The potential contribution of biomass and bioenergy for near-term national mitigation: A geospatial analysis in China

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Nearly all 1.5 °C/2 °C scenarios rely on the extensive application of BECCS

**BECCS: bioenergy with carbon capture and storage**

CO$_2$ fluxes for the 1.5 °C scenario

Sectoral 2016-2100 cumulative emissions

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[van Vuuren et al., Nat. Clim. Change 2018]

Nearly all 1.5 °C/2 °C scenarios relay on the extensive application of BECCS.

**However, only relatively small investments are being made in them...**

For a specific region or country, the role of bioenergy in mitigation is still vague, which limits the local initiatives for bioenergy development.

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**BECCS**

**CO₂ emission reduction target in 2100**

- 3.3 gigatonne stored per year
- 5 facilities operating

- Captures 1.5 Mtpa CO₂
- One large-scale facility
- Bioethanol dominates

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[van Vuuren et al., Nat. Clim. Change 2018]

In China, refining the spatial distribution of biomass and its energy potential is very necessary.

In recent years, the Chinese Government has continuously increased attention to biomass and introduced a series of policies and measures for bioenergy development.

Two key development principles:

- “Customizing the development of bioenergy to local conditions”
- “Prioritizing distributed utilization”
Previous studies have weakness in spatial resolution and often only focus on one type of biomass

<table>
<thead>
<tr>
<th>Country</th>
<th>Literature</th>
<th>Spatial resolution</th>
<th>Time scale</th>
<th>Methodology</th>
<th>Biomass type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Shuai Xue (2016)</td>
<td>1-km</td>
<td></td>
<td>GIS, Monteith radiation model</td>
<td>Energy crops</td>
</tr>
<tr>
<td></td>
<td>Huaguang Qiu (2015)</td>
<td>1-km</td>
<td>2010</td>
<td>Spatial statistical analysis</td>
<td>Residues</td>
</tr>
<tr>
<td></td>
<td>Xinhua Xu (2013)</td>
<td>1-km</td>
<td>2008</td>
<td>Land use model</td>
<td>Energy crops</td>
</tr>
<tr>
<td></td>
<td>Wen Wang (2013)</td>
<td>1-km</td>
<td>2006</td>
<td>Remote sensing and statistical methods</td>
<td>Residues, energy crops</td>
</tr>
<tr>
<td>US</td>
<td>Hanna M. Breunig (2018)</td>
<td>County level</td>
<td>2018</td>
<td>Microstatistical analysis</td>
<td>Residues</td>
</tr>
<tr>
<td>Russia</td>
<td>Mithun Saha (2018)</td>
<td>1-km</td>
<td>2018</td>
<td>GIS method</td>
<td>Energy crops</td>
</tr>
<tr>
<td>Brazil</td>
<td>Andrew Welfle (2017)</td>
<td>-</td>
<td>2015, 2020, 2030</td>
<td>Scenario analysis</td>
<td>Residues, energy crops</td>
</tr>
<tr>
<td>Netherlands</td>
<td>Oludunsin Arobadu (2014)</td>
<td>Site research</td>
<td>2014</td>
<td>Energy model</td>
<td>Waste, energy crops</td>
</tr>
</tbody>
</table>

The statistical method and the GIS method are widely used, but they both have own limitations (resolution, data availability, uncertainty, etc.)

GIS: Geographic Information System; RS: Remote Sensing
Hence, we proposed a new assessment framework to assess the biomass and bioenergy potential in China.

Questions:
- What is the high-resolution distribution of usable biomass in China?
- Whether the current technical bioenergy potential can meet near-term policy targets?

Methodologies:
- An assessment framework integrated with crop growth models, the RS-GIS method, and the statistical downscaling method

Objectives:
- Identifying the spatial distribution of biomass and bioenergy in China
- Laying a foundation for optimal deployment and siting researches
Core equations for estimating usable biomass and technical bioenergy potential

**Usable biomass** - the amount of biomass that can be used for energy production within natural (soil, water, etc.) and economic constraints (uses for animal feeding, paper making, fiber production, etc.)

\[
B = N \times \alpha / \beta \\
P = B \times r \times (1 - c - e - l)
\]

- \(B\) - biologically available biomass,
- \(N\) - net biomass,
- \(P\) - usable biomass for energy production
- \(\alpha, \beta, r, c, e, l\) - exogenous parameters

**Technical bioenergy potential** - the amount of bioenergy converted from usable biomass through current conversion technologies

\[
E = P \times C \times \text{LHV}
\]

- \(E\) - technical bioenergy potential,
- \(P\) - usable biomass for energy production,
- \(C\) - energy conversion coefficient,
- LHV - lower heating value
The specific assessment methods for residues, waste, and energy crops have some differences.

The assumptions of energy conversion technologies and efficiencies are made based on current conditions.

