Bio-economy:
Determining the nature and scale of sustainable, low-carbon bio-resources supply

ENERGY TRANSITIONS COMMISSION

8th June, 2020

Agenda for today

Sustainable, low-carbon biomass availability

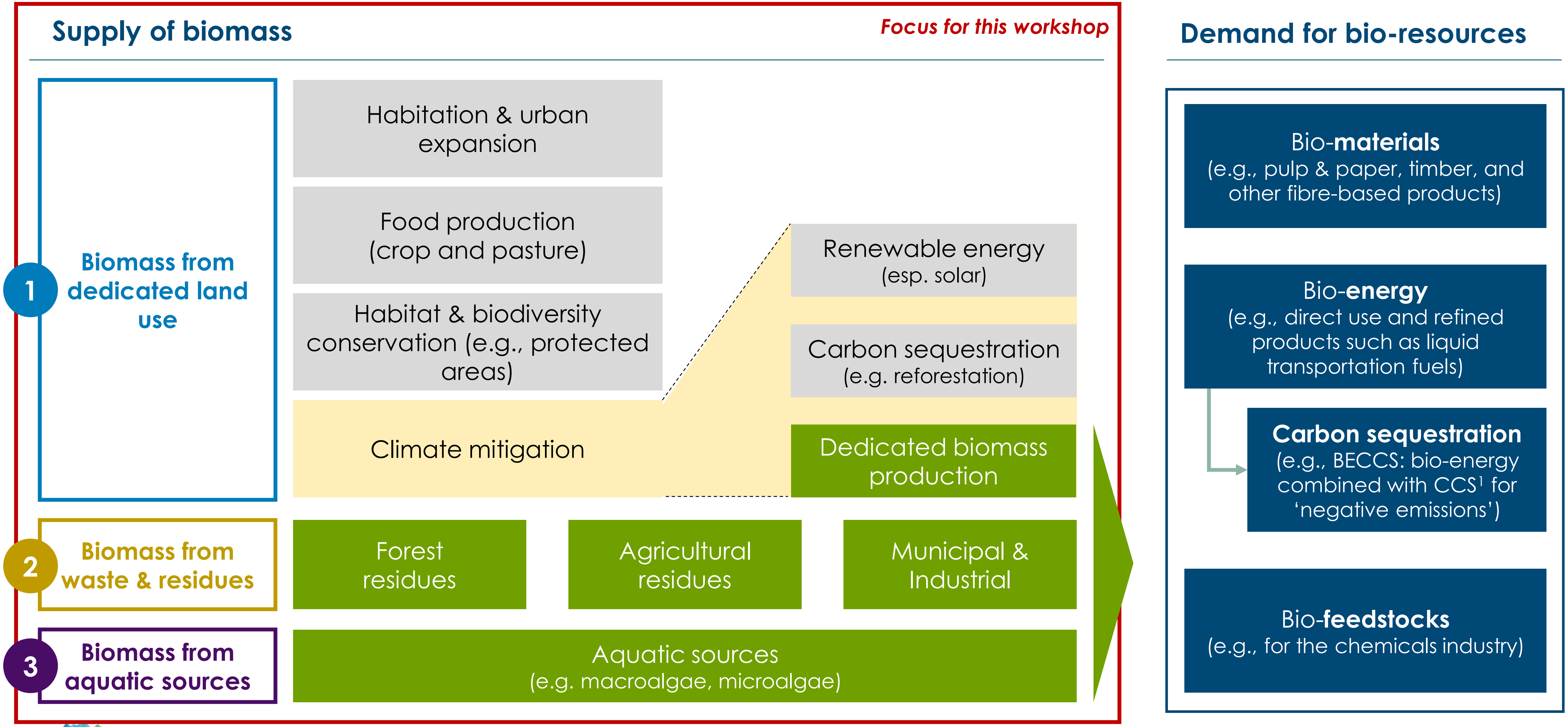
Understand the range of estimates for the prudent **scale of bio-resources available** for industrial uses today and by mid-century, taking into account sustainability criteria and carbon trade-offs, considering

- Biomass from dedicated land use
- Biomass from waste and residual sources
- Biomass from aquatic sources

Actions to ensure sustainability

Discuss the **actions needed from policymakers and industry** to ensure the sustainability and low-carbon attributes of this biomass (e.g. regulations, standards)

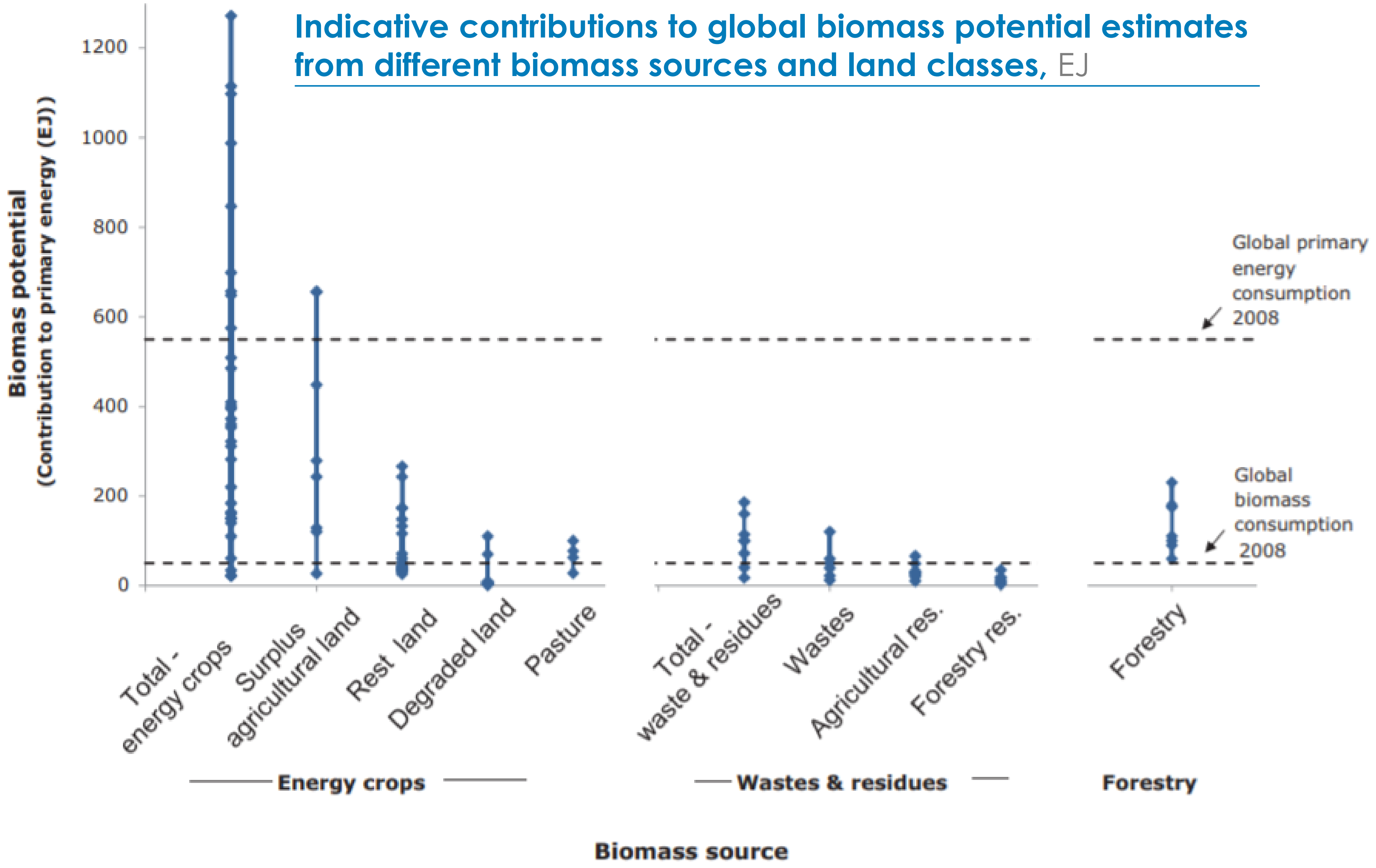
Competing uses of land constrain biomass supply, for which there are numerous demands



