Technical University of Denmark

Modeling Future Potential of Bioenergy

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Modeling Future Potential of Bioenergy

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Systems Analysis

How do you model potential?

- What do you need to know?
- What do you have to assume?
- How do you approach this topic?

What is “potential”?

- Theoretical Potential – total amount that theoretically can be produced
- Supply (Technical) Potential – often used interchangeably with technical potential, but could also vary if one considers sustainability constraints
- Demand (Market, Economic) Potential – amount of biomass demanded by the global market at a given price or under a given policy scenario, in consideration of other energy options

Biomass Resources

Classification based on resource

1. Energy Crops

Primary Residues

2. Agricultural crop harvest residues
3. Forest residues from industrial roundwood and fuelwood/charcoal production

Secondary Residues

4. Food processing residues
5. Wood and other fiber processing residues (mill residues)
6. Animal Dung

Tertiary Residues

7. non-eaten food (compost and municipal solid waste)
8. non-food organic waste (municipal solid waste)

Aquatic Resources

9. Freshwater Algae
10. Seawater Algae

Other

11. biomass presently used for fuel wood and charcoal
12. unspecified forest biomass
13. unspecified residues

Biomass Resources II

Table 1
The biomass resource categories distinguished to assess the theoretically available potential of biomass for energy use

Different classification based on land use

Category	Description
Category I: biomass production on surplus agricultural land	The biomass that can be produced on surplus agricultural land, after the demand for food and fodder is satisfied
Category II: biomass production on surplus degraded land	The biomass that can be produced on deforested or otherwise degraded or marginal land that is still suitable for reforestation
Category III: agricultural residues	Residues released together with food production and processing (both primary and secondary)
Category IV: forest residues (incl. material processing residues)	Residues released together with wood production and processing (both primary and secondary)
Category V: animal manure (dung)	Biomass from animal manure
Category VI: organic wastes	Biomass released after material use, e.g. waste wood (producers), municipal solid waste
Category VII: bio-materials	Biomass directly on used as a feedstock for material end-use options like pulp and paper, but also as feedstock for the petrochemical industry

Hoogwijk et al. 2003

Biomass Resources III

Different classification based on technology

1. Traditional Biomass

First Generation Bioenergy

2. Sugars and Starch to Alcohol fuel
3. Transesterification and biodiesel production
4. Waste oil to biodiesel
5. Syngas
6. Biogas

Second Generation Bioenergy

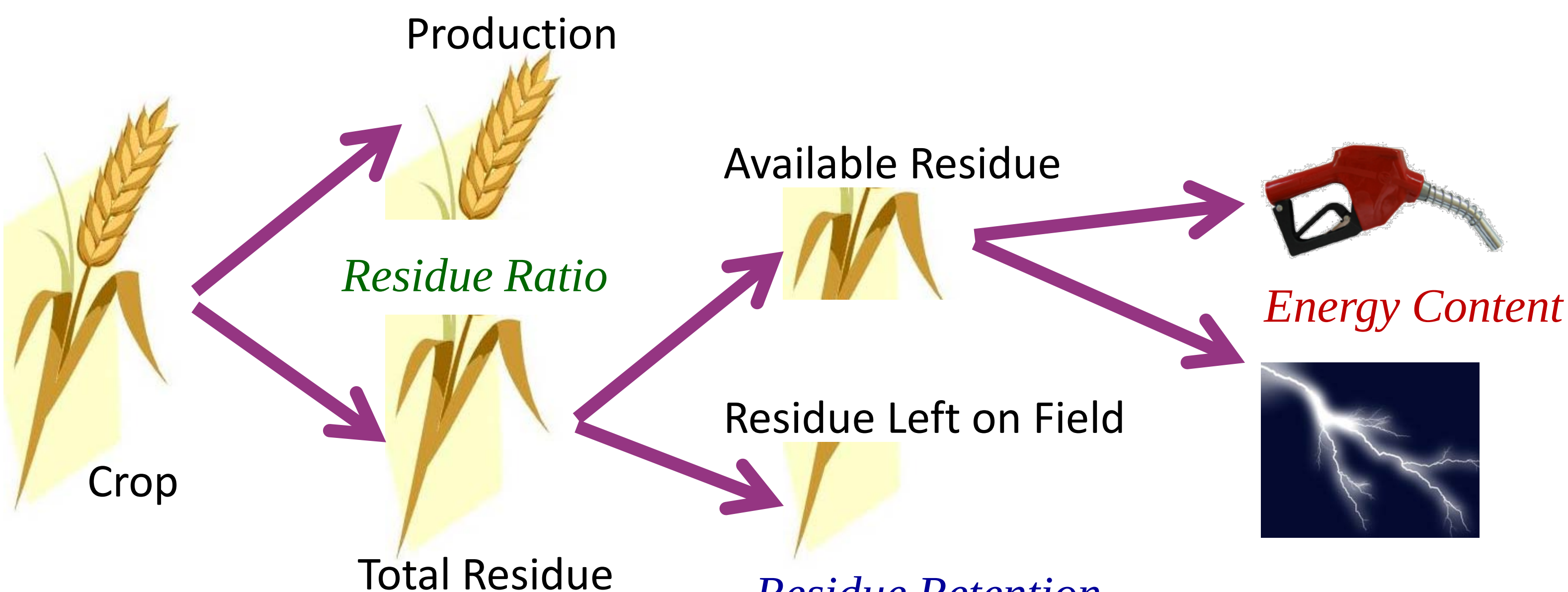
7. Cellulosic Ethanol
8. Algael Biodiesel
9. Biohydrogen
10. Biomethanol

Etc.

