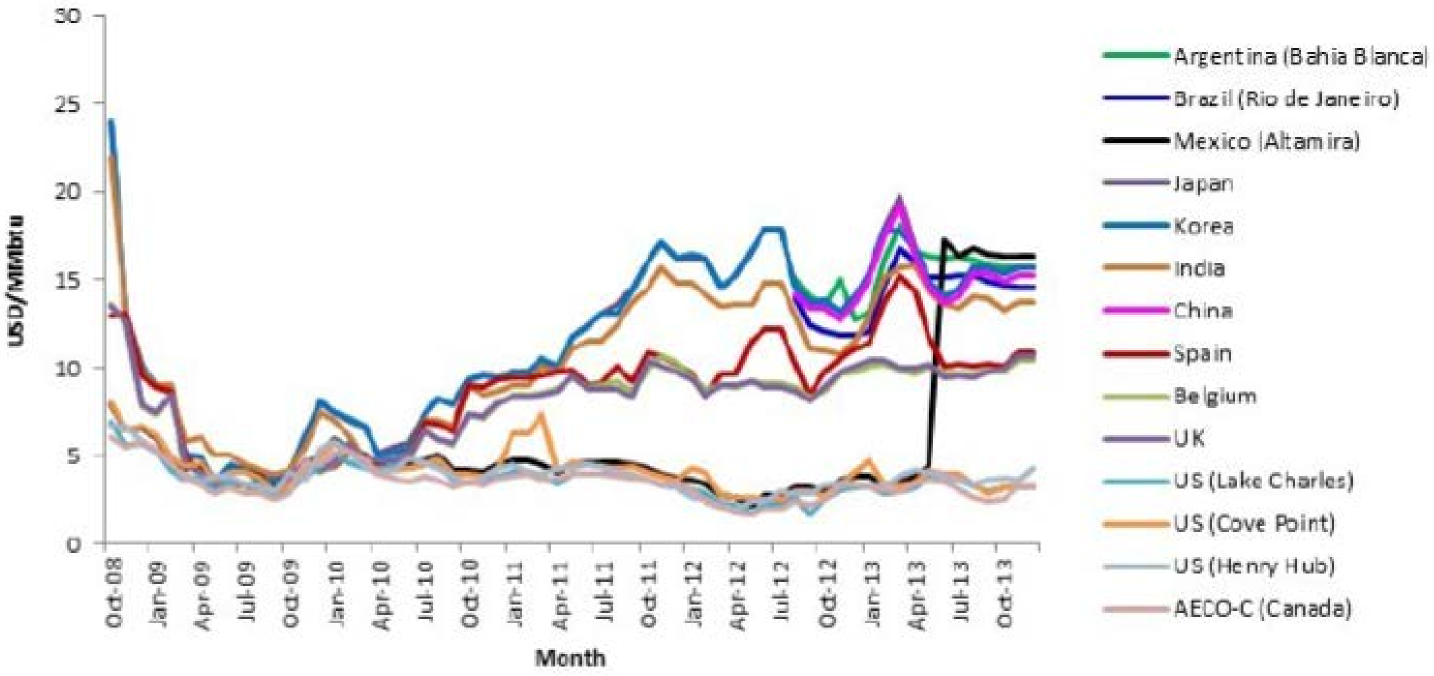
Inter-regional policy variability also effects the overall ability to achieve emissions reductions. Climate-related policies are developed according to a region's political influences, resource availability, and economic development status (amongst other factors).

Liquefied natural gas (LNG) export and GHG emissions

- LNG markets expanded rapidly in recent years in response to market demand.
- Three natural gas markets emerged: Asia, Europe, Americas.
- Markets still evolving in 2016 with landed prices in Asia still dropping.



FERC 2016



** Latest figure to be released upon publication **

- Purpose: to assess GHG implications of LNG export.
- Our work includes:
  - A review of markets,
  - Compilation of US and Canadian life cycle studies,
  - Country-level assessment per unit electricity delivered, emissions displacement scenarios.

Kasumu, Li, Coleman, Liendo, Jordaan (in prep); Working paper: http://prism.ucalgary.ca/retrieve/44157/LNG-OP49.pdf