(1) BECCS: bio-energy carbon capture & storage

Estimates for total global biomass potential vary substantially, especially in the rigour and methodology used to apply 'sustainability criteria'

Indicative contributions to global biomass potential estimates from different biomass sources and land classes, EJ



- **Each dot represents a different estimate** in the literature
- **Many studies do not have rigorous sustainability criteria**
- The differing **degrees of stringency** in which potential land is excluded for sustainability results in **high variability amongst estimates** of biomass potential

Source: UKERC, 2011, *Energy from biomass: the size of the global resource*

Over the past two months we have reviewed 7 studies which assess 'sustainable' biomass availability in detail (globally and for Europe)

Global studies		Food and Land Use Coalition / IIASA		ICCT
	ACRE Satellite Model ①	Low Energy Demand Scenario (LED) ②	BECCS Scenario ③	ICCT *(additional global study shared by ICCT team)* ④
Purpose & general Approach	***Bottom-up geospatial mapping analysis*** *to determine sustainable supply biomass available for bioenergy demand*	*Balance multiple demands on land use to meet triple targets for food security, climate mitigation and environmental protection, via* ***integrated assessment partial equilibrium model*** *drawing on land-use spatial analysis*		*Consolidate and revise global sustainable biomass supply estimates via* ***review of literature + application of additional adjustments***
Scope & Timeframe	Global 2018	Global 2020-2050	Global 2020-2050	Global 2050

European studies	IIASA		
	EU Commission Study (RECEBIO) ⑤	Land Use change impact of biofuels in EU (Valin et al.) ⑥	ECF EU study conducted by ICCT ⑦
Purpose & general Approach	***Integrated assessment model using GLOBIOM/PRIMES*** *targeting increased EU use of bioenergy for electricity and heat via modelling of wood biomass production and use*	***Integrated Assessment model using GLOBIOM*** *to provide new insights to the EUC about indirect carbon & land impacts from biofuels, with more details individual feedstocks*	***Top-down analysis using public datasets*** *to determine biomass availability for bio-fuels for transportation purposes*
Scope & Timeframe	EU 2020-2050	EU 2020-2030	EU 2018-2030

(*) First gen bioenergy not included in the total final energy demand because not a feature of the model.

We systematically reviewed each study's conclusions on availability by source to develop a consensus view of truly sustainable, low-carbon biomass supply

Topics		Key questions addressed
1. Biomass from dedicated land use	Land for climate mitigation	▪ How much **land can be dedicated to climate mitigation** among other land uses (food production, habitation, biodiversity conservation)?
	Climate mitigation alternatives	▪ What are the **carbon trade-offs between alternative uses of land** available for climate mitigation (e.g. renewables, sequestration, biomass production for bio-products or bio-energy)? ▪ What does this imply for level of **biomass supply**?
2. Biomass from waste and residual sources	Forest	▪ What is the **availability of biomass** from each of these sources? ▪ What drives the range of estimates? ▪ How will this evolve over time? ▪ What is the cost of collection/ transportation?
	Agriculture	
	Municipal & Industrial	
3. Biomass from aquatic sources		

Aim of today's session is to share the key insights and conclusions of this detailed review

You will find highlights in this presentation, and further detail (including comparison of input data, methodologies, and underlying assumptions) in the appendix document

Source # 1: Biomass from dedicated land use

Topics		Key questions addressed
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Use of biomass is a complex and controversial topic

1 Biomass from dedicated land use

Science Advances

RESEARCH ARTICLE | BIOENERGY

Forests: Carbon sequestration, biomass energy, or both?

Alice Favero[1], Adam Daigneault[2,*] and Brent Sohngen[3]

+ See all authors and affiliations

Science Advances 25 Mar 2020:

ENVIRONMENT

Ecological land grab: food vs fuel vs forests

Marlowe Hood 6 Aug 2019

THE WALL STREET JOURNAL.

MARKETS | HEARD ON THE STREET

Biomass Mess Shows Trouble with Sustainable Investing

Biofuels are increasingly seen as less green than they claim, highlighting key challenge for environmental investment strategies

By Jon Sindreu

March 7, 2019 6:24 am ET

中外对话 chinadialogue 中国与世界，环境危机大家谈 china and the world discuss the environment

As palm oil for biofuel rises in Southeast Asia, tropical ecosystems shrink

Nithin Coca

中文版本 0 comments

15.04.2020

Indonesia and Malaysia are looking to shore up demand domestically and in China, with the EU having changed course away from biofuels

SCIENTIFIC AMERICAN

ENVIRONMENT

Congress Says Biomass Is Carbon-Neutral, but Scientists Disagree

Using wood as fuel source could actually increase CO_2 emissions

By Chelsea Harvey, Niina Heikkinen, E&E News on March 23, 2018

Science

POLICY FORUM | ENERGY

Beneficial Biofuels—The Food, Energy, and Environment Trilemma

David Tilman[1,*], Robert Socolow[2], Jonathan A. Foley[3], Jason Hill[3], Eric Larson[4], Lee Lynd[5], Stephen Pacala[6], John Reilly[7], Tim Searchinger[8], Chris Somerville[9], Robert Williams[4]

Biomass supply from dedicated land is constrained by competing primary land uses and alternative climate mitigation options

1 Biomass from dedicated land use

A Primary uses of land

Land available to dedicate to climate mitigation purposes after trade-offs between primary uses of land considered

- **Human habitation**
- **Food production**
- **Land & habitat conservation**
- **Climate mitigation**

B Climate mitigation options

Land available for biomass production after trade-offs between climate mitigation options considered

- **Renewable energy (esp. solar)**
- **Carbon sequestration (e.g. reforestation)**
- **Dedicated biomass production**

Potential biomass from dedicated land

Factors that affect availability of land for climate mitigation:

- (−) **Population growth**
- (+) **Dietary shifts** towards plant-based diets
- (+) **Productivity and yield improvements** (e.g. precision genetic engineering)
- (+) **Food waste reduction**
- (−) **Land conservation** to preserve pristine forests and other habitats

Factors that affecting use of land for biomass production:

- (/) **Carbon trade-offs**, incl. with alternative land uses
- (−) **Biodiversity protection**
- (/) **Solar to final energy conversion efficiency**

Legend
- (+) Positive impact
- (−) Negative impact
- (/) Impact situation dependant