Example: Agricultural Crop Residues

$$Energy = [Production \times Residue\ Ratio - (Residue\ Retention \times Area)] \times Energy\ Content$$

$$Residue\ Ratio = \left(HI_{wet}^{-1} - 1\right) \qquad HI_{wet} = \frac{HI_{dry}}{water\ content \cdot \left(HI_{dry} - 1\right) + 1}$$



Constraints: Water, Land, Nutrients, etc.

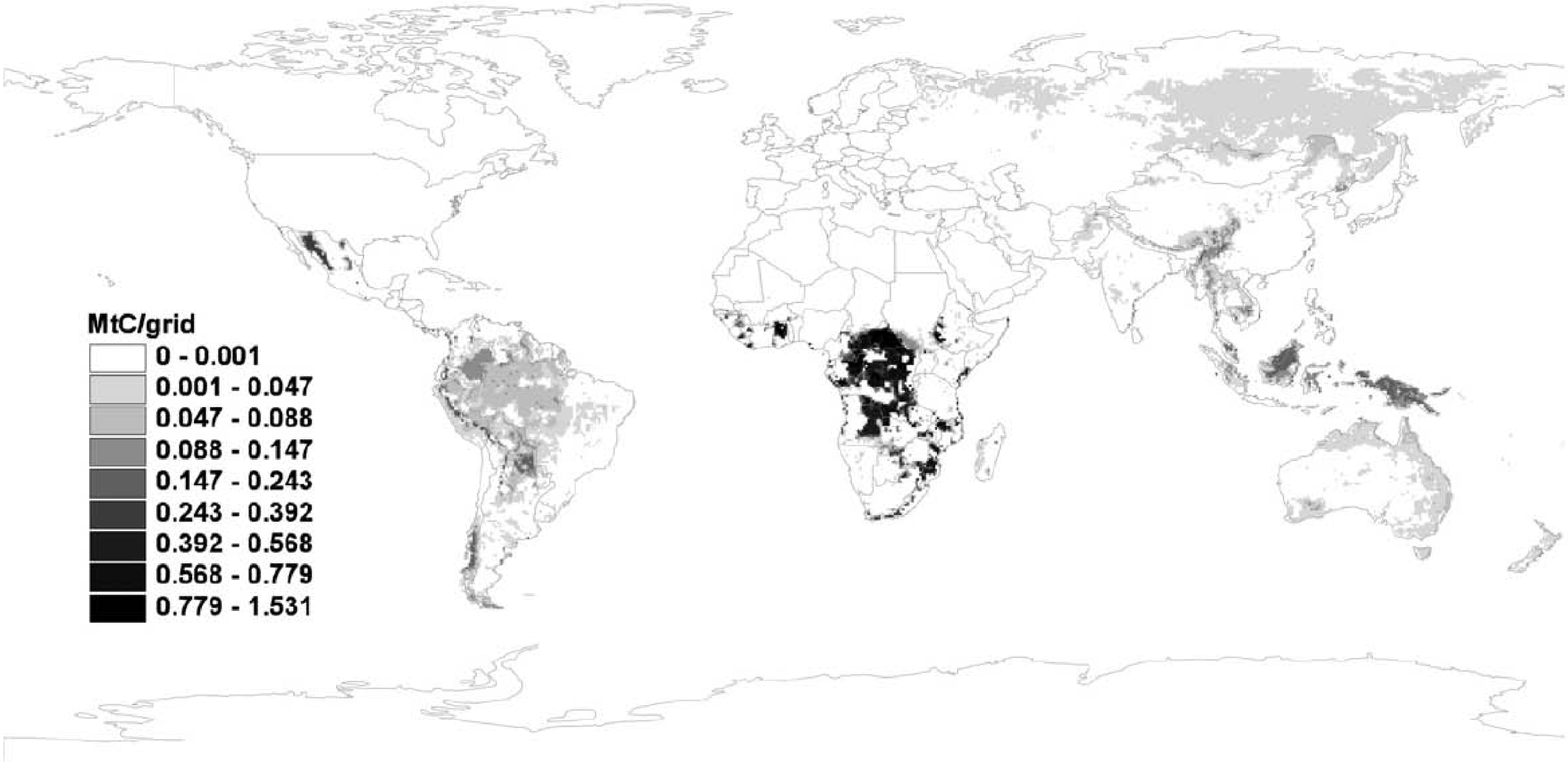
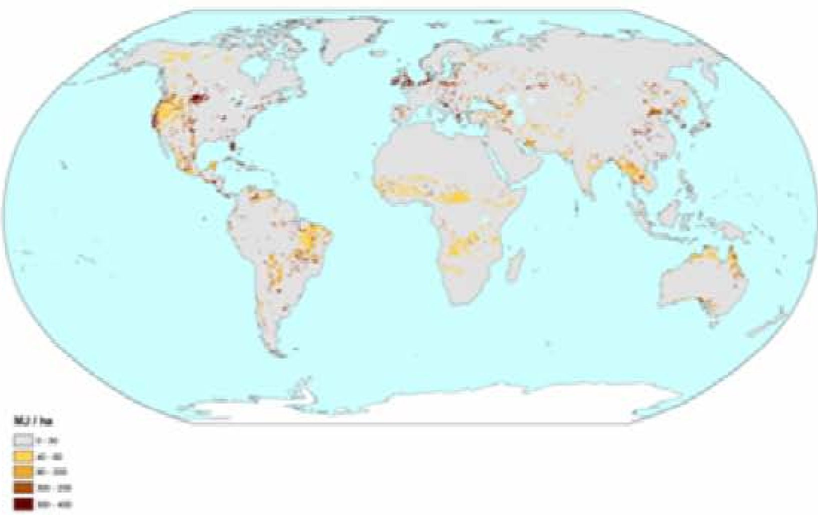


