Land-Use Competition in a 1.5oC Climate Stabilization Pathway

Angelo Gurgel[a], Jennifer Morris[a], Martin Haigh[b], Andy D. Robertson[c], Robin van der Ploeg[d], Sergey Paltsev[a],

[a]MIT Joint Program on the Science and Policy of Global Change

[b]Shell Scenarios Team

[c]Shell International Exploration and Production

[d]Shell Global Solutions International

GTAP 27th ANNUAL CONFERENCE ON GLOBAL ECONOMIC ANALYSIS

Enhancing Global Food System Sustainability

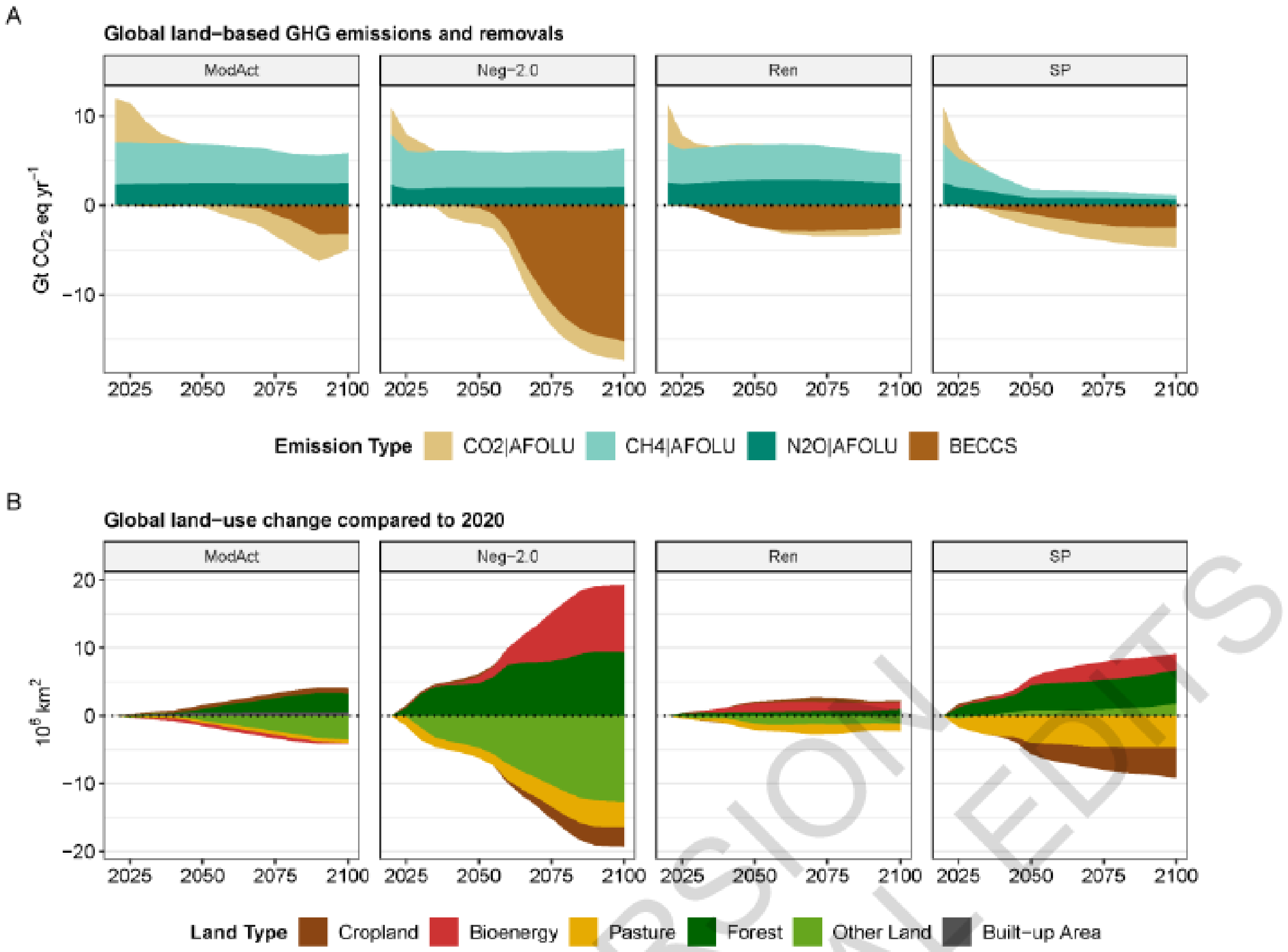
Draft: do note cite

Outline

- Introduction
- Current global land use and land-use emissions
- Methods
- Results
- Final remarks

Introduction

- Net-zero GHG emissions and climate stabilization goals require reducing GHG emissions and increasing removals.
- Land plays an important role in low-emissions pathways:
  - bioenergy (which and without carbon capture and storage - BECCS)
  - afforestation/reforestation and other nature-based solutions (NBS)
  - energy crops
  - changing agricultural practices
  - expansion of wind and solar generation
  - potentially direct air capture facilities



Land-based emissions and land-use changes from alternative scenarios and models (IMAGE, AIM/CGE, Remind-MAgPIE) reported by the IPCC – AR6.
Source: IPCC – AR6 – WG III (2022)

Draft: do note cite

Introduction

However, many trade-offs related to land use:
- mitigation/sequestration potential
- energy production
- implications for food security,
- impact on wider ecosystems.

FAO (2018) - increase in global arable land:
- 165 million hectares (Mha) (11%)
- 325 Mha (21%)

Fajardy et al. (2021): BECCS may require between:
- 80 Mha
- more than 500 Mha.

Smith et al. (2016): bioenergy may require:
- 380 Mha of land required (170 EJ/yr)
- Roe et al. (2021): NBS/NCS may require:
- 2 to 4 billion hectares (Gha) to remove ~30 $GtCO_2e/yr$

Draft: do note cite

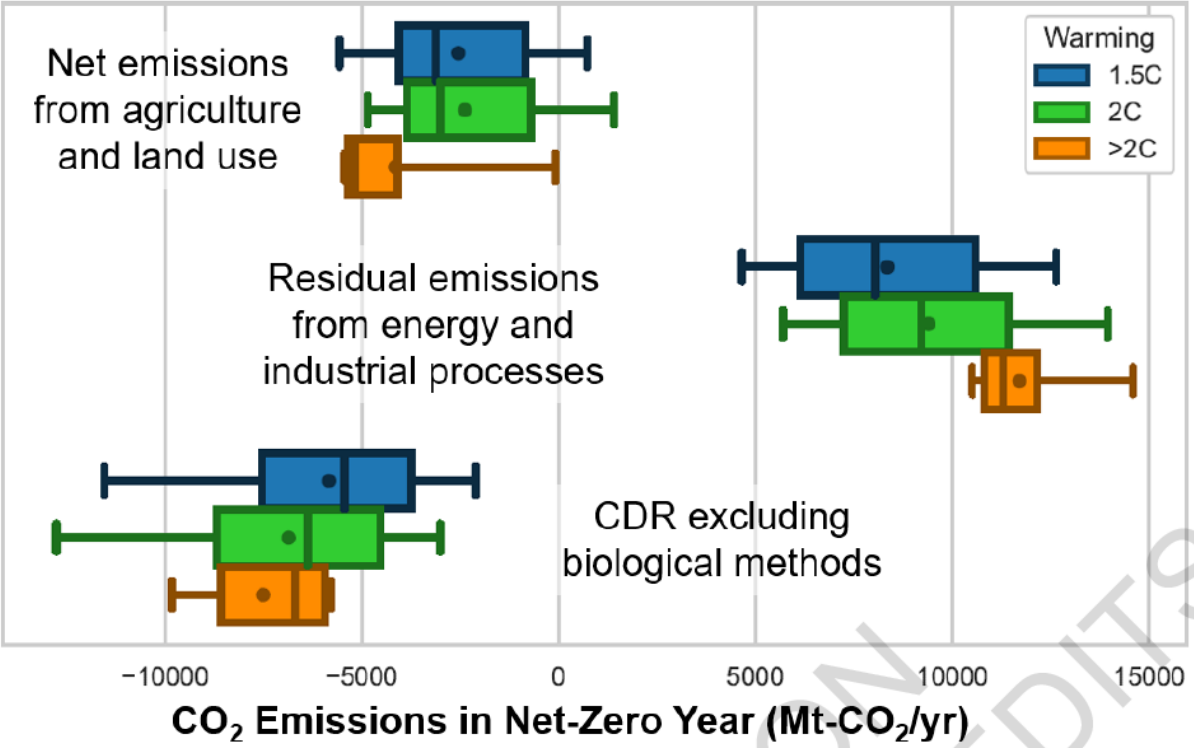


Figure 6.21 Residual emissions and CDR when global energy and industrial CO_2 emissions reach net zero. Residual emissions and CDR in net zero scenarios show global differences across warming levels (blue = <1.5˚C, green = <2.0˚C, orange = >2.0˚C). Points represent different models and scenarios from the AR6 database. In each case, the boxes show the 25th to 75th percentile ranges, and whiskers show the 5th and 95th percentiles. Lines and circles within the boxes denote the median and mean values, respectively.