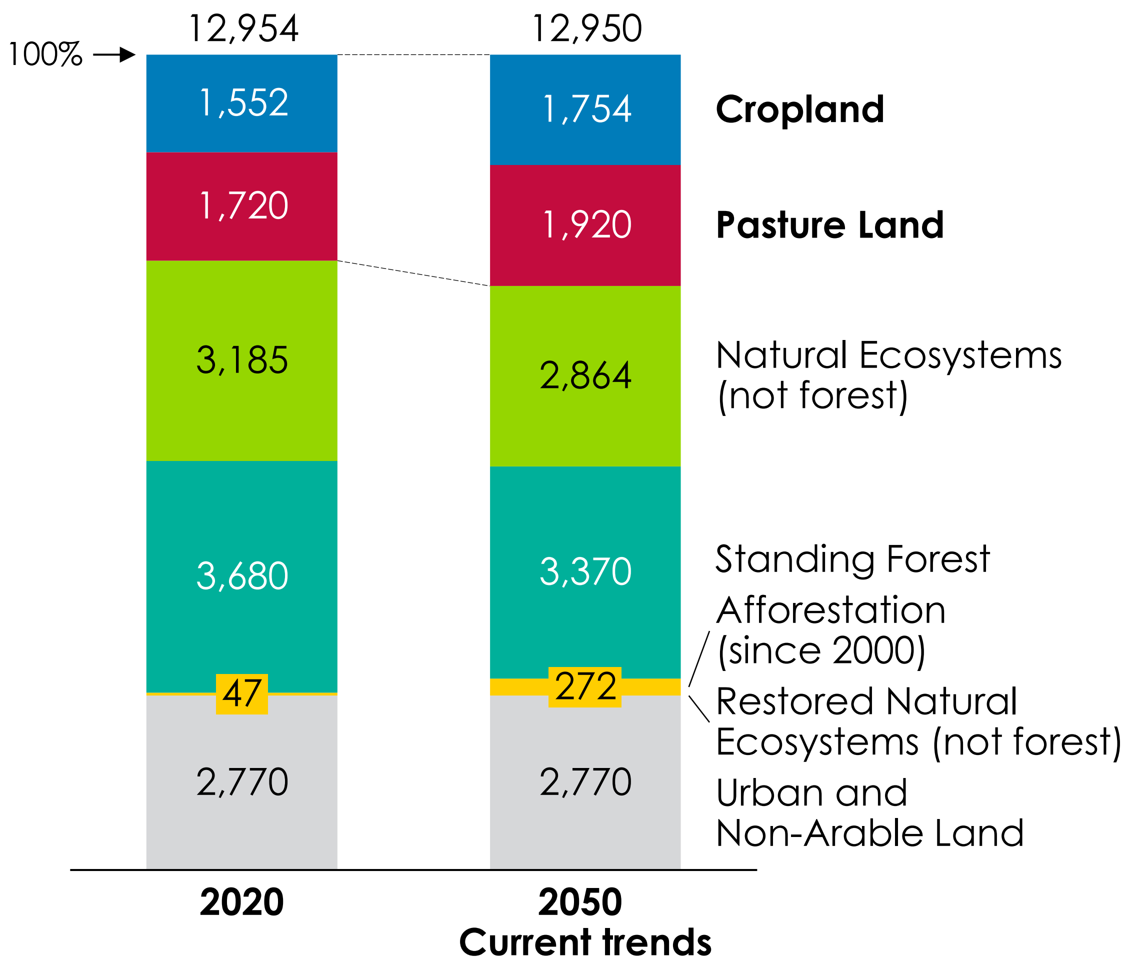
Population growth: Under current trends, demand for agricultural land will grow to provide food for a booming global population

1 Biomass from dedicated land use

A Primary uses of land

- **Population growth** will drive demand for food
- **Feeding >9 billion people** by mid-century will put huge pressures on land for agriculture (both cropland and pasture)
- The Food and Land Use (FOLU) Coalition predicts **400 million hectares of additional agricultural land will be needed by 2050** under current trends (an area twice the size of Mexico)
- This will come at the expense of forested and other natural lands

Global land by use (million hectares)



Note: according to IIASA estimates, parts of the permanent pastures are pastures without significant contribution to total livestock production and thus, as included in the classification "Natural Ecosystem Land". The "Pasture" land use classification includes only grassland utilised for agricultural production.
Baseline data forecast from 2000.
Source: IIASA GLOBIOM 2019. Food and Land Use Coalition (2019), *Growing Better: 10 critical transitions to transform food and land use.*

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Trends in food: Freeing up of agricultural land depends on successfully making major changes in global food production and consumption

1 Biomass from dedicated land use

A Primary uses of land

Food trends modelled in FOLU Better Futures Scenario restores 1.2B hectares of agricultural land to nature by 2050

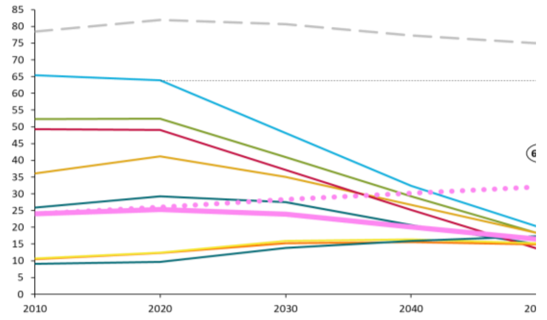
Dietary Shift

A global **convergence** on a **"human and planetary health diet"**.

This includes reduced animal-based protein consumption, e.g. approx.:

- 65% reduction in Europe
- 25% increase in SSA

Domestic livestock protein supply



Productivity Increases

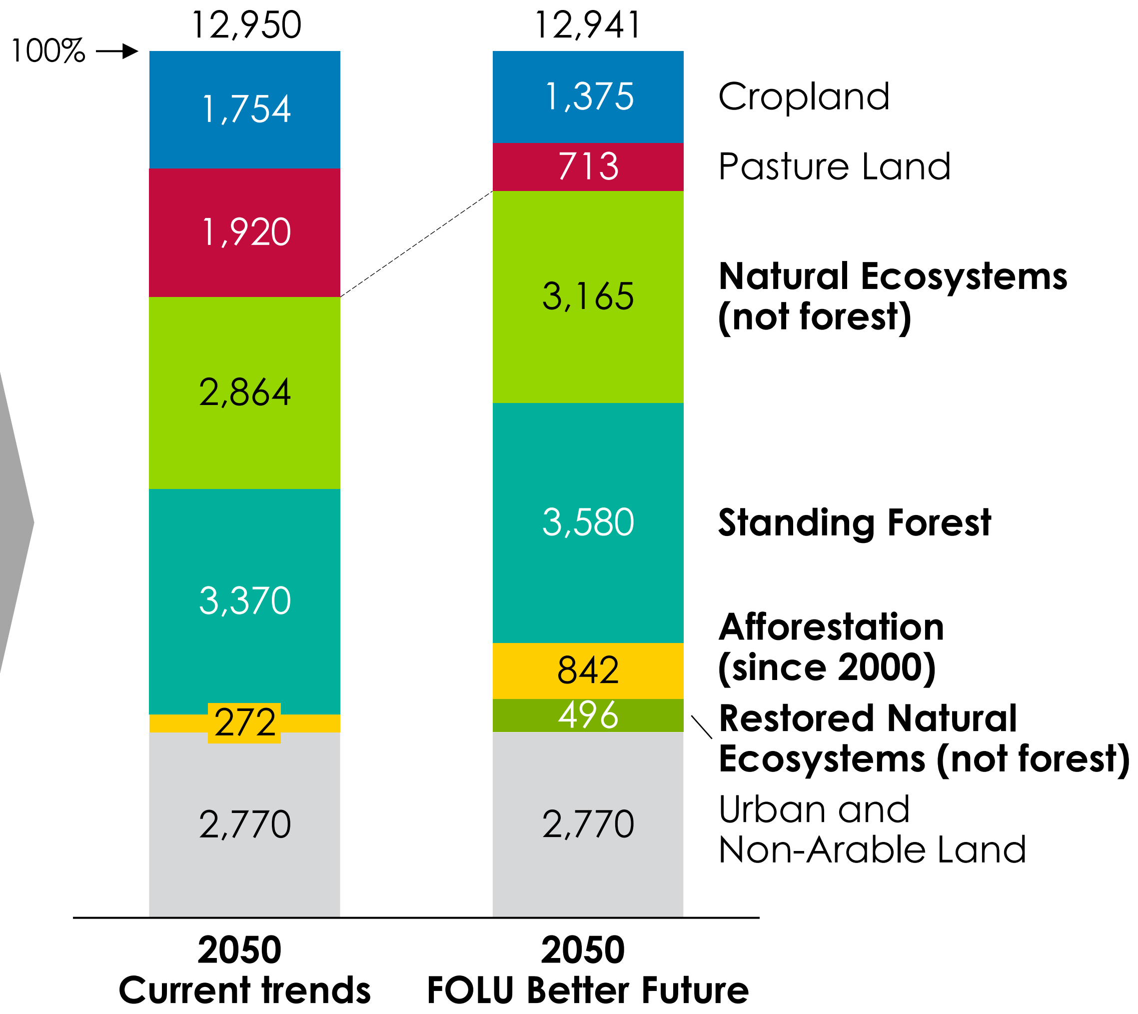
By 2050 **yields are increased an additional 10%** beyond current trajectories due both **technology and regenerative practices**.

Better information sharing between countries helps **close yield gap between poorest & richest regions by 25%.**

Reducing Food Loss and Waste

Reducing food loss and waste results in a **25% decrease in end-use calorie demand.**

Global land by use (million hectares)



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Source: Food and Land Use Coalition (2019), *Growing Better: 10 critical transitions to transform food and land use.* IIASA GLOBIOM 2019; EAT-Lancet 2019

Biodiversity conservation: Protection of biodiversity rich area, natural parks, areas of outstanding natural beauty, etc. prevents use of land for alternative uses

1 Biomass from dedicated land use

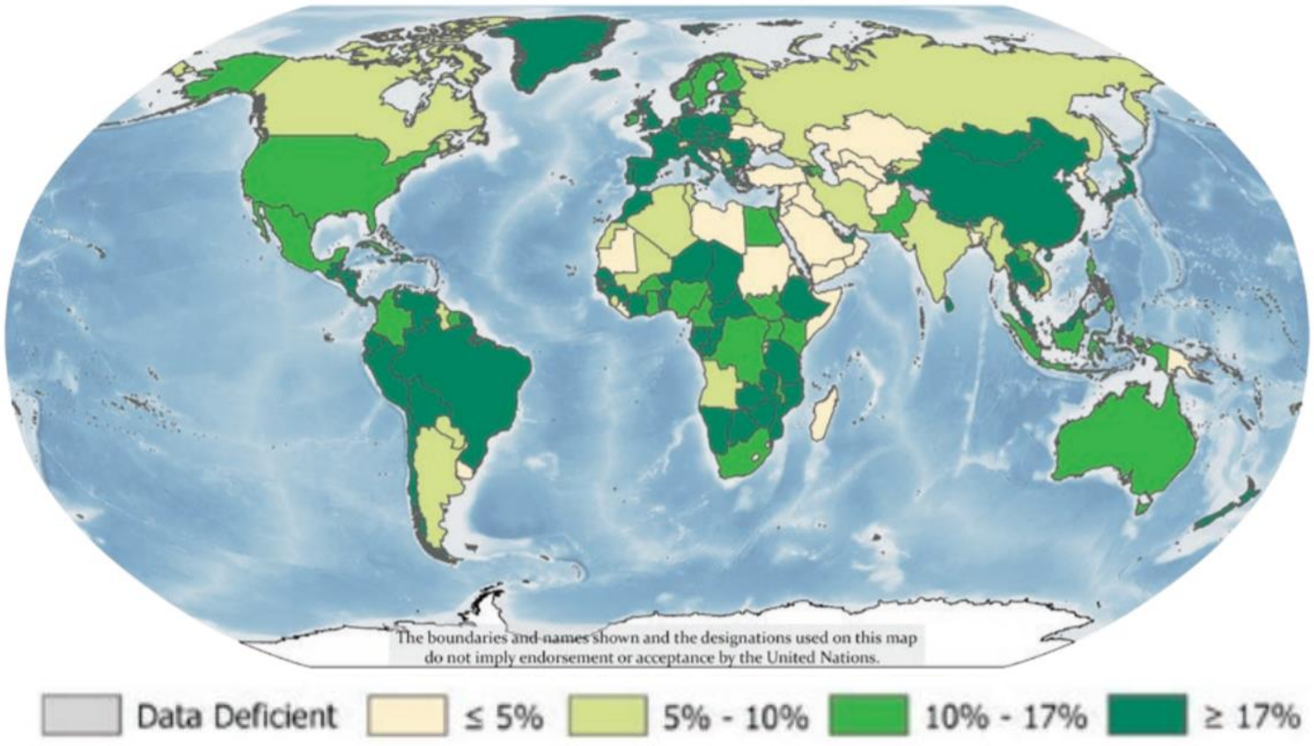
A Primary uses of land

- Interest in **conserving habitats,** such as pristine forests, and protected areas will **reduce land availability** for climate mitigation by dedicated biomass production

- Production of biomass (for all uses) has been associated with >95% of **land-use related biodiversity stress**, attributed primarily to **forestry and logging** (33%) and cattle farming (22%)

- Food and Land Use Coalition modelling included **biodiversity subsidies to incentivise protection and restoration of land** for natural ecosystems

Percentage of the terrestrial and inland waters covered by protected areas



Sources: UNEP Protected Planet Report 2016; Cabernard, L. et al. (2019); A new method for analyzing sustainability performance of global supply chains and its application to material resources. Science of The Total Environment Volume 684, 164-177.
Food and Land Use Coalition (2019), *Growing Better: 10 critical transitions to transform food and land use.* IIASA GLOBIOM 2019; EAT-Lancet 2019

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B Climate mitigation options

Land available for biomass production after trade-offs between climate mitigation options considered

- Renewable energy (esp. solar)
- Carbon sequestration (e.g. reforestation)
- Dedicated biomass production

Factors that affecting use of land for biomass production:

- (/) **Carbon trade-offs**, incl. with alternative land uses
- (−) **Biodiversity protection**
- (/) **Solar to final energy conversion efficiency**