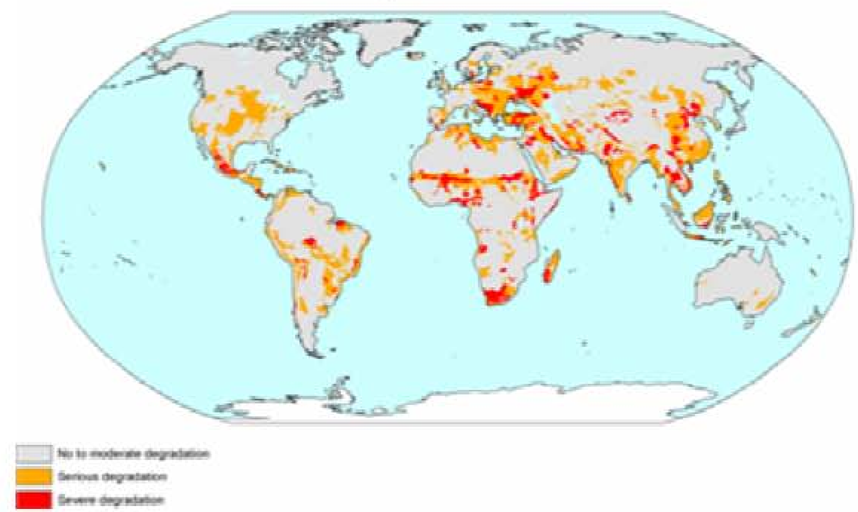
Fig. 6. Carbon implications (MtC/grid) from avoided deforestation (compared with the baseline case) using a dynamic carbon price projected by MESSAGE in 2090–2100 in A2r.

Rokityanskiy et al. 2006

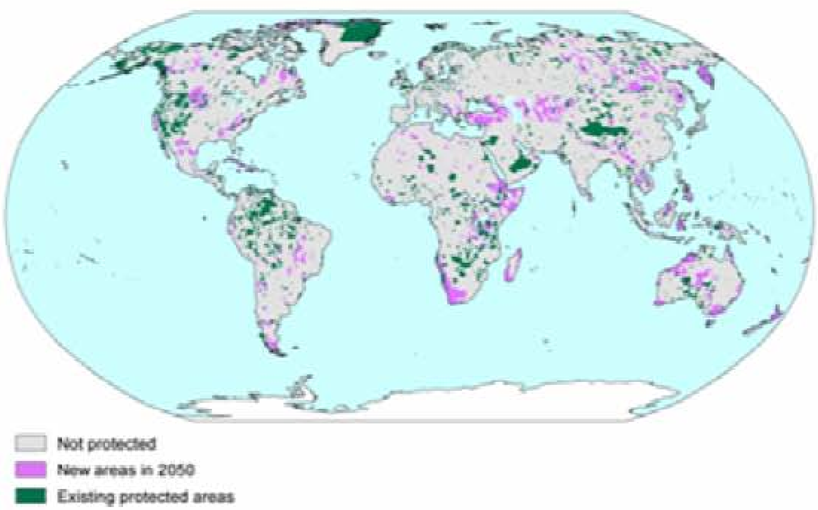
Potential for Woody Biomass 2050



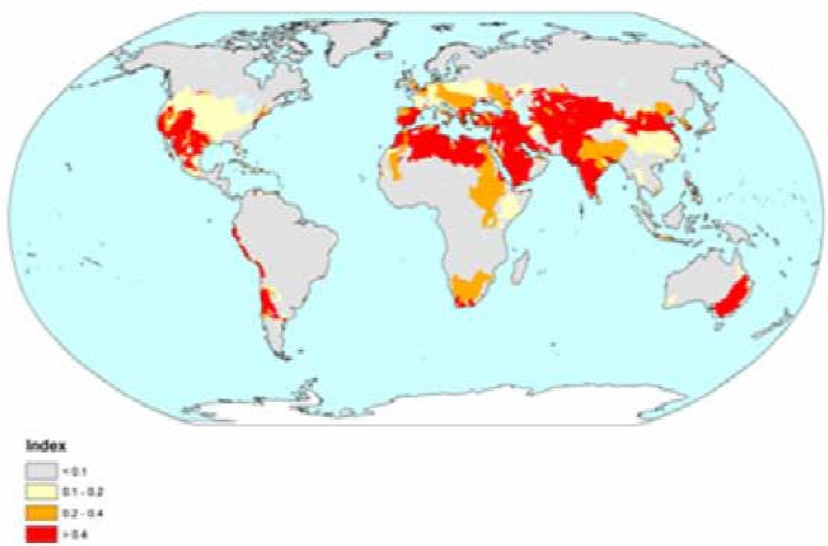
Land degradation risk 2050



Protected areas 2050



Watershortage 2050



Dornburg et al. 2008

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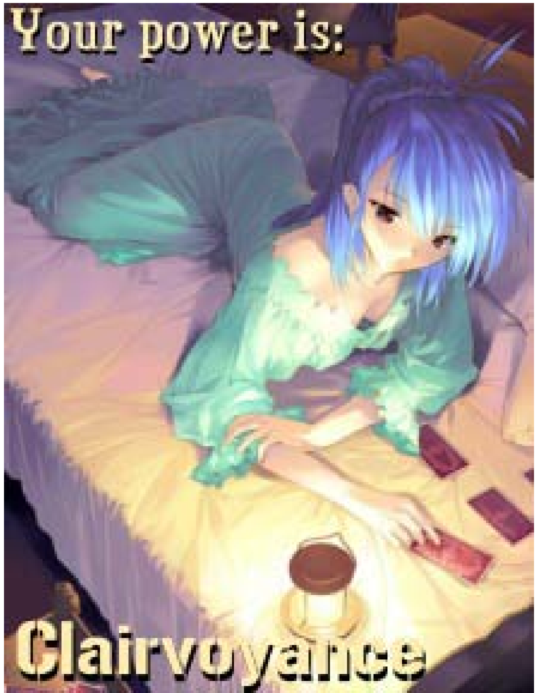
Science and Policy Analysis

- We want to know how important this technology can be in addressing climate change, sustainable development, and energy security.
- How important will this option be in the future relative to other options?
- How much will it cost and what will be the effect on the economy?
- Challenges of modeling the future:
  - Is it possible for a model to predict the future?
  - Is it possible to test the model by running from a past date to the present?