LNG export and GHG emissions

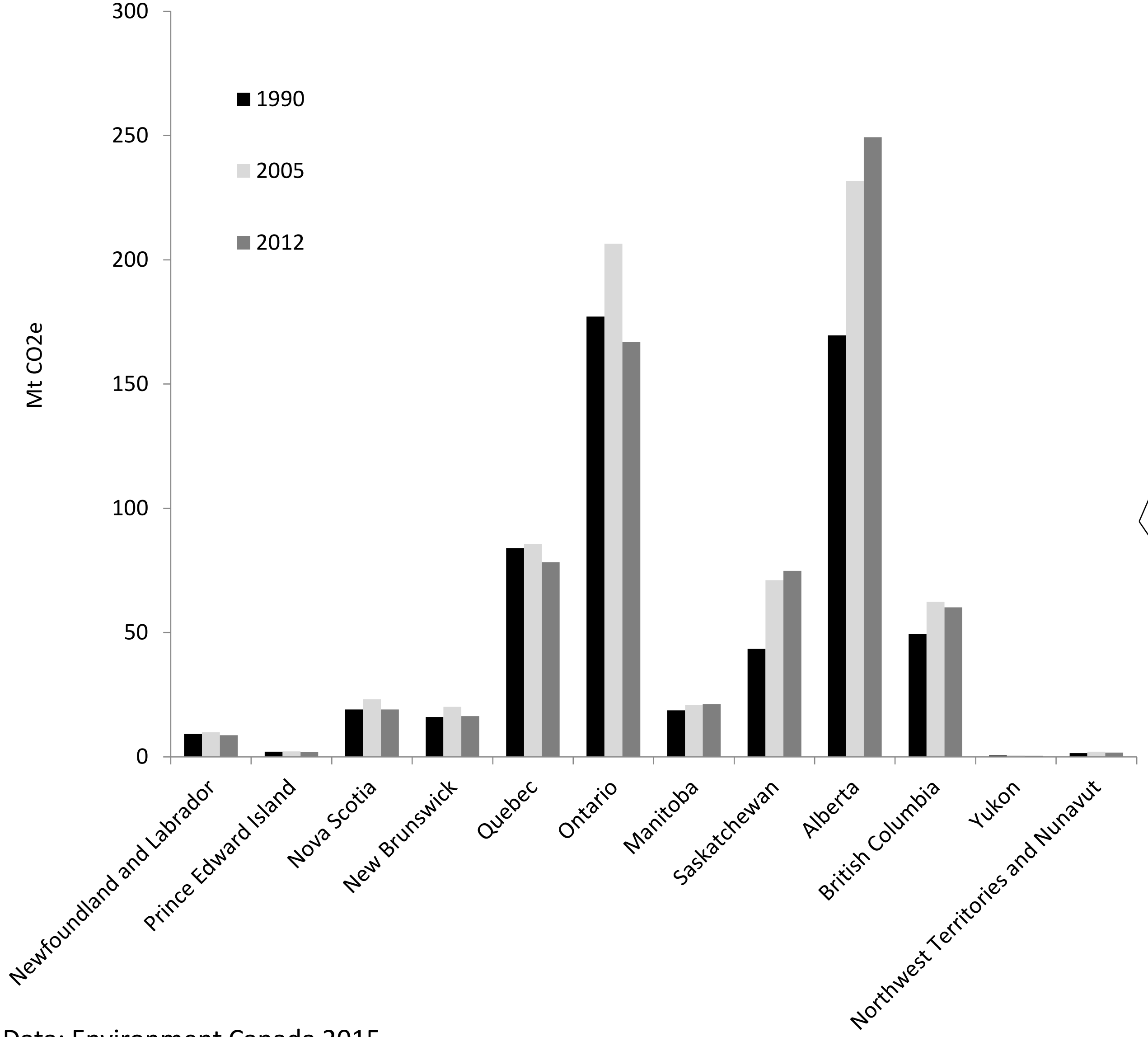
- LCA study results were made consistent through simplified harmonization.
- Life cycle LNG emissions were calculated by varying ocean transport factors, transmission and distribution losses, and country-level efficiency.
- Emissions displacement scenarios were developed, varying assumptions on what is displaced in a subset of countries.

** Figures to be released upon publication **

Kasumu, Li, Coleman, Liendo, Jordaan (in prep)

Regional policies: resource endowments and political influences

Review of policies that support emissions reduction (part of broader study on energy technology innovation in Canada).



- Emissions reduction (2005-2012):
  - Leaders: Ontario (-19%), Nova Scotia (-18%), New Brunswick (-18%), Quebec (-9%), Yukon (-20%).
  - Renewable portfolio standard.
  - Feed-in-tariff.
  - Coal phase-out (Ontario).

- Emissions growth(2005-2012):
  - Alberta (8%), Saskatchewan (5%), Manitoba (<1%).
  - Emissions intensity targets, carbon pricing.
  - Too early in policy implementation.
  - Success in meeting renewable targets not achieved (or not reported).

Jordaan, Romo-Rabago, McLeary, Reidy, Nazari, Herremans (submitted)

Data: Environment Canada 2015

Policy implications

- In trade, national and sub-national policies of nations play a large role in emissions reductions.
- National level: what should the focus for emissions reductions be?
- Sub-national level: sub-national governments play a large role, particularly in federalist nations.
- Significant work left to do on methane emissions from natural gas production systems, from understanding regional differences in production and infrastructure to operator practice.
- The role of regulation/policy in improving consistent data availability across regions (differences in emissions thresholds for reporting, data (dis)aggregation).

- Governments:
  - Priority areas for greenhouse gas reductions should include a careful examination of infrastructure.
  - Policies should be selected for effective reduction within the country context.
  - Increased transparency in operational data.
  - Standardization of reporting.

- Firms:
  - Increased transparency or participation in improving operational data.

Common threads

- Regional differences exist in the productivity and impacts of energy projects including the effects of federal/regional policies and available resources.

- Technology assessment (e.g. LCA) does not transfer to inter-regional results without the application of new and mixed methods.

- Methods are rapidly becoming more advanced in some cases (e.g. water) and less so in others (land).

- Overall, the integration of technology assessment with spatiotemporal analysis opens large new areas for research, which will improve with software and new datasets.

- Such new methods will uncover the reasons why policy-makers face different opinions and challenges, opening up new solutions.

The path forward: what next?

- Applying new methods to regions globally to understand where scarcity or constraints may effect or restrict operations.
- Re-defining conventional approaches (e.g. life cycle assessment) to better examine spatial and temporal effects of development.
- Increasing resolution and the accuracy of current metrics.
- Developing more robust planning tools: integrating international, federal, state/provincial policies with actual impacts.
- Embrace uncertainty and complexity: expand present policy uncertainty models to other areas in energy and environment.

Discussion

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