Potential biomass from dedicated land

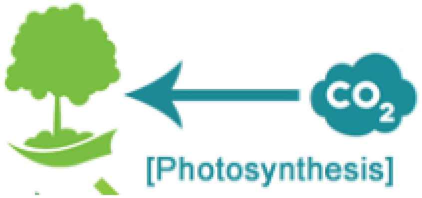
Legend
- (+) Positive impact
- (−) Negative impact
- (/) Impact situation dependant

Carbon trade-offs: For biomass to create a net reduction in GHG emissions, it must sequester more CO_2 than emitted in production & use

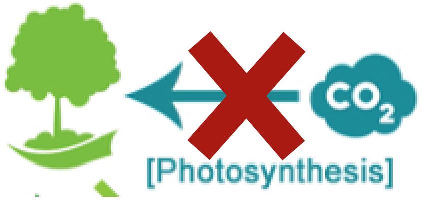
1 Biomass from dedicated land use

B Climate mitigation options

Greenhouse gas accounting must include:



Carbon sequestration during plant growth



Foregone sequestration (the opportunity cost of using the land for energy crops)

Production and transportation emissions (soil, fertilizer, transport, processing, etc.)

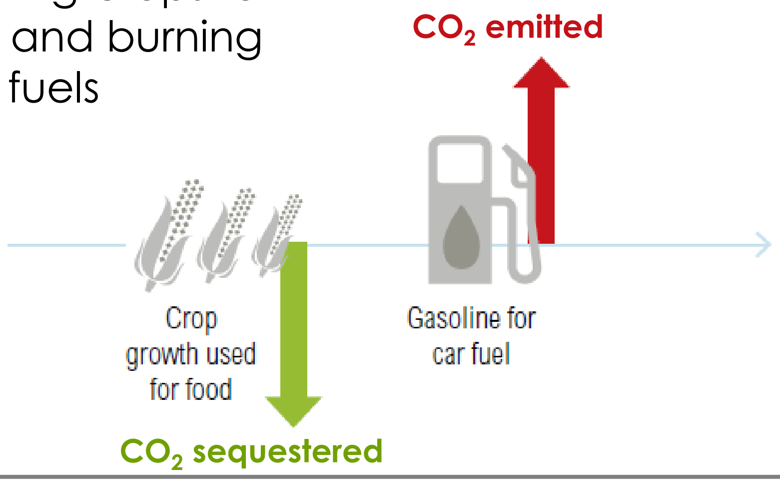
Emissions from use of the bio-resource

For biomass to be low carbon, it must be grown in addition to what would have grown without intervention, or be biomass which would otherwise have been wasted or burned.

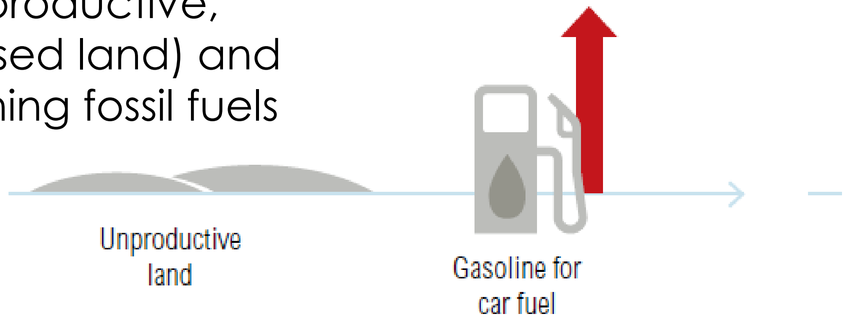
<u>Carbon trade-offs:</u> Biomass needs to be 'additional' to have a carbon benefit – *an illustrative biofuels example*

What would have happened without bio-resources

Growing crops for **food** and burning fossil fuels

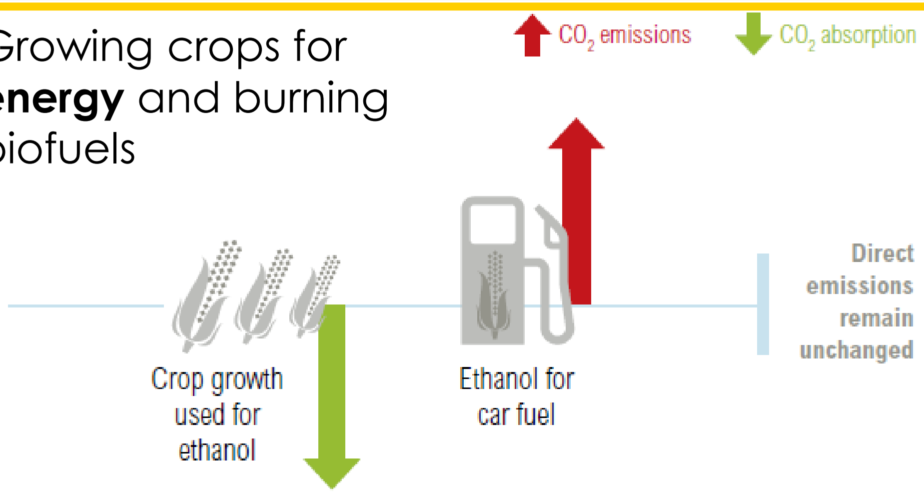


No biomass growth (unproductive, unused land) and burning fossil fuels



Now with use of bio-resources (as bio-ethanol)

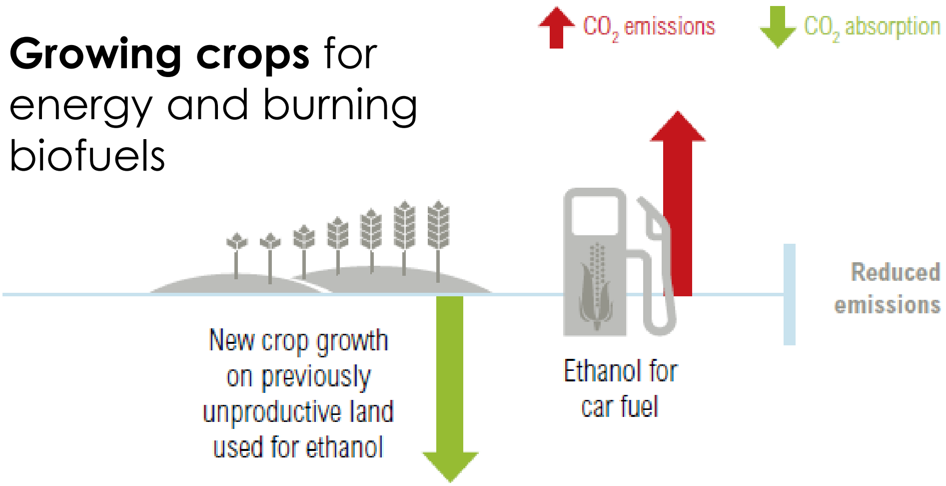
Growing crops for **energy** and burning biofuels



Not low carbon

Biomass is diverted (would have grown anyway) => net GHG **emissions are unchanged**

Growing crops for energy and burning biofuels



Low carbon

Biomass is <u>additional</u> (would not have grown) => net **emissions reduction**