Source: IPCC – AR6 – WG III (2022)

Introduction

Is there enough land to meet all the needs for food and nature, urban environments, energy production, and nature-based carbon sequestration?

Is it possible to allocate land for food, carbon sequestration, energy and nature globally and regionally to address both human and environmental needs? What are the required actions and changes in land use to achieve these needs?

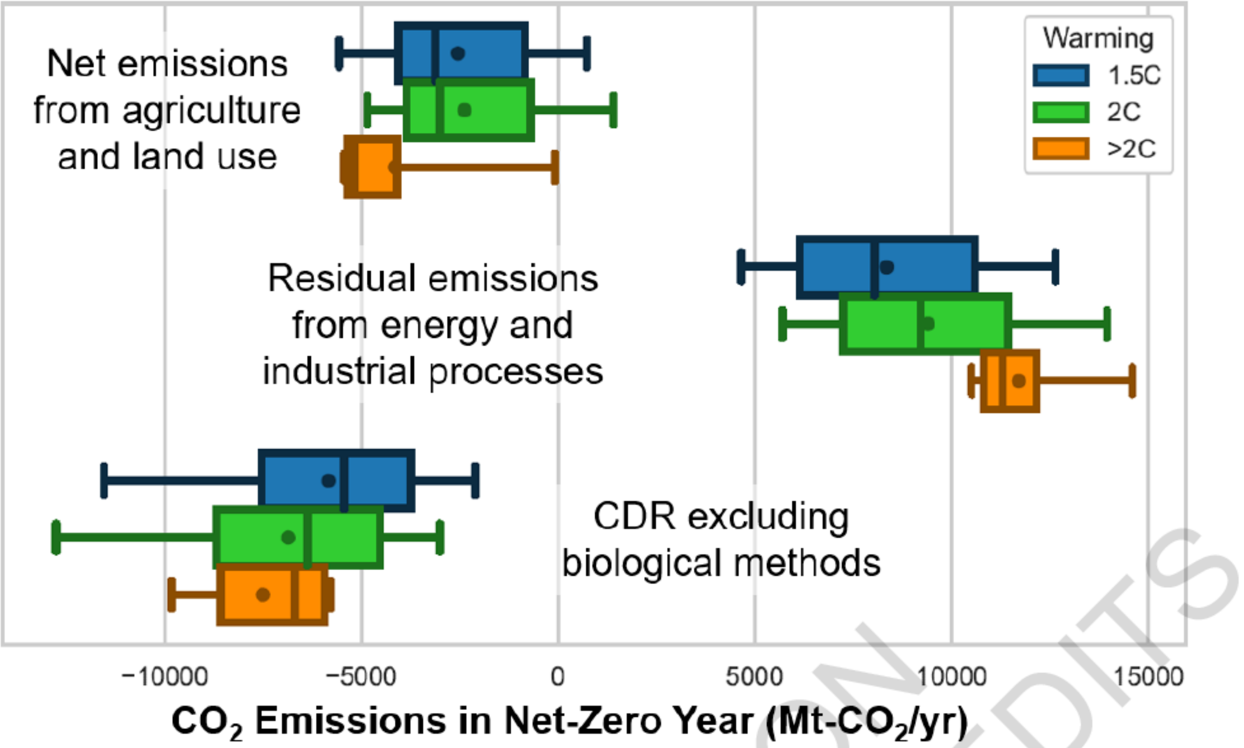


Figure 6.21 Residual emissions and CDR when global energy and industrial CO_2 emissions reach net zero. Residual emissions and CDR in net zero scenarios show global differences across warming levels (blue = <1.5˚C, green = <2.0˚C, orange = >2.0˚C). Points represent different models and scenarios from the AR6 database. In each case, the boxes show the 25th to 75th percentile ranges, and whiskers show the 5th and 95th percentiles. Lines and circles within the boxes denote the median and mean values, respectively.

Source: IPCC – AR6 – WG III (2022)

Draft: do note cite

Current global land use and land-use emissions

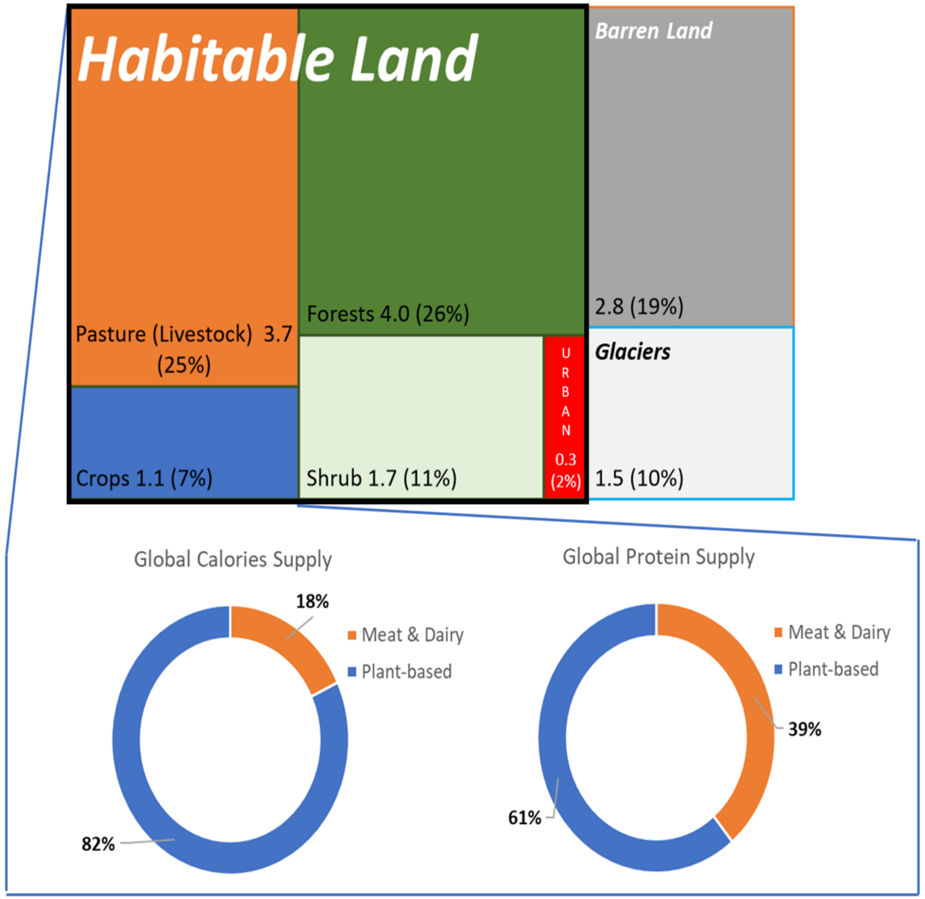


Table 1. Land area (in Mha) used for bioenergy, wind generation and solar generation in 2020.

Region	Land for: Bioenergy	Wind	Solar	Total Land	Share of land for energy (%)
USA	22.6	1.6	0.1	930	2.6
Europe	8.8	1.8	0.1	486	2.2
China	12.0	2.9	0.2	933	1.6
India	2.2	0.5	0.0	296	0.9
Brazil	13.9	0.3	0.0	855	1.7
Rest of the World	36.4	1.3	0.2	9950	0.4
WORLD	95.9	8.0	0.6	13450	0.8

Draft: do note cite

Method

- Bottom-up modeling of the potential for nature-based solutions (NBS)