No!



Differences between physical science and policy analysis

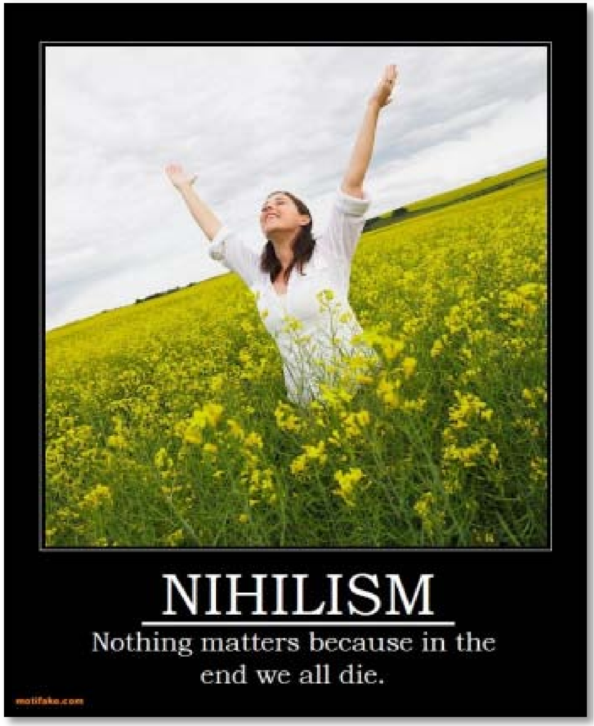
For policy analysis to make sense, we have two philosophical assumptions:

1. Non-Determinism:

- If we assume that whatever is going to happen is already predestined, then policy has no role. We have to assume that policy has the power to change the course we are on.

2. Non-Nihilism:

- We have to assume that some outcomes are better than others and that there exists a criteria for deciding between the different outcomes. If not, policy again would have no purpose because every possible future would be equally desirable.

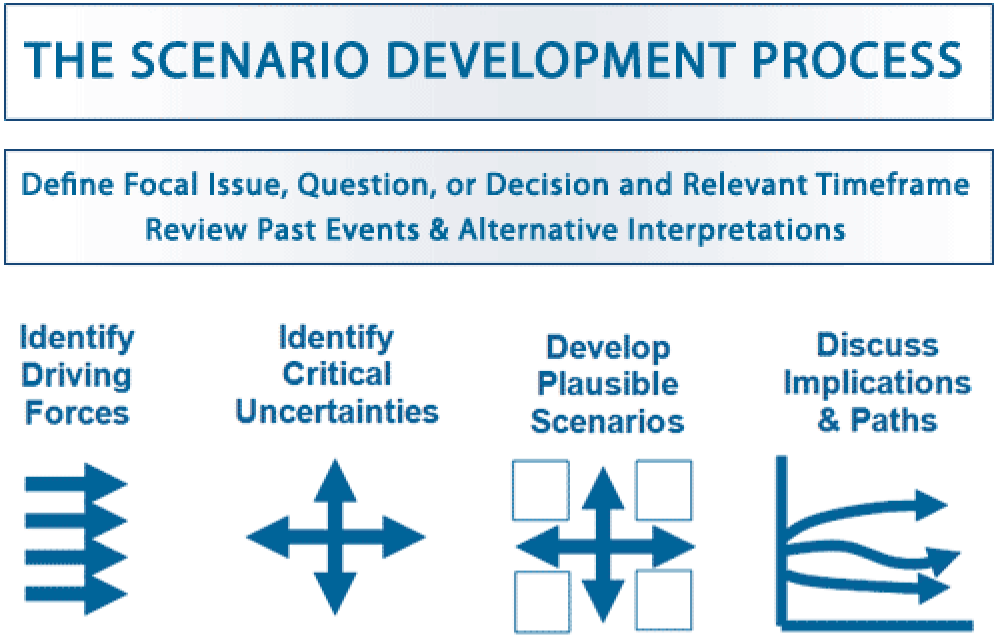


Scenarios

- Scenarios are created to bracket sets of outcomes. They are designed to answer specific types of questions while holding constant a set of assumptions about the future.

- Scenarios are not predictions or forecasts for the future! They are storylines about how a hypothetical future might develop, constructed to answer specific policy and economic questions.

- Scenarios allow for strategic planning and decision making when facing an uncertain future.



Scenarios

- Examples:

What if more economic growth occurs in China and India and less in the developed world? How will that change the regional distribution of energy consumption?

How will a climate agreement change the global energy portfolio versus a business-as-usual world? What if we only have a partial climate agreement (not all regions participating)?

What if there is twice as much biomass available in the world than we assume by default? What if there is only half as much available? What if it is twice as expensive? etc.

What are the key uncertainties in the scientific understanding of biomass production and which make the largest impact?