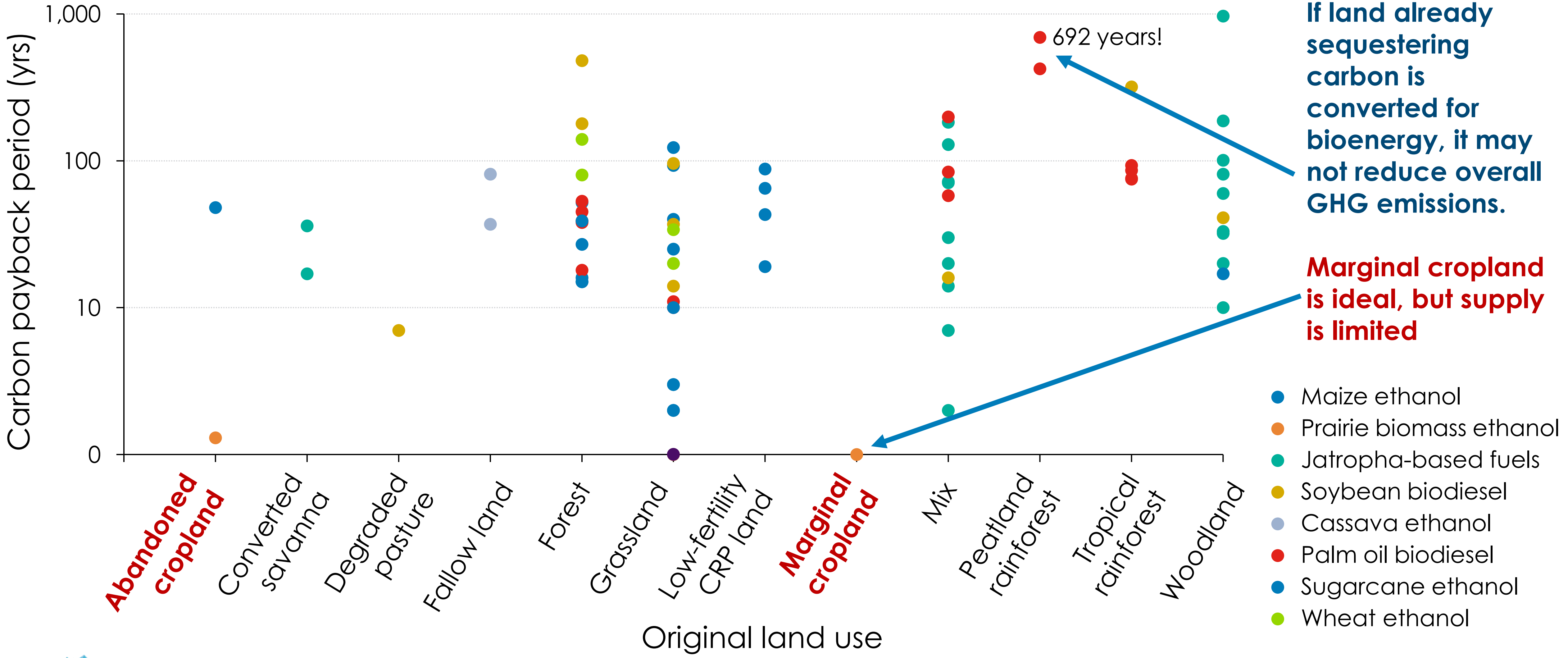
Source; Searchinger, T. and R. Heimlich. (2015) "Avoiding Bioenergy Competition for Food Crops and Land." Working Paper, *World Resources Institute*

Carbon trade-offs: Transformation of land for biofuels can lead to long carbon payback periods due to the opportunity cost of using the land

1 Biomass from dedicated land use

B Climate mitigation options

Biofuels example



If land already sequestering carbon is converted for bioenergy, it may not reduce overall GHG emissions.

Marginal cropland is ideal, but supply is limited

Source: Adapted from Table 1 of Gasparatos A. et al., 2017. Renewable energy and biodiversity: implications for transition to a green economy. Renewable and Sustainable Energy Reviews, 70 (2017), pp. 161-184, 10.1016/j.rser.2016.08.030

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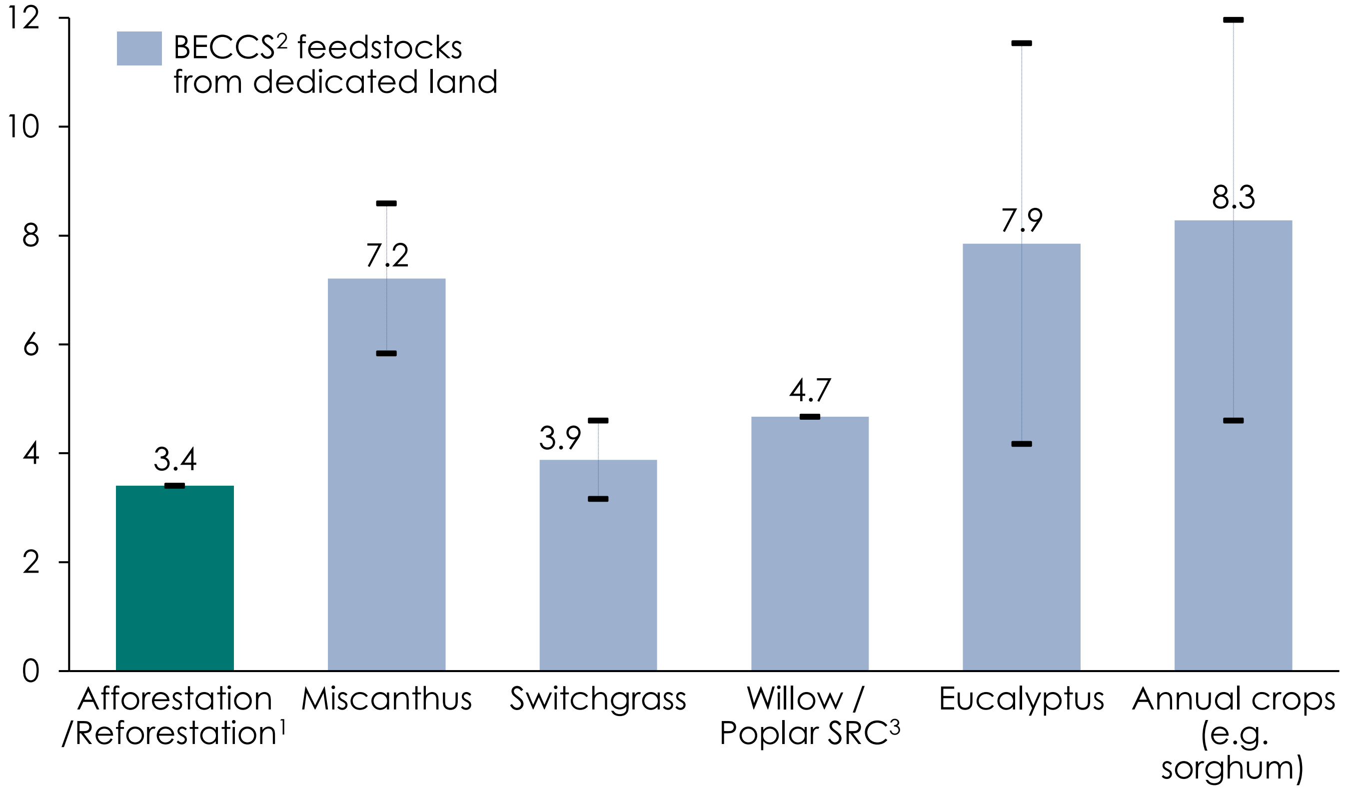
Carbon sequestration: Where marginal land is available for new biomass production, three use options offer varying levels of CO2 sequestration