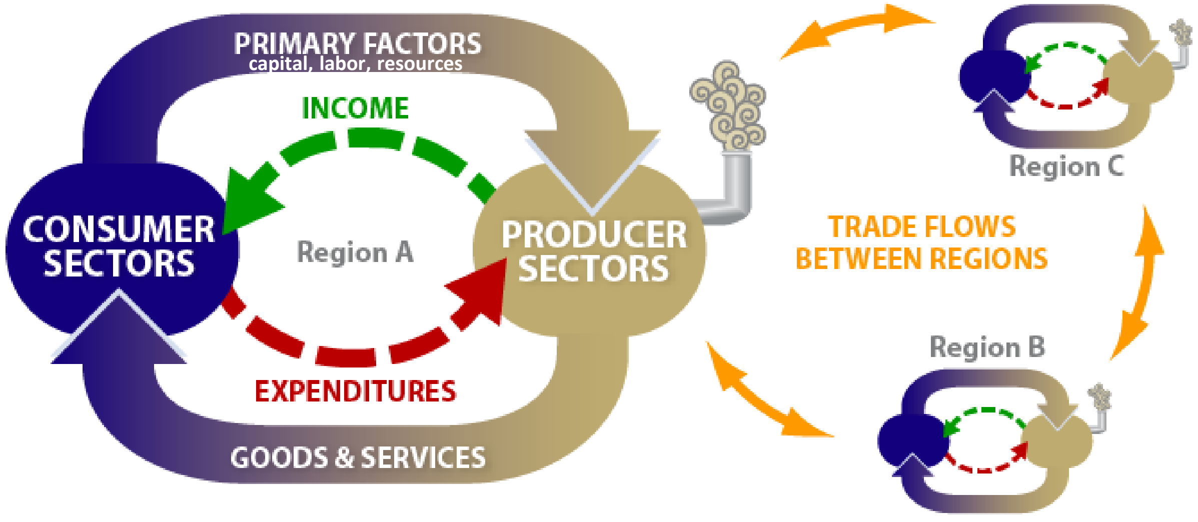
- Top-down modeling: The Economic Projection and Policy Analysis (EPPA) model

Draft: do note cite

Method

MIT Economic Projection and Policy Analysis (EPPA) Model

Multi-sector, multi-region computable general equilibrium (CGE) model of the world economy for energy, economy and emissions projections



Non-Energy Sectors
- Crops
- Livestock
- Forestry
- Food
- Energy-Intensive Industry
- Manufacturing
- Service
- Commercial Transport
- Household Transport

Energy Sectors
- Crude Oil
- Refined Oil
- Liquid Fuel from Biomass
- Oil Shale
- Coal
- Natural Gas (conv., shale, tight)
- Electricity
- Synthetic Gas (from Coal)

Regions and sectors can be added for special studies

Energy-Intensive Industry:
Iron & Steel
Cement
Chemicals
Non-Ferrous Metals
+ *low-carbon options*

Household Transport:
ICE (gasoline & diesel)
Plug-in Electric
Battery Electric
Hydrogen

Liquid Fuel from Biomass:
Current Generation
Advanced Biofuel

New Technologies Continually Added

Electricity:

Conv. Fossil (coal, gas, oil)	Advanced Nuclear
Adv. Fossil (NGCC, Adv Coal)	Hydro
Coal with CCS	Solar
Coal + Bio Co-firing w/ CCS	Wind
Gas with CCS	Renewables with Backup
Gas with Advanced CCS	Biomass
Nuclear	Biomass with CCS

Key Features
- Global Coverage & International Trade
- Economy-Wide Coverage & Inter-Industry Linkages
- Feedbacks Across Regions & Sectors
- Theory-Based (microeconomics with full input-output data)
- Endogenous Prices, Investments & Capital Accumulation
- GDP and Welfare Effects
- Policies (emissions limits/prices, sector/technology regulations…)
- Distortions (taxes, subsidies, etc.)
- Accounting for Physical Quantities (energy, electricity, land)
- **Links to MIT Earth System Model (MESM)**

Draft: do note cite

Method

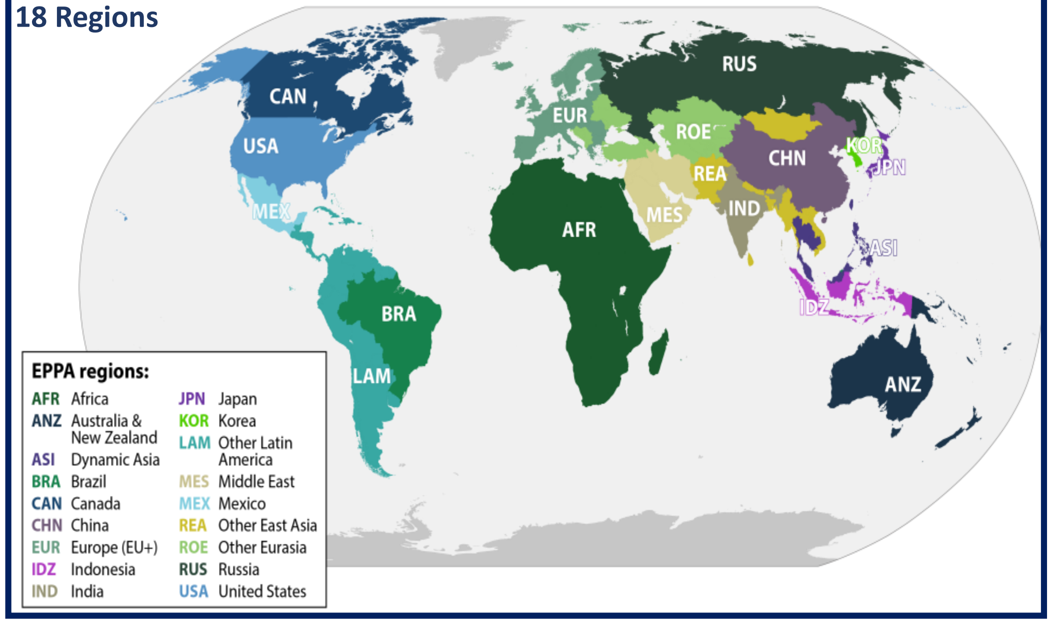
MIT Economic Projection and Policy Analysis (EPPA) Model

Multi-sector, multi-region computable general equilibrium (CGE) model of the world economy for energy, economy and emissions projections

Key Inputs
Policy Assumptions
Population Growth
Capital/Labor Productivity Growth
Energy Efficiency Improvements
Technology Costs
Rate of Technology Penetration
Elasticities of Substitution
(related to labor, capital, energy, fuels, etc.)
Fossil Fuel Resource Availability
Urban Pollutant Initial Inventories & Trends
Land Productivity

Key Outputs
GDP
Consumption
Emissions (GHGs, Air Pollutants)
Primary/Final Energy Use
Electricity Generation
Technology Mix
Commodity and Factor Prices
Sectoral Output
Land Use
At global and regional levels

18 Regions



Key Equations
Firms maximize profit: choose technology, level of output and inputs subject to production functions and costs

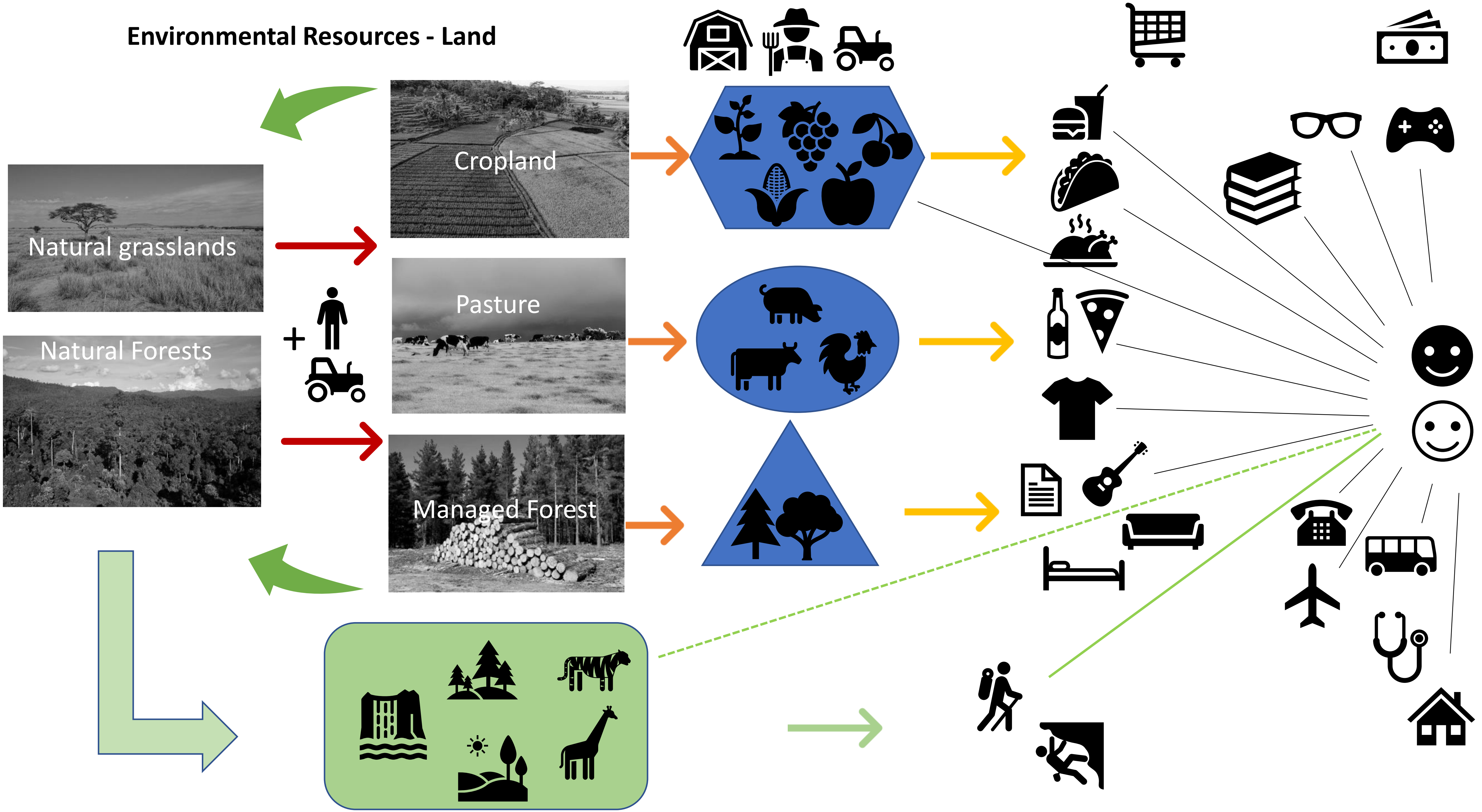
Household maximize welfare: choose savings and consumption subject to budget constraint