Biomass Potential Scenarios

1. Technology
- Investment, Domestic Development, Tech Transfer (e.g. CDM, JI)
- Some tech can increase supply potential (e.g. fertilizer, pesticides increase yield, allow farming of marginal lands)
- Some tech can change demand potential (e.g. tractors, equipment can reduce labor costs)
- Investment in industrialization over ag can reduce supply potential

2. Sustainability Concerns
- Can reduce technical supply
- Can influence crop choice

3. Foreign Trade in biomass and food
- Can increase or reduce supply potential based on profits to land owners

4. Economic Development
- Affects cost of labor, labor mobility, and immigration (affects demand potential)
- Affects international trade of bio-products (affects supply potential)
- Affects tech development and tech transfer (affects supply and demand potential)

Specific Issues when Modeling Future Biomass Potential

Biomass Potential		
Theoretical	Technical (Supply)	Market (Demand)
•Land availability (crop land, forestland, urban, pasture, rangeland, marginal land) •Water availability •Climate	•Future ag yield •Harvest efficiency (Technology) •Sustainability criteria •Population •Diet •Crop Distribution •Animals	•Cost curves •Labor cost •Profits to land owners •Carbon price (land carbon) •Subsidies •Economies of Scale •Foreign trade

Modeling Approaches for Bioenergy

- Top Down: Maximize economic value of land, Benefit-Cost, or long term utility under a given carbon constraint

Versus

- Bottom Up: Obtain detailed information on technologies, costs and options for a given piece of land and then determine the carbon prices at which the various options become economic

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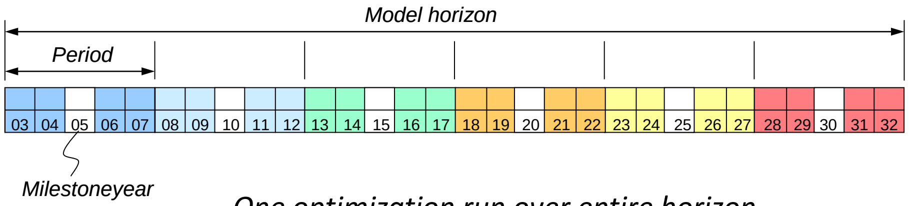
- Integrated: a dynamic land allocation system is built into the model and calculates land distribution and economic land use endogenously (IMAGE, GCAM)

Versus

- Soft Linked: Land distribution/ Land use scenarios/ Biomass production are derived exogenously and input into the Integrated Assessment Model (IAM) (Most IAMs)

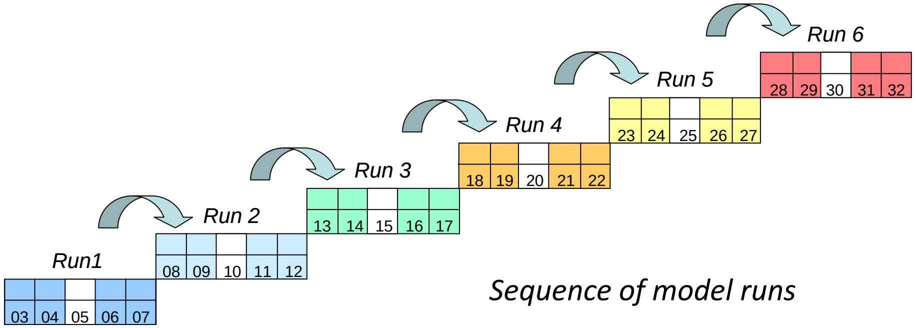
Modeling Approaches

Perfect foresight



One optimization run over entire horizon

Myopic foresight (Dynamic-recursive)



Sequence of model runs

- Perfect foresight versus dynamic recursive: how the economic optimization works.

Integrated Assessment Models

- IAMs provide a framework for understanding climate change from a point of view that takes into account economics, demographics, policy, technology, and other human factors.