The simulation of energy crop consists of land suitability assessment and yield simulation through crop models GEPIC and AquaCrop (Jiang et al., 2019; Nie et al., 2019).
## Types of biomass and bioenergy in this research

<table>
<thead>
<tr>
<th>Biomass feedstock</th>
<th>LHV of resource, MJ/kg</th>
<th>Conversion technology</th>
<th>Energy conversion coefficient</th>
<th>Bioenergy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agricultural residues</td>
<td>17.3</td>
<td>Thermal combustion</td>
<td>0.21</td>
<td>Heat and electricity</td>
</tr>
<tr>
<td>Forestry residues</td>
<td>18.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shrubbery residues</td>
<td>18.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orchard residues</td>
<td>18.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grass residues</td>
<td>18.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MSW</td>
<td>16.7</td>
<td>Thermal combustion</td>
<td>0.26</td>
<td>Heat and electricity</td>
</tr>
<tr>
<td>Municipal sewage sludge</td>
<td>16.7</td>
<td>Anaerobic digestion</td>
<td>0.19</td>
<td>Biogas</td>
</tr>
<tr>
<td>Animal manure</td>
<td>16.7</td>
<td>Anaerobic digestion</td>
<td>0.19</td>
<td>Biogas</td>
</tr>
<tr>
<td><strong>Sweet sorghum</strong></td>
<td><strong>15.1</strong></td>
<td>Saccharification and fermentation</td>
<td><strong>0.12</strong></td>
<td><strong>Bioethanol</strong></td>
</tr>
</tbody>
</table>

* MSW: municipal solid waste; LHV: lower heating value

*: Conversion technologies and conversion coefficients may change in the future.
Energy crops are assumed to be grown on marginal land under two cultivation scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sustainable scenario</td>
<td>Energy crop cultivation depends solely on rainfall without increasing the local water pressure.</td>
</tr>
<tr>
<td>Optimal scenario</td>
<td>The maximum possibilities of production. Energy crops can be cultivated with full irrigation and other optimal environmental conditions.</td>
</tr>
</tbody>
</table>

- **Sweet sorghum** is chosen as the representative energy crop in this study.
- The definition of **marginal land** and the simulation of yield per hectare refer to previous studies (Jiang et al., 2019; Nie et al., 2019).
The southern region has abundant forestry residues. The central region has plentiful agricultural residues. The northeast region is rich in both forestry and agricultural residues.

Water is a significant factor for sweet sorghum potential estimation.
Results  Technical bioenergy potential and its distribution

- **Electricity and heat** are widely distributed in most provinces.
- **Biogas** has a centralized distribution in urban and rural areas.
- Xinjiang and Inner Mongolia account for most of the **bioethanol** potential in the optimal scenario.
- Jilin and Heilongjiang are the most suitable areas for **bioethanol** in the sustainable scenario.
Results  Energy flow of “land-biomass-bioenergy”

- At the national level, the final biogas potential is 1.91 EJ.
- The bioethanol potential is 0.96 EJ with irrigation and 0.04 EJ without irrigation, satisfying 3.12 times and 13% of the national E10 (gasoline containing 10% ethanol) mandate in 2020, respectively.
- The heat potential (1.06 EJ) can contribute 20% of the total national demand for heating (5.38 EJ).
- Total: 3.01~3.93EJ
Whether the biomass potential can meet the demand of co-firing in coal power plants?

In 2015, there were 980 coal-fired power plants in China and the total installed capacity was 873,103 MW.
**Discussion** Whether the biomass potential can meet the demand of co-firing in coal-fired power plants?

- Under the co-firing ratio of 20%, only **Shanghai** cannot meet the demand.
- Under the co-firing ratio of 100%, there are **11 provinces** cannot meet the demand.

\[ \Delta E = \text{Biomass potential} - \text{biomass demand of co-firing ratio} \]
Discussion: Whether the bioethanol potential can meet the demand for transportation at the provincial level?

- Xinjiang, Tibet, Inner Mongolia, Ningxia, Qinghai, Gansu, Shaanxi, Heilongjiang, and Jilin can satisfy the bioethanol demand of the E10 mandate (gasoline containing 10% ethanol); while Guangdong, Zhejiang, and Jiangsu have serious shortages (more than 20 PJ).

- The bioethanol demand is calculated based on the nationwide E10 mandate and the gasoline consumption of each province in 2015.

**Bioethanol supply potential (optimal scenario)**

**Bioethanol demand**

**Supply minus demand**
Discussion  Whether the biomass heat potential can meet the demand for urban heating?

- Heat from biomass in most southern provinces can meet the demand for urban heating, while Xinjiang, Shandong, Beijing, Tianjin, Liaoning, Heilongjiang, and Jilin cannot.