Equilibrium Conditions: Market-Clearing, Zero-Profit, Income Balance

Technical Features
Written in GAMS using MSPGE
Recursive-Dynamic
Uses GTAP Database
Calibrated to current economic and energy levels based on IMF and IEA
Documented in peer-reviewed literature
Publicly Available Version
2100+ (in 5-year steps)

https://globalchange.mit.edu/research/research-tools/human-system-model

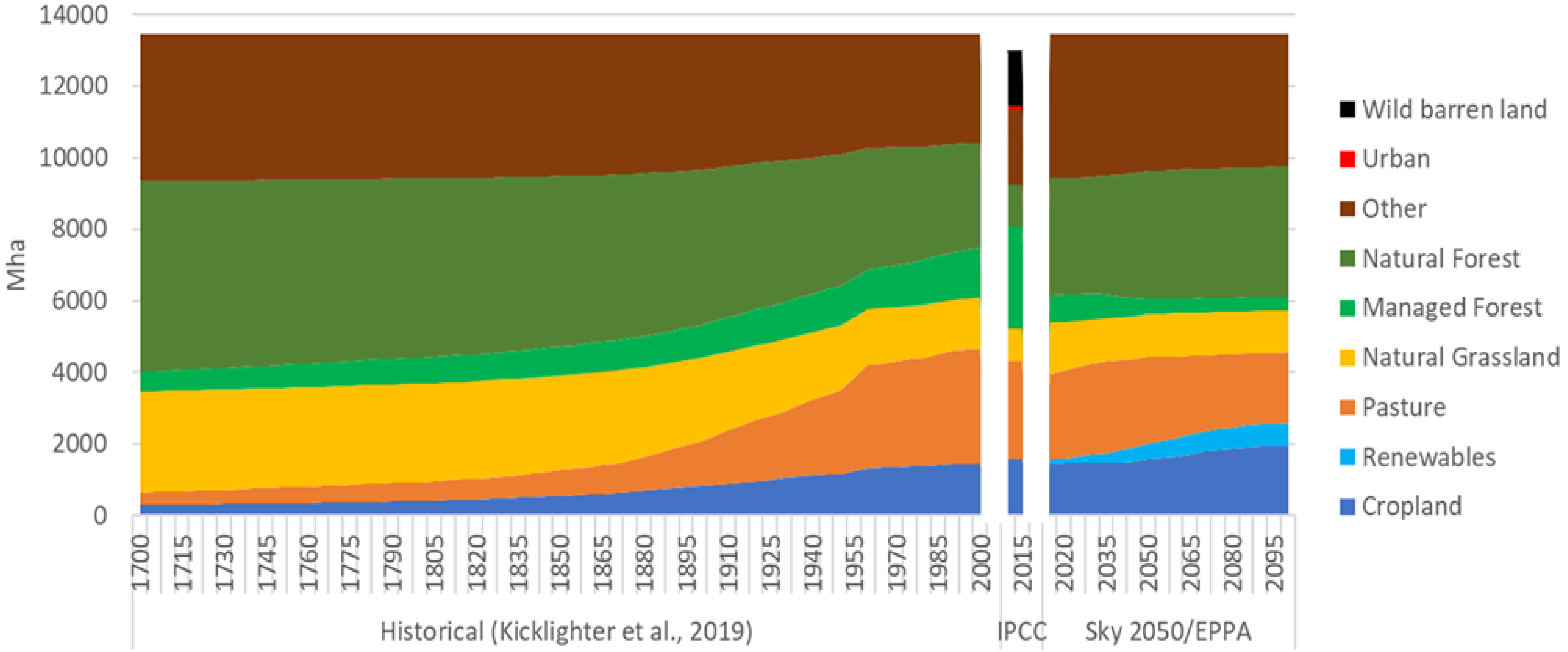
Environmental Resources - Land



Draft: do note cite

Results

Global land use: 1700-2100

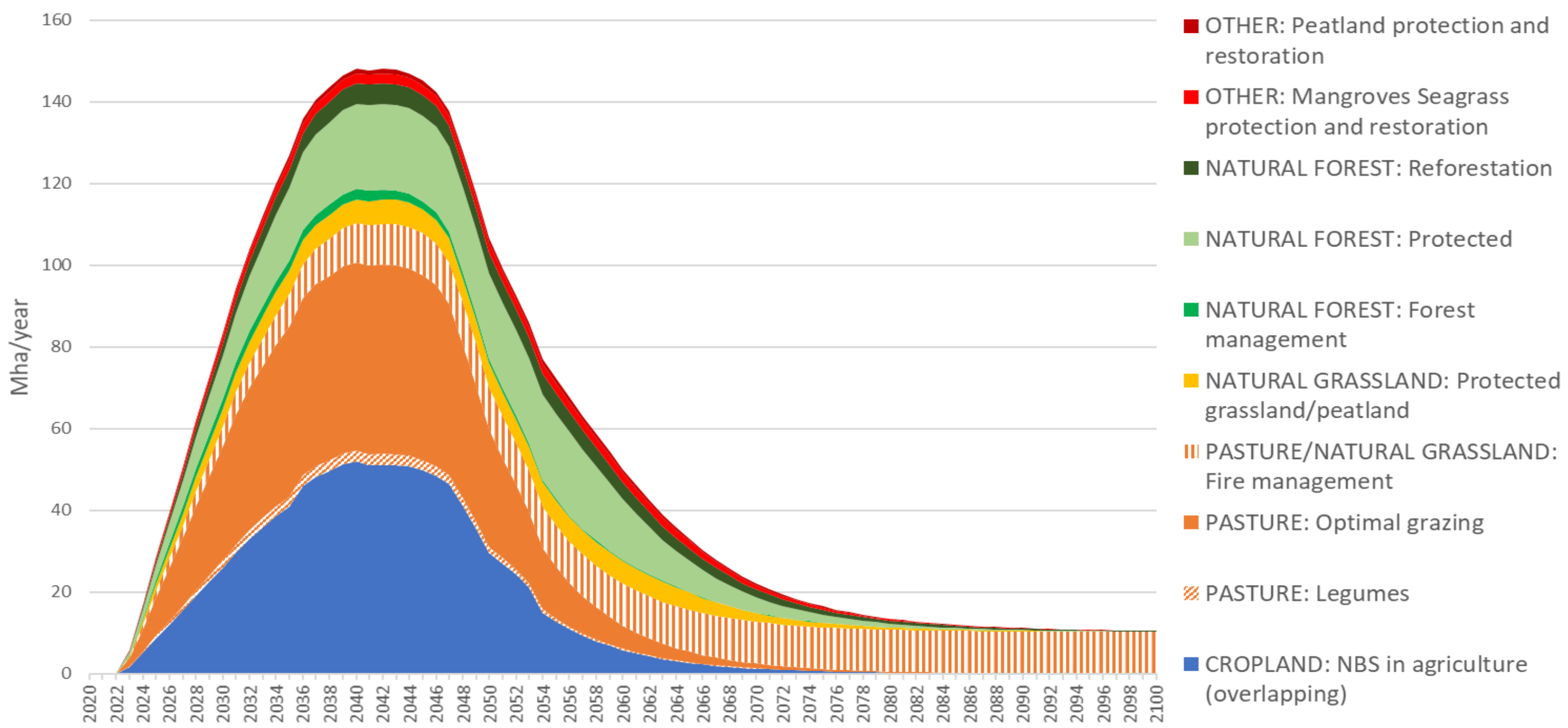


Historical global land use and future projections by broad categories (in Mha)