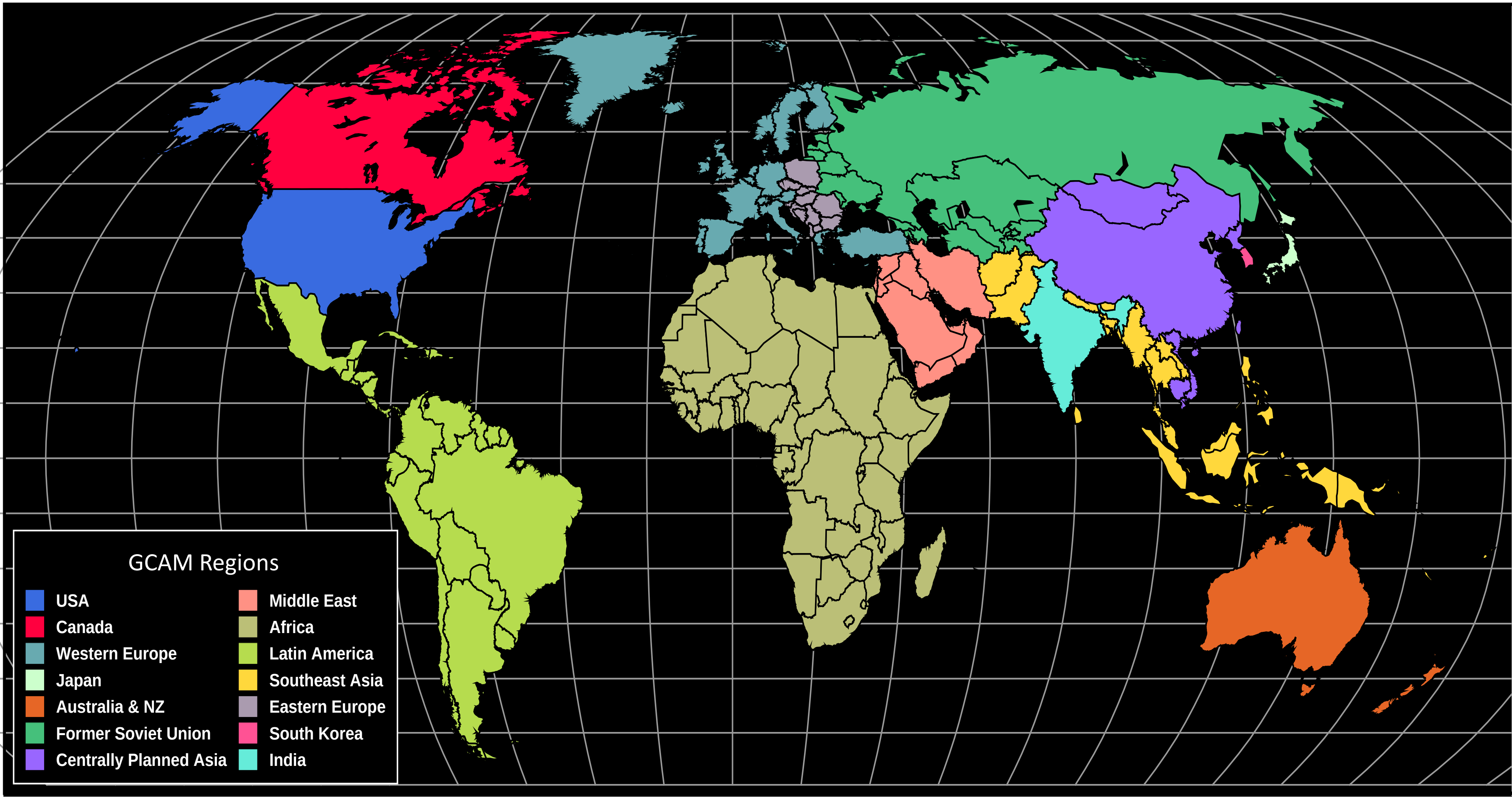
- The world is represented as a set of regions, with each region having specific resources they are able to develop and trade with other regions. Regional information on population, economy and prices also demand to be modeled.

- IAMS allow the testing of different policy scenarios and market dynamics.

- IAMs typically have a simple climate model built in that can estimate atmospheric GHG concentrations and the economically optimal schedule for emissions reductions.