1 Biomass from dedicated land use

B Climate mitigation options

Fast growing crops can remove more carbon per year than forests

Annual net removals of carbon from the atmosphere per unit area (t Ceq./ha/yr)



But carbon sequestration potential varies between bioenergy, BECCS[2], & forests

Bioenergy:

- CO_2 released rapidly at point of use (unless combined with CCS, as in BECCS[2])

BECCS:

- Sequestration potential renewed over time
- Not all CO_2 released during biomass burning can be captured in CCS process (80-90%)
- Concerns around permanence of geologic storage

Standing forests:

- Proven and low-cost technology for carbon storage
- Carbon capture plateaus at forest maturity
- Forest permanence not guaranteed (e.g. wildfires, land use change)

(1) Afforestation/Reforestation assumes 500 tCO2/ha = 136 tC/ha from forest regrowth over 40 years to maturity (assumes linear uptake), so mean annual accrual rate is 3.4 tC/ha/yr ; (2) BECCS: Bioenergy with carbon capture and storage; (3) SRC: Short rotation coppice

Smith, P. *et al.* (2018) Impacts on terrestrial biodiversity of moving from a 2°C to a 1.5°C target. Phil. Trans. R. Soc. A 376: 20160456

Smith, P. et al. (2016) Biophysical and economic limits to negative CO2 emissions. Nature Climate Change 6, 42–50.

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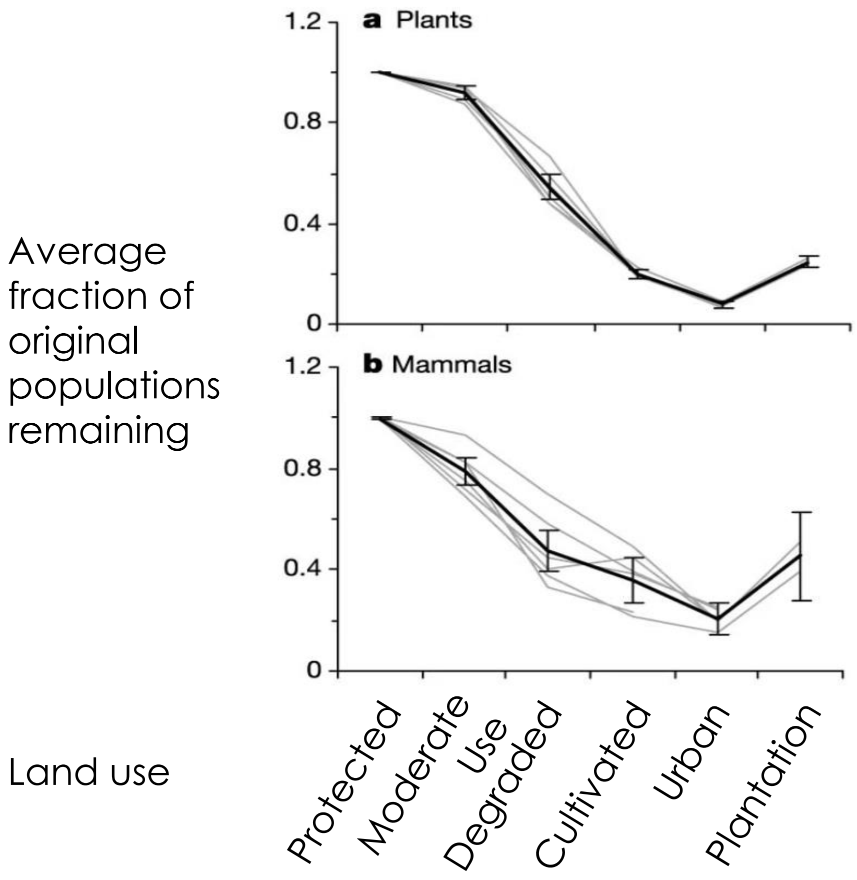
Biodiversity conservation: Long-term carbon sequestration options have very different impacts on biodiversity

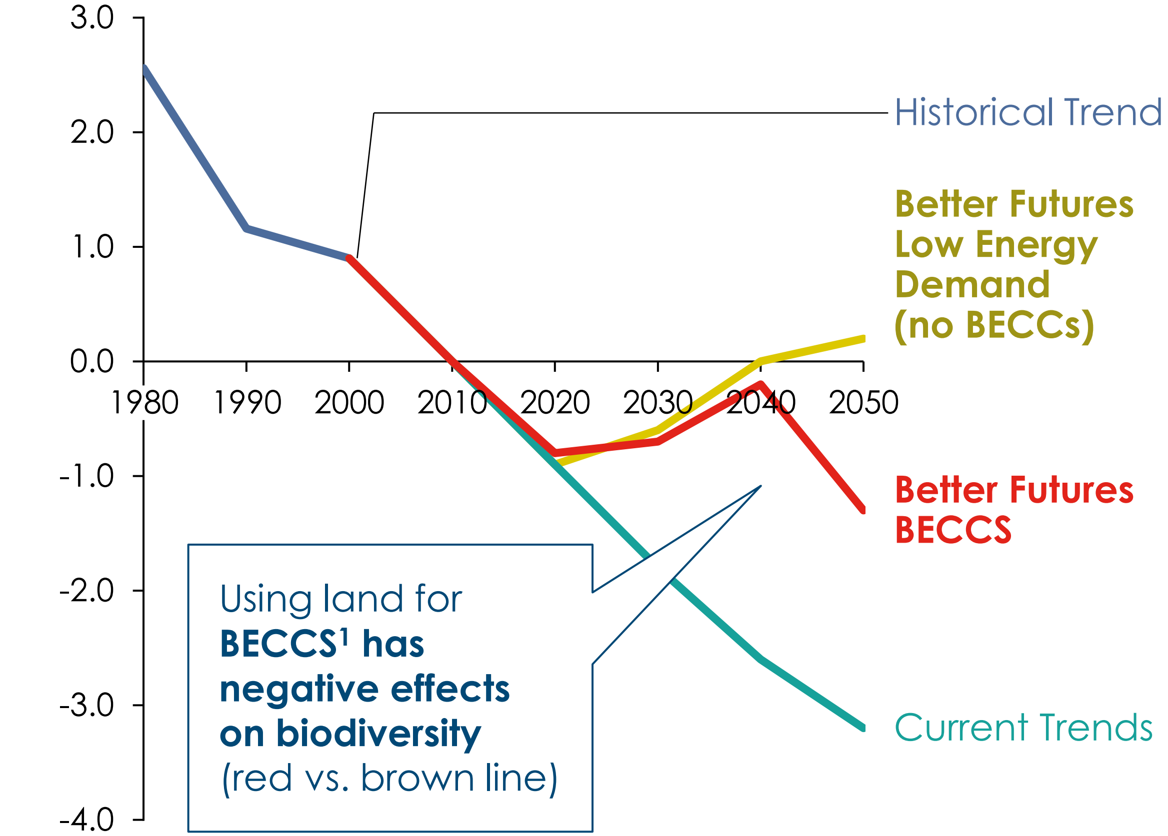
1 Biomass from dedicated land use

B Climate mitigation options

Most biodiversity supported on protected / moderate-use land; cultivation & plantation have negative impact



A large use of BECCS could have significant negative impact on biodiversity



(1) BECCS: Bioenergy with carbon capture and storage

Sources: Food and Land Use Coalition. IIASA GLOBIOM 2019; Leclère et al 2018 for historical reconstruction; Bernes et al. (2015) What is the impact of active management on biodiversity in boreal and temperate forests set aside for conservation or restoration? A systematic map. *Environmental Evidence* 4,25; Scholes, R., Biggs, R. A biodiversity intactness index. *Nature* 434, 45–49 (2005).