Draft: do note cite

Results

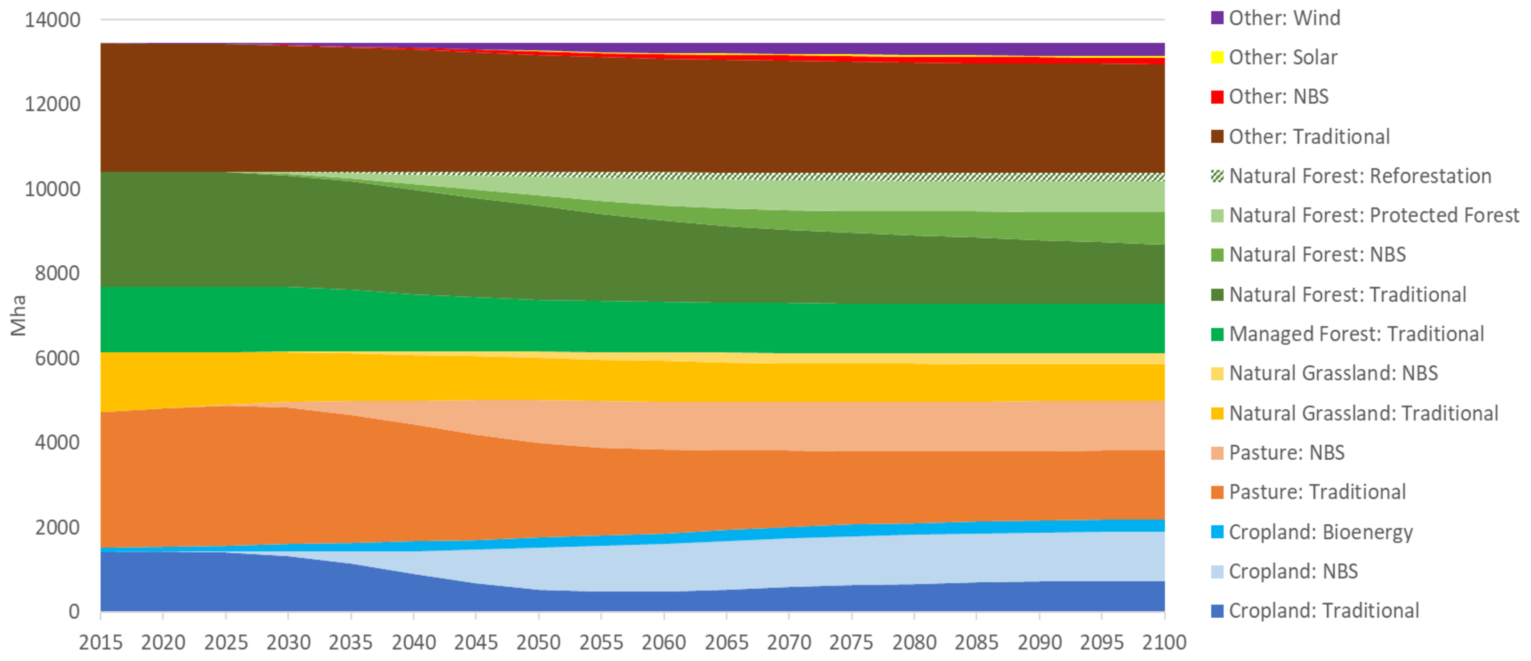
Nature-based solutions



Annual increments in land areas for different categories of nature-based solutions

Draft: do note cite

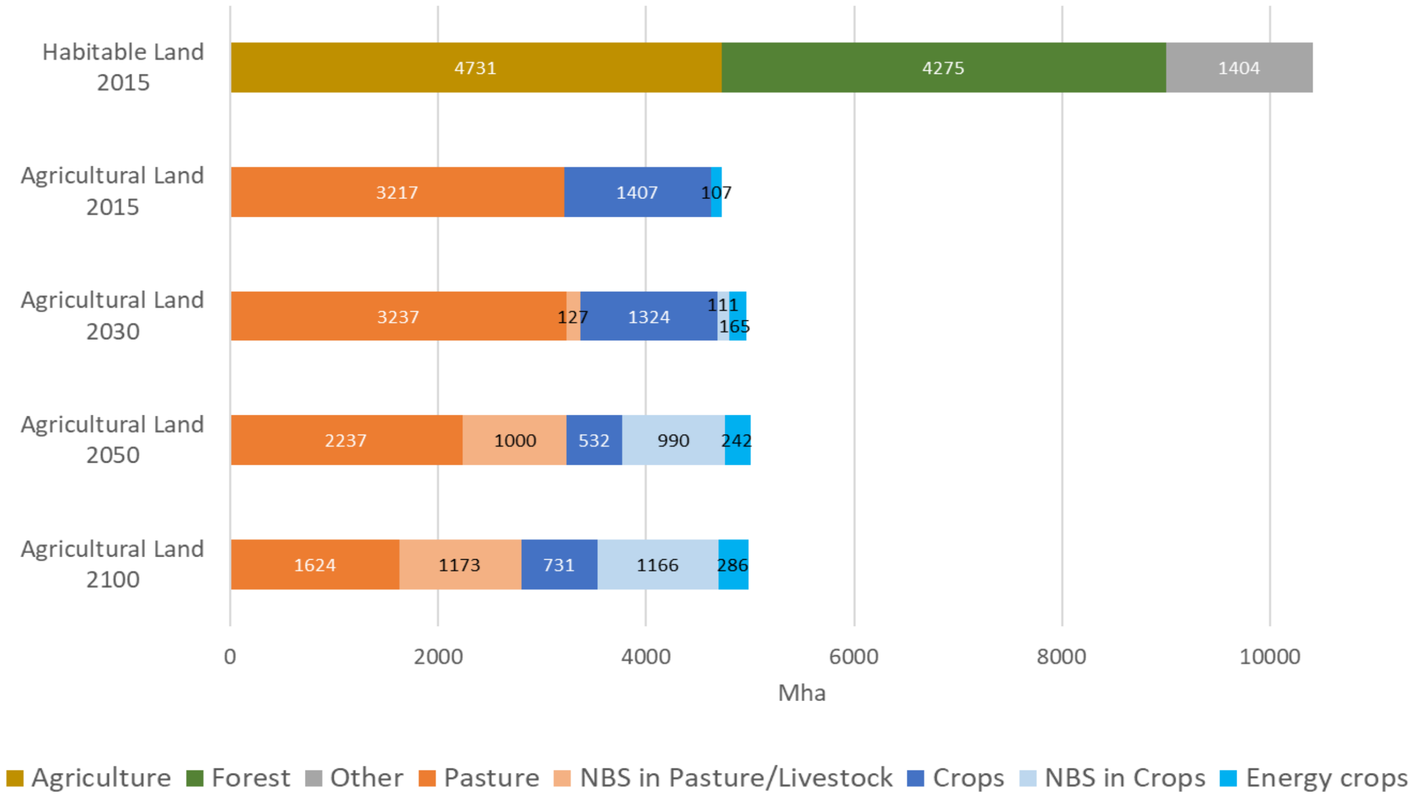
Results



Global land use by categories

Draft: do note cite

Results



Projections for agricultural land use in the Sky scenario

Draft: do note cite

Results

Land for energy

Mha	Land for			Total Land	Share of land for energy (%)
	Bioenergy	Wind	Solar		
USA	50.2	16.8	1.1	930	7.3
Europe	13.5	12.6	1.0	486	5.6
China	39.0	33.6	5.3	933	8.3
India	2.7	19.5	3.1	296	8.5
Brazil	16.8	2.7	0.4	855	2.3
Rest of the World	119.8	94.0	10.1	9950	2.3
WORLD	242.0	179.1	21.0	13450	3.3