TIAM: Times Integrated Assessment Model

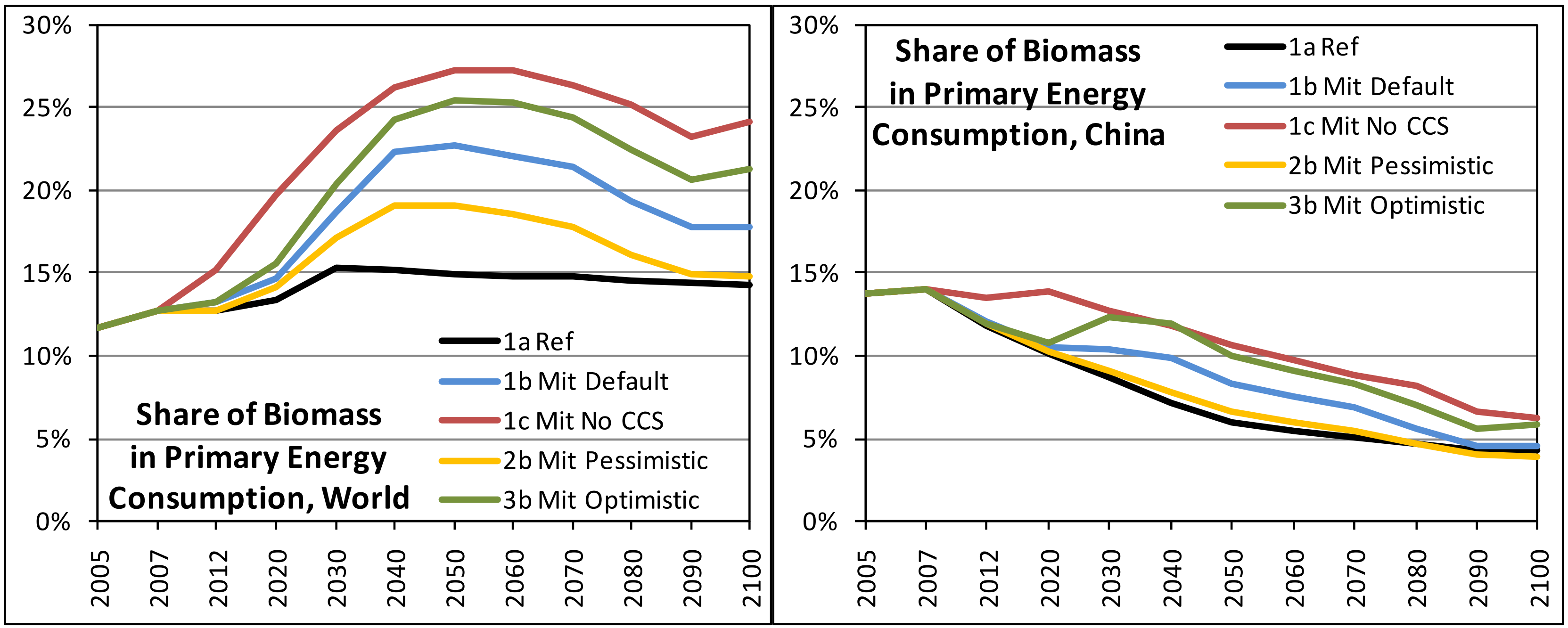
GCAM: Global Climate Assessment Model



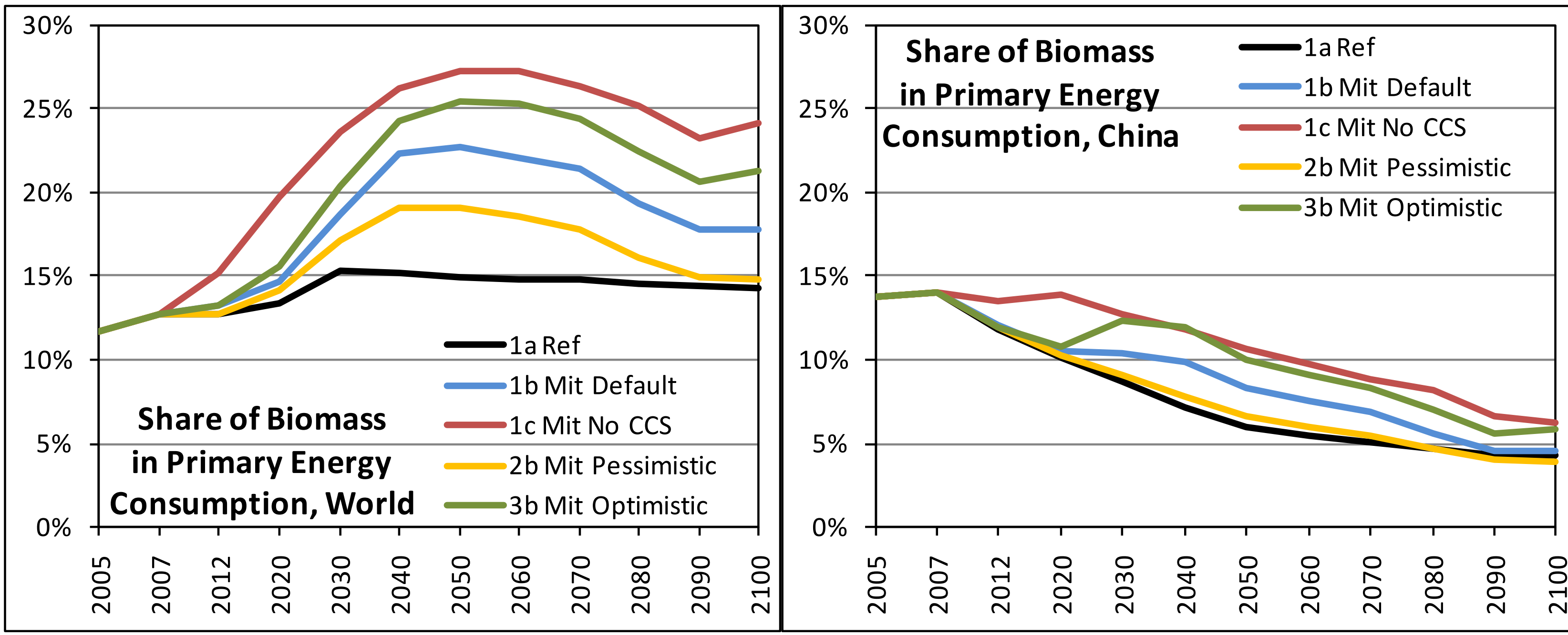
Example: Bioenergy and CCS in China

- What is the potential for bioenergy and CCS in China under a reference scenario and 2-degree C climate policy scenario?
- How does China compare to the rest of the world in this respect?
- What is the most optimal use for biomass in China in a carbon constrained world?