- The heat demand is estimated according to urban heating days and hot water supply power in each province in 2015.
Uncertainties and limitations

Uncertainties:
- Parameters chosen for simulation
- Selection of crop models
- Technology development uncertainties
- Definition of the marginal land
- ...

Limitations:
- **Economic constraints** are not considered when estimating the technical bioenergy potential
- **The bioenergy conversion technologies** are simplified into three main types which would be more complicated in reality
- **Cellulosic crops** which may have great potentials in the future are not considered
- ...

Implications and contributions of this work

**For policy design**
- The high-resolution biomass and bioenergy potential distribution can help local governments to make early decisions on political priorities to develop bioenergy.

**For other regional/national cases**
- The transparent and replicable assessment framework can serve as a common research ground for other regions and countries.

**For further research**
- This work lays a foundation for further researches related to the optimal deployment and siting analysis of bioenergy.

Group introduction: framework

Model

Hybrid (Economy + Technology)
- Disaggregated Environmental extended Input/Output model
- Environmental CGE model

Data

Model

Global

National/regional

Sectoral/Grid/plant

Economic Data

Environment Data

Work

- Develop future development scenarios (including non-mitigation and mitigation)

Policy

- What are the emission & land-use change scenarios driven by human activities?
- What are the environmental and employment impacts of carbon mitigation?
- How are these impacts distributed among different groups of people and why?
- A good mitigation policy for all

Wenjia CAI (Group Leader)
Case  The uneven distribution of mitigation’s health impacts

**Editor’s Choice**

The Lancet Countdown on PM_{2.5} pollution-related health impacts of China’s projected carbon dioxide mitigation in the electric power generation sector under the Paris Agreement: a modelling study

**Innovative findings:**

The overall health benefits in 2050 could increase to 3-9 times the implementation costs. The uneven distribution of health benefits and losses at sub-national level should get the due attention. → facilitate the policy making of carbon mitigation and inter-regional compensation scheme.

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The Paris Agreement could save lives in China increase in the northwest. Such a result shows the value of subnational studies for co-benefits. This study adds to the body of knowledge that reducing greenhouse gas emissions also reduces air pollution and benefits health, and does so in the particularly important context of China. This study,

*Jonathan A Patz, JJason West*
Case  The role of bioenergy in national deep decarbonization pathways and its local impacts

Bottom-up
- Assessing the biomass and bioenergy potential at a high-resolution
- Geospatial analysis, crop models
- Local environmental impacts (water, land use, etc.)

Top-down
- Exploring the demand for biomass and bioenergy to realize the national deep decarbonization target
- A hybrid general equilibrium model
- Socio-economic impacts (GDP, employment, welfare, trade, etc.)

[Weng et al., 2018]
[Nie et al., 2018]
Thanks for your attention!

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Wenjia Cai, wcai@tsinghua.edu.cn
Rui Wang, vickeywr98@163.com
A generic model for estimating usable biomass

\[ B = N \times \frac{\alpha}{\beta} \]

\[ P = B \times r \times (1 - c - e - l) \]

Table 1: Parameter values of different land and biomass resources for calculating biomass potential

<table>
<thead>
<tr>
<th>Biomass type</th>
<th>Land-use type</th>
<th>N</th>
<th>( \alpha )</th>
<th>( \beta )</th>
<th>r</th>
<th>c</th>
<th>e</th>
<th>l</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agricultural residues</td>
<td>Paddy land</td>
<td>Production of rice</td>
<td>0.5</td>
<td>0.5</td>
<td>Table S2</td>
<td>0.313^a</td>
<td>0.499^a</td>
<td>0.05</td>
</tr>
<tr>
<td>Agricultural residues</td>
<td>Dry land</td>
<td>Production of other 16 crops</td>
<td>0.5</td>
<td>0.5</td>
<td>Table S2</td>
<td>0.313^a</td>
<td>0.499^a</td>
<td>0.05</td>
</tr>
<tr>
<td>Woodland residues</td>
<td>Orchard</td>
<td>Orchard residues</td>
<td>0.5</td>
<td>0.5</td>
<td>1</td>
<td>0.3^b</td>
<td>0.318^c</td>
<td>0.05</td>
</tr>
<tr>
<td>Woodland residues</td>
<td>Forest</td>
<td>Forestry residues</td>
<td>0.5</td>
<td>0.5</td>
<td>1</td>
<td>0.3^b</td>
<td>0.318^c</td>
<td>0.05</td>
</tr>
<tr>
<td>Woodland residues</td>
<td>Shrubbery</td>
<td>Shrubbery residues</td>
<td>0.5</td>
<td>0.5</td>
<td>1</td>
<td>0.3^b</td>
<td>0.318^c</td>
<td>0.05</td>
</tr>
<tr>
<td>Grass residues</td>
<td>Grassland</td>
<td>NPP</td>
<td>0.2^d</td>
<td>0.5</td>
<td>1</td>
<td>0.3^b</td>
<td>0.447^e</td>
<td>0.05</td>
</tr>
<tr>
<td>Waste</td>
<td>Urban land</td>
<td>Municipal solid waste</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0.05</td>
</tr>
<tr>
<td>Waste</td>
<td>Industrial land</td>
<td>Municipal sewage sludge</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0.05</td>
</tr>
<tr>
<td>Waste</td>
<td>Residential land</td>
<td>Animal manure</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0.5^f</td>
<td>0.05</td>
</tr>
<tr>
<td>Energy crop</td>
<td>Marginal land</td>
<td>Simulated data</td>
<td>0.5</td>
<td>0.5</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0.05</td>
</tr>
</tbody>
</table>
Methods of biomass feedstocks and bioenergy potential estimation