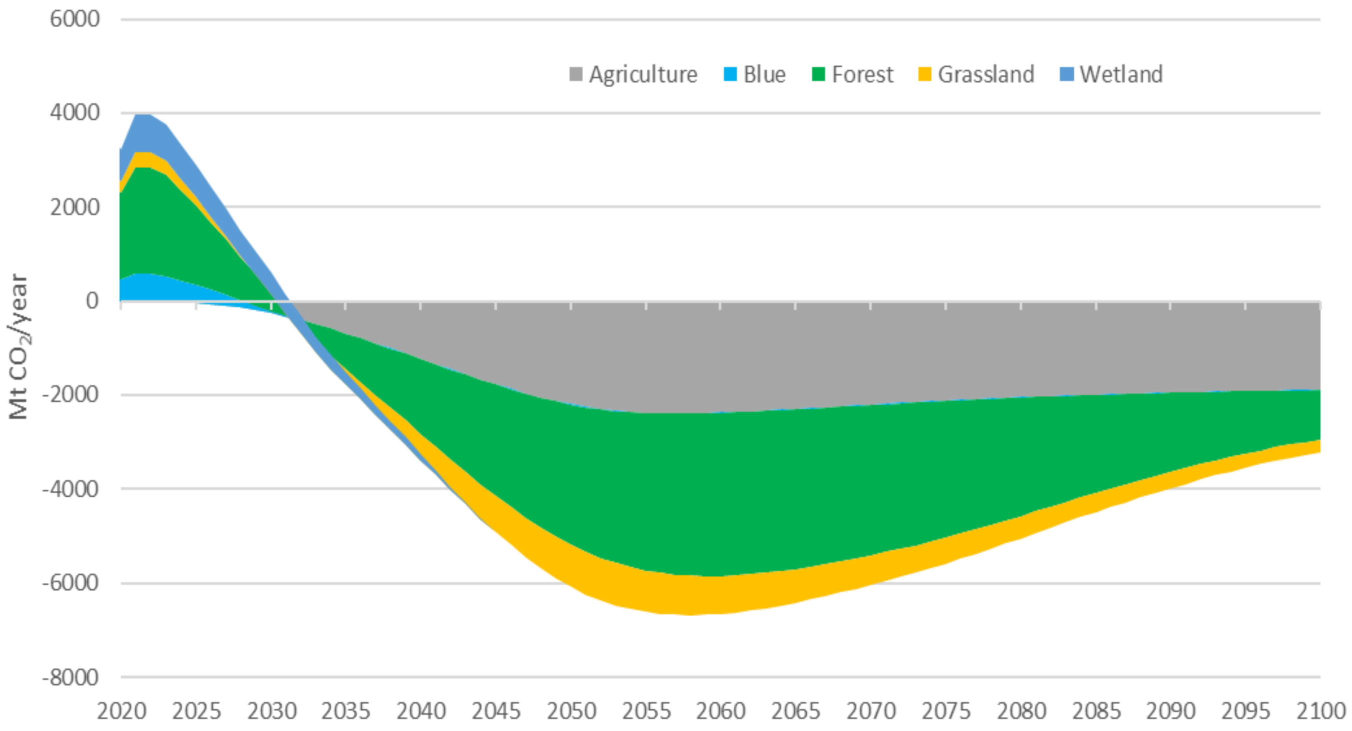
Table 2. *Land area used for bioenergy, wind generation and solar generation in 2050*

Mha	Land for			Total Land	Share of land for energy (%)
	Bioenergy	Wind	Solar		
USA	58.0	26.2	2.1	930	9.3
Europe	13.5	14.5	1.0	486	6.0
China	45.4	18.3	5.6	933	7.4
India	3.4	17.2	6.8	296	9.3
Brazil	16.7	3.5	0.7	855	2.4
Rest of the World	149.3	222.9	28.3	9950	4.0
WORLD	286.2	302.7	44.5	13450	4.7

Table 3. *Land area used for bioenergy, wind generation and solar generation in 2100*

Results

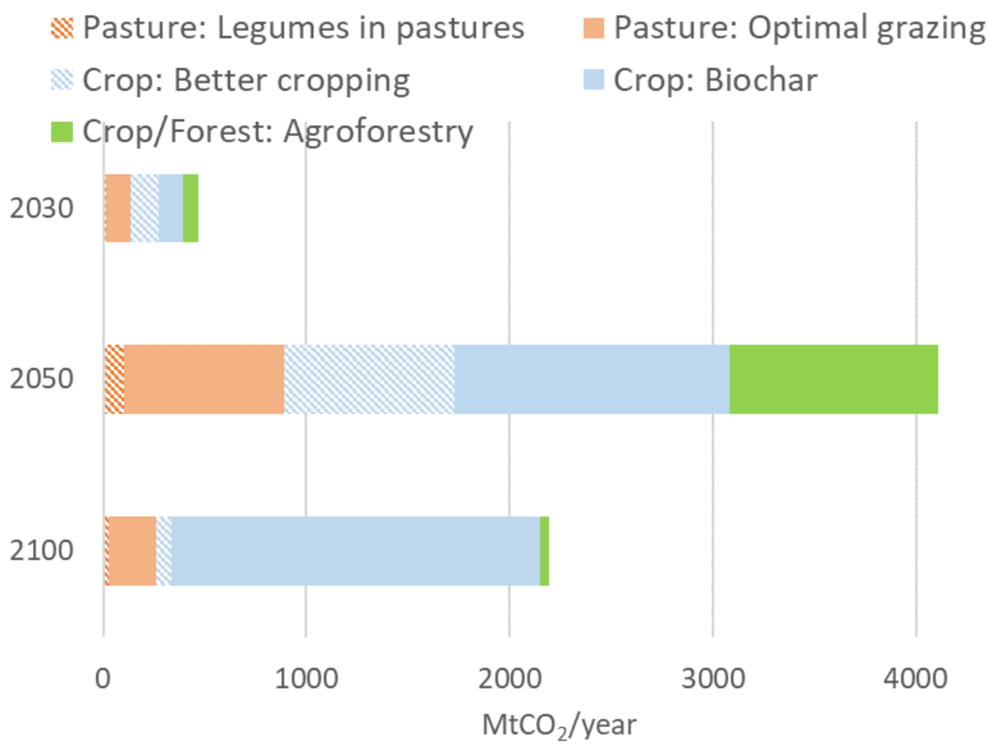
CO_2 sequestration



Annual carbon emissions and sequestration from different NBS types (agriculture, blue, wetland, grassland, forest)