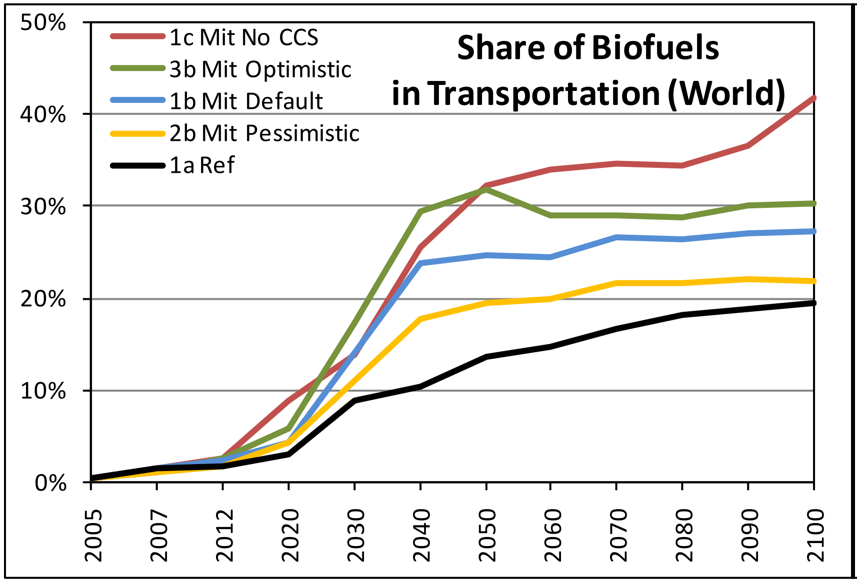
Example: Biomass in primary energy

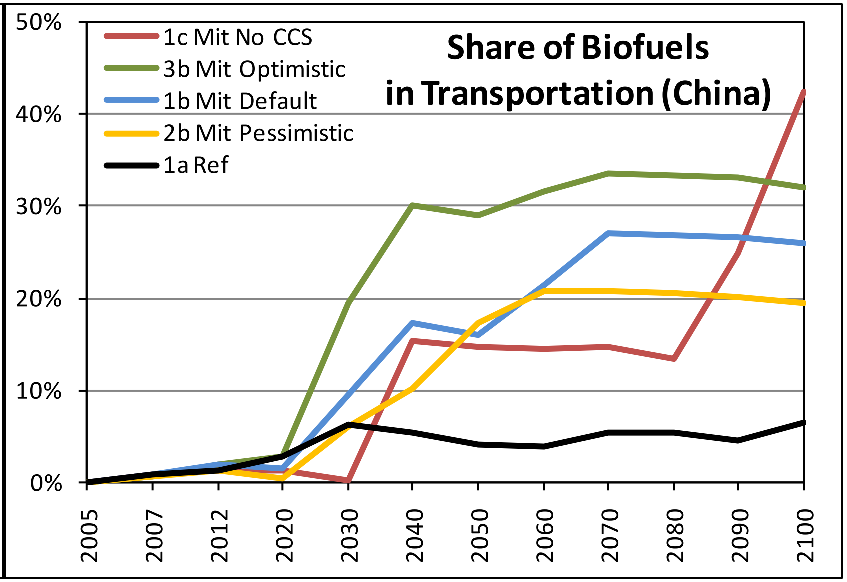


Example: Biomass in primary energy

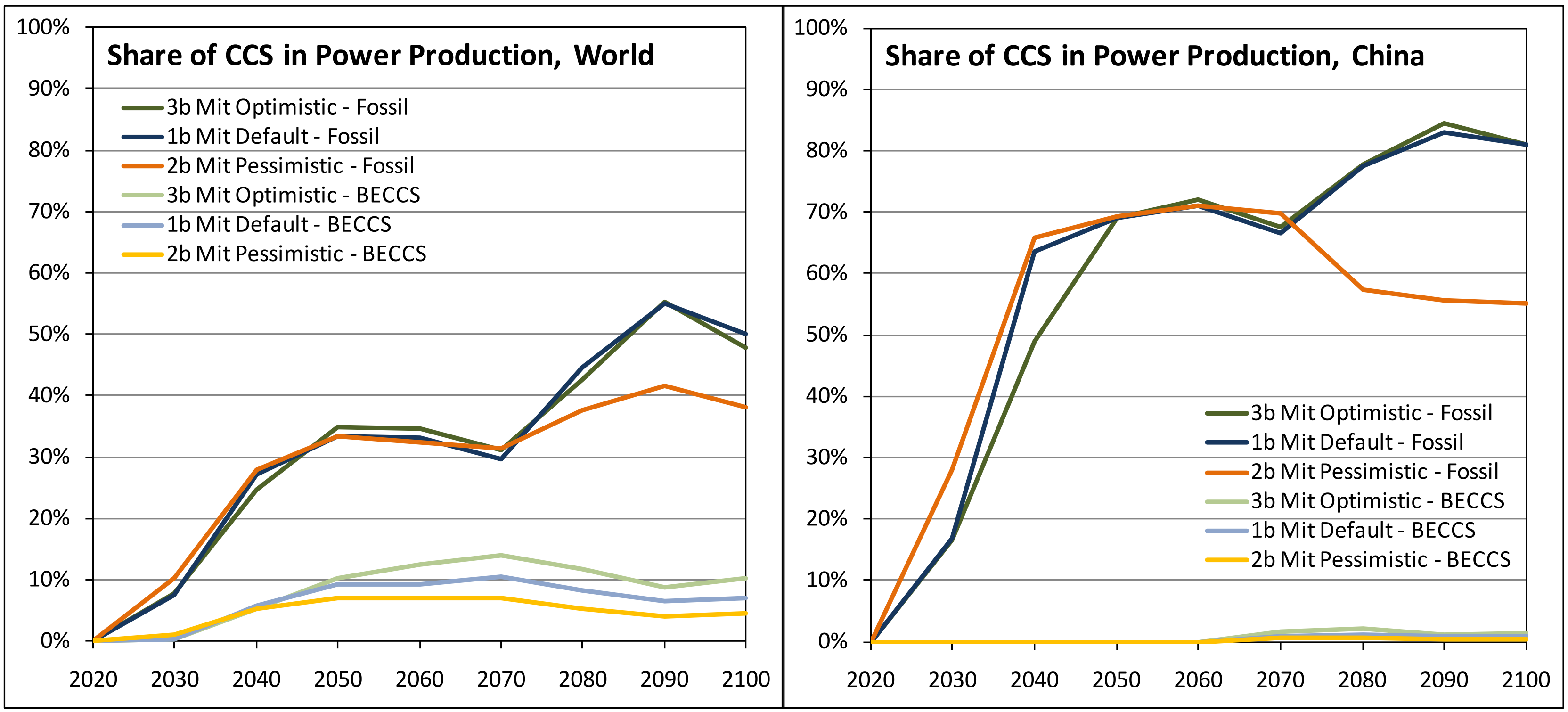


Example: Biomass in transportation





Use of CCS technologies



Example: China Biomass Conclusions

- Chinese economic growth causes a dramatic increase in energy demand final energy demand grows 500-600% from 2010 to 2100
- Even with optimistic assumptions on future biomass, it can only cover around 10% of the Chinese primary energy consumption in 2050 and around 5% in 2100. Most of the available biomass in China is optimally used in the transport sector, thereby favoring CCS over BECCS.
- CCS is a key technology for China in an emissions constrained world
- The CCS storage potential in China is not a limiting factor

Conclusions of Bioenergy Modeling

- The future potential for bioenergy will depend on both physical and human factors
- Policy can influence the future potential of bioenergy
- Estimating the future potential for bioenergy requires an integrated approach