Residues

- Global Spatially Disaggregated Crop Production Statistics Data
  - Statistical data of production and area
  - Statistical data of woodland residues
  - NPP
- GIS and downscaling
  - Residue-to-product ratio
  - Woodland distribution data
  - GIS
- Agricultural land
  - Woodland
  - Grassland
- Parameter values for land use and biomass
- Agricultural residues
  - Woodland residues
  - Grassland residues
- Combustion and conversion efficiency
- Heat and electricity at 1 km resolution

Waste

- Chinese statistical yearbook
  - MSW and COD
  - Animal manure
- GIS
  - Urban land
  - Rural land
- Statistical downscaling and calibration based on GDP and population at 1 km resolution
- MSW
  - COD
  - Animal manure
- Combustion and conversion efficiency
  - Gasification and conversion efficiency
- Heat and electricity
  - Biogas

Energy crops

- Sustainable scenario
  - Optimal environmental conditions scenario
  - Rainfed yield per hectare (Jiang, 2019)
  - Fully irrigated yield per hectare
- Marginal land
- Sweet sorghum
- Fermentation and conversion efficiency
- Biofuel in two scenarios
### TABLE 2 Application, resolution, and sources of the data and information used in this research

<table>
<thead>
<tr>
<th>Application</th>
<th>Dataset/Information</th>
<th>Resolution</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residues estimation</td>
<td>Agricultural land, woodland, and grassland</td>
<td>1 km</td>
<td>RESDC</td>
</tr>
<tr>
<td></td>
<td>NPP</td>
<td>1 km</td>
<td>Viowy (2016)</td>
</tr>
<tr>
<td></td>
<td>Global spatially-disaggregated crop production statistics data</td>
<td>10 km</td>
<td>Harvard Dataverse</td>
</tr>
<tr>
<td></td>
<td>Area and production of 17 crops</td>
<td>—</td>
<td>National Bureau of Statistics (2016b)</td>
</tr>
<tr>
<td>Waste estimation</td>
<td>Municipal solid waste</td>
<td>Municipal level</td>
<td>National Bureau of Statistics (2016c)</td>
</tr>
<tr>
<td></td>
<td>Municipal sewage sludge</td>
<td>Provincial level</td>
<td>National Bureau of Statistics (2016a)</td>
</tr>
<tr>
<td></td>
<td>Animal manure</td>
<td>Provincial level</td>
<td>National Bureau of Statistics (2016b)</td>
</tr>
<tr>
<td></td>
<td>Urban land and rural land</td>
<td>1 km</td>
<td>RESDC</td>
</tr>
<tr>
<td></td>
<td>Grid population/GDP</td>
<td>1 km</td>
<td>RESDC</td>
</tr>
<tr>
<td>Energy crop simulation</td>
<td>Rainfed yield per hectare of sweet sorghum</td>
<td>10 km</td>
<td>Jiang et al. (2019)</td>
</tr>
<tr>
<td></td>
<td>Fully irrigated yield per hectare of sweet sorghum</td>
<td>Provincial level</td>
<td>Nie et al. (2019)</td>
</tr>
<tr>
<td></td>
<td>Marginal land</td>
<td>1 km</td>
<td>RESDC</td>
</tr>
<tr>
<td>Conversion</td>
<td>Technical coefficient</td>
<td>—</td>
<td>Table 3</td>
</tr>
</tbody>
</table>

Abbreviation: GDP, gross domestic product; RESDC, Data Centre for Resources and Environmental Sciences.
The distribution of usable biomass feedstocks at 1 km resolution in China: (a) forestry residue; (b) shrubbery residue; (c) grassland residue; (d) orchard residues; (e) dry land agricultural residue; (f) paddy land agricultural residue; (g) animal manure; (h) municipal sewage sludge; (i) municipal solid waste; (j) sweet sorghum in sustainable scenario; (k) sweet sorghum in optimal environmental conditions scenario. All the base maps of China in this research are referred from Map number: GS(2019)1682