Draft: do note cite

Results

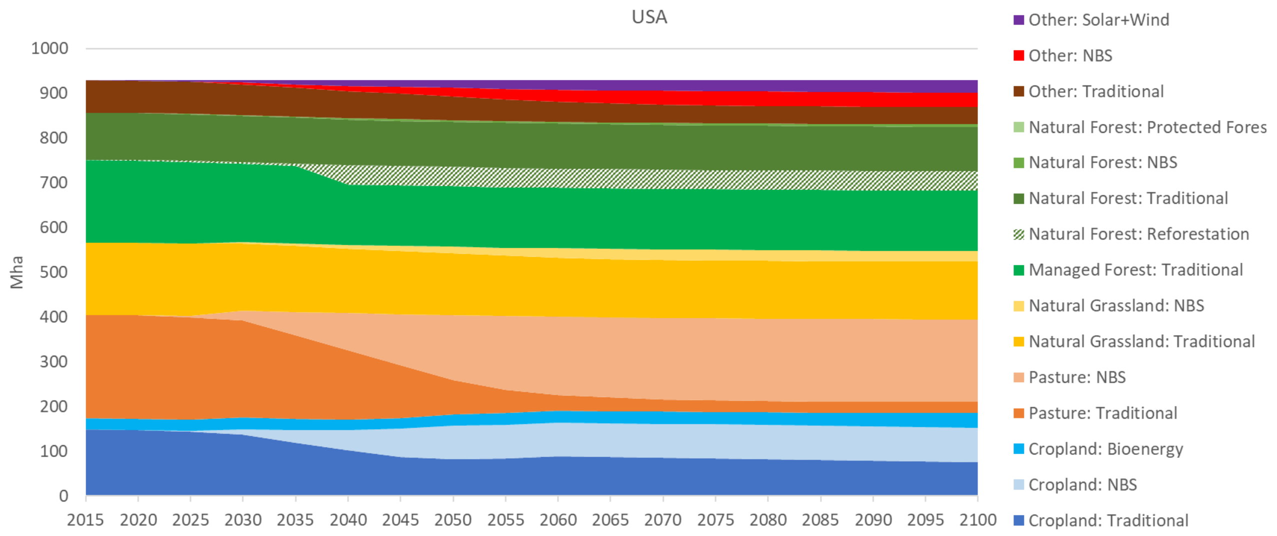


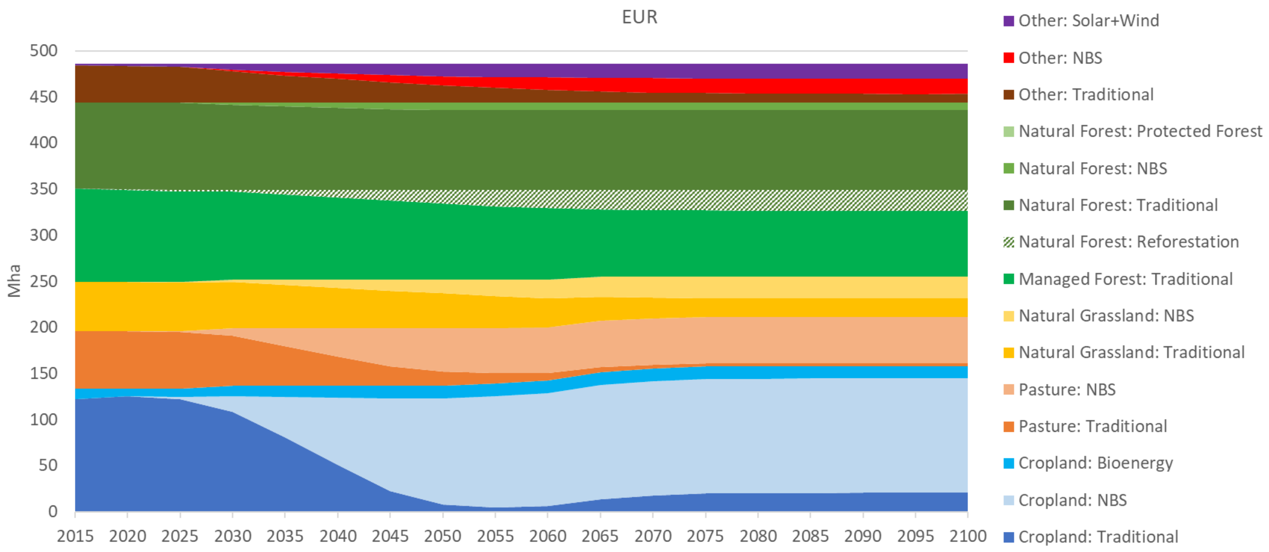
Projections for CO_2 sequestration in crops and livestock

Draft: do note cite

Results

Regional land-use changes

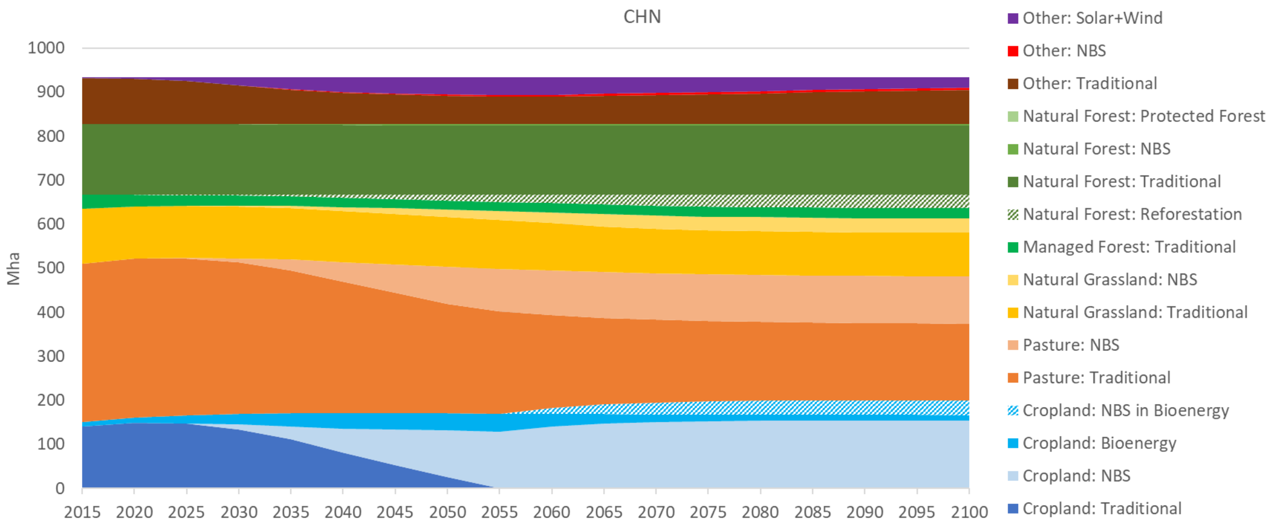


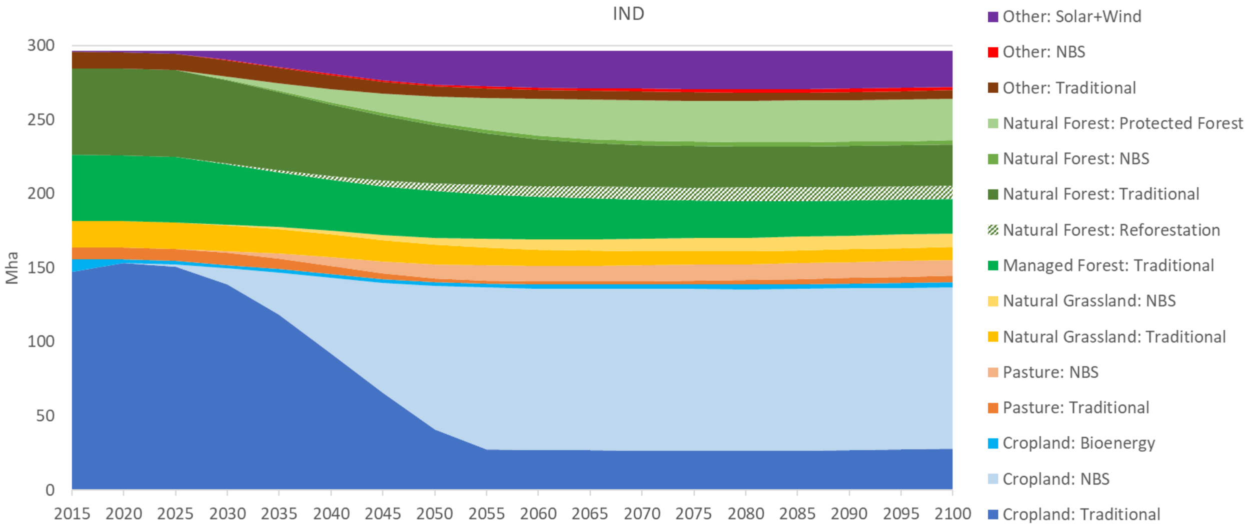


Draft: do note cite

Results

Regional land-use changes

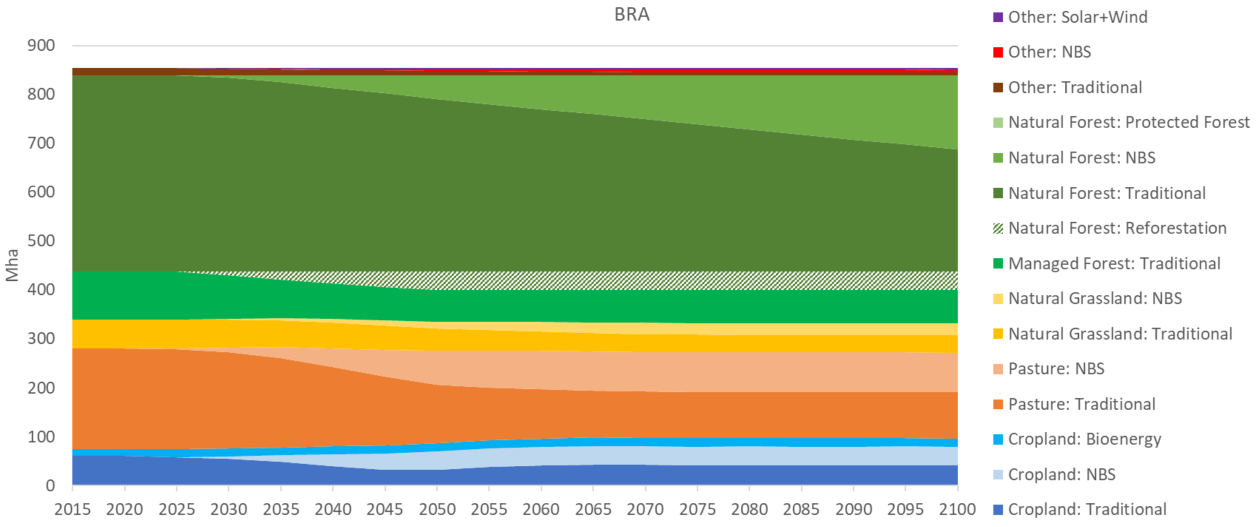


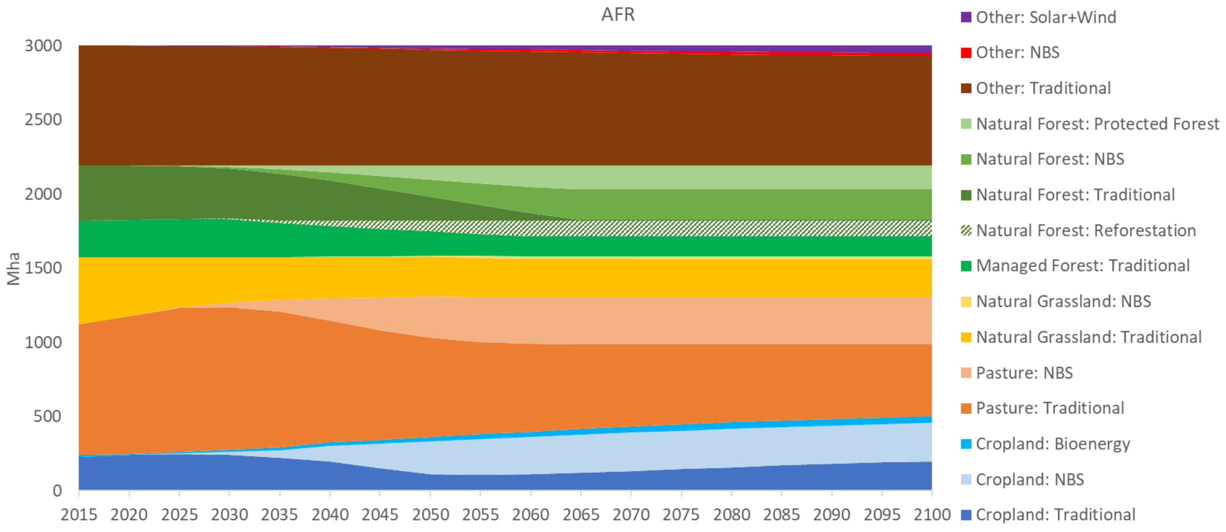


Draft: do note cite

Results

Regional land-use changes

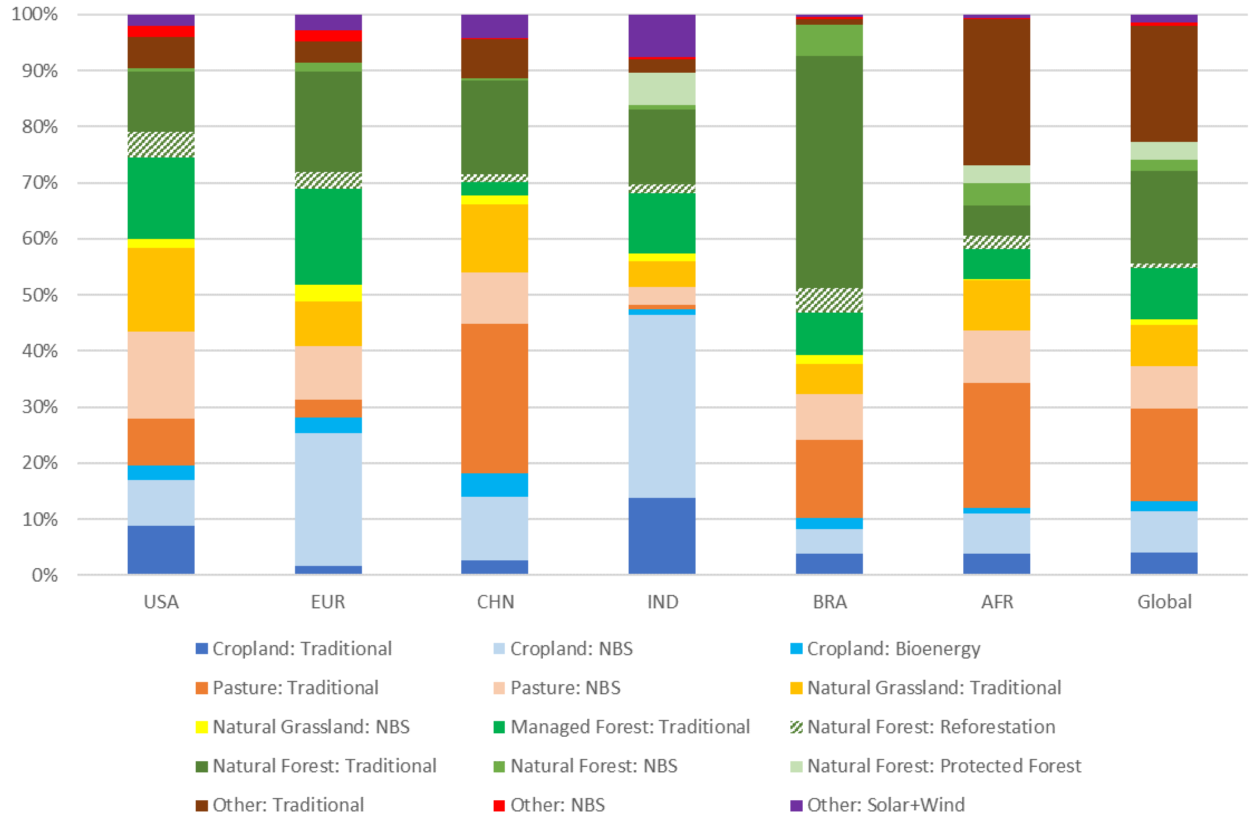




Draft: do note cite

Results

Regional land-use changes



Comparison of 2050 land use shares (%) in selected regions (USA, Europe, China, India, Brazil, Africa, and The World)

Draft: do note cite

Final Remarks

GLOBAL CHANGE

- Achieving climate stabilization of 1.5ºC by the end of the century: strong societal changes, reversal of current trends on land use changes and a reconfiguration of land cover distribution and agricultural activities.
- Many opportunities to mitigate emissions and sequester carbon in soils through nature-based solutions, but also, many challenges to accommodate such practices in synergistic ways with food provision and renewable energy requirements.
- The global land system can accommodate 3.5 Gha of NBS to remove about 6 $GtCO_2$/year. However, several trade-offs related to land use competition:
  - NBS activities may affect agricultural output and food production, unless effective adoption of regenerative agricultural practices does not negatively impact yields and increases nutrient cycling efficiencies
  - land required for energy production (wind, solar, and biomass) can compete with the land for food and preserving nature, unless limit bioenergy demand to levels below published potential resource base estimates (*Sky 2050*). Land for bioenergy and renewable energy takes only about 3-5% of total land.
  - Forest products and trade-offs between timber production and forest protection and reforestation (between 2020 to 2100 forestry products per capita increase by 213%) NBS, forest protection and restoration.
  - Trade-off with biodiversity, as well as impacts on water availability, we do not capture these impacts, we fully support the need for further examination of the issue. In *Sky 2050* scenario NBS takes a holistic view of appropriate ecosystem restoration (not only increasing the land stock of CO_2) Putting the regulations in place to deliver this is far from straightforward. There is a need for systematic biodiversity indicators that would help to understand and predict the fate of global biodiversity amidst an increasingly complex and changing world (construct comprehensive metric that quantifies the current state of biodiversity and captures future trends that are driven by a variety of stressors across environmental, social, and economic systems).
  - Engineering carbon capture solutions (such as bioenergy with carbon capture and storage (BECCS) or direct air CO_2 capture and storage (DACCS)). These put additional pressure on land, however, these options should be deployed as an addition to the efforts for emission mitigation.
- At global level, in the second half of the 21st century land is available to provide 3-6 $GtCO_2$/year sink through 2.5-3.5 Gha of NBS practices of protecting, managing, and restoring land, and, at same time, providing 325-650 EJ/year of renewable energy, using 0.4-0.6 Gha of land, including 0.2-0.3 Gha for bioenergy and 0.2-0.35 Gha for wind and solar power generation.
- At regional level: it is possible to fit land for major human needs, while protecting and restoring land, but it may be quite challenging for some regions. NBS deployment over time would not disturb food and primary goods production from agriculture more than the multiple economic pressures which are associated with a 1.5ºC stabilization target, such as changes in energy and good prices and impacts on income and overall demand.
- We share concerns (e.g., Searchinger and Heimlich, 2015; Rulli et al., 2016; Fehrenbach et al., 2023) about the urgent need for advancing sustainable approaches to land management for food and nature.
- Challenges: NBS practices in agriculture need to be massively adopted and in such a way that will maintain observed trends in crop yield improvements.
- Livestock sector, pasture yields and productivity gains must accelerate, at the same time as NBS is adopted, in order to free up land for other uses. It requires engagement of local communities and small landholders. Special attention to protection of indigenous communities. Adoption of NBS will likely also require incentives with implications for equity depending how they are designed.
- Ensure that policies encouraging certain land uses (such as carbon sequestration or energy) do not negatively impact land uses needed to meet other societal goals, such as food security to biodiversity. Future competition between the different land uses depends on several factors: economic and population growth, land productivity, climate change impact, land and technology costs, and policy design and stringency.
- For NBS to contribute to climate targets, pricing land use emissions/sequestration and/or require certain practices. Covering the land sector under an emissions policy, creating separate offset markets for sequestered carbon, or other regulatory policies such as NBS requirements or targets for carbon removal. Careful monitoring, accounting and crediting of emissions is needed, requiring agreement on issues such as permanence, additionality and leakage. Existing voluntary offset markets as well as policies being implemented in various countries may teach us about these.

Thanks!

gurgel@mit.edu