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Energy conversion efficiency: Solar power is most efficient use of scarce land available, but biomass production offers alternative forms of energy

1 Biomass from dedicated land use

B Climate mitigation options

	Final energy form	Commentary
PV array	Electricity	**PV more efficient than photosynthesis at harvesting sunlight energy[1] :** • PV ≥15% efficient commercially • Photosynthesis in crop plants ≤1% overall, up to 4.3% during rapid growth[2] • Photosynthesis of microalgae in bioreactors: ~3%, up to ~7% during growth
BECCs Example: Incineration of wood pellets	Dispatchable electricity	• Ability to store and dispatch biomass means it can provide balancing and flexibility for the power system • However, one solution among multiple technological options – to be evaluated as part of biomass use-cases assessment
2nd generation biofuel Example: miscanthus feedstock converted via Fischer-Tropsch	Liquid energy-dense fuel	For certain energy use-cases (e.g. aviation) electrification is not feasible and an energy-dense, storable chemical is required **Currently more cost-effective to transform biomass to biofuels than solar energy to synthetic liquid fuels** (i.e. via production of hydrogen via electrolysis powered by PV) • ~€3,000/tonne to produce synthetic jet fuel in near term • €1,500-2,000/tonne to produce bio-kerosene using residual biomass from forestry and agriculture
Synfuels Example: synfuel synthesised using H2 from electrolysis powered by PV	Liquid energy-dense fuel	

(1) Energy efficiency of photosynthesis defined as energy content of biomass that can be harvested divided by solar irradiance over the area; theoretical maximum efficiency of ~12%

(2) During the growing season, C3 and C4 plants can reach 3.5% and 4.3% efficiency, respectively

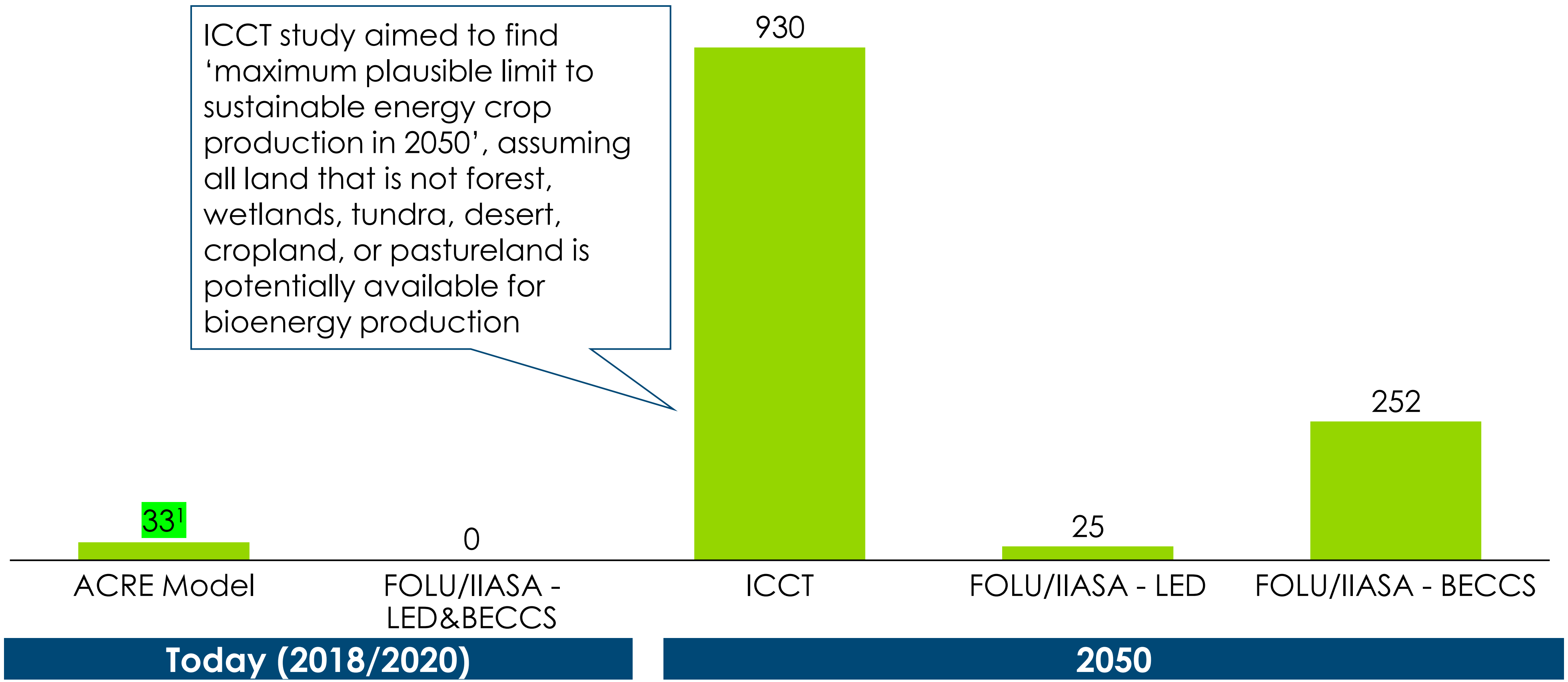
Sources: Blankenship RE, et al. (2011) Comparing photosynthetic and photovoltaic efficiencies and recognizing the potential for improvement. *Science* 332(6031):805–809; Press search; De Jong et al (2018) Green Horizons

Comparison of sustainability studies: Key assumptions
Dedicated Land Area for Production of Biomass for Energy

1 Biomass from dedicated land use

B Climate mitigation options

Dedicated Land Area for Production of Biomass for Energy
Millions Ha. (Non-Food Crops)



Inferred from information provided

Cover and winter crops: Note, not covered in detail in the sustainability studies reviewed – Evidence currently limited on potential future supply, but likely to be limited as only applicable in Northern latitudes with winter season. Currently, major hurdles are that it is not economically attractive option for farmers and it is difficult to trace providence to ensure additionality.

Note: Energy crop yield figures relate to miscanthus on degraded land for ACRE model and ICCT estimates, and miscanthus/SRC (poplar, eucalyptus) for ICCT estimates; (1) Calculated as 10% of India's surface area; (2) FOLU Crop yield is an approximate global estimate for Short Rotation Coppice, or Miscanthus; data provided by Deppermann, IIASA.

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Sustainable, low carbon supply subtotal: Biomass from dedicated land

1 Biomass from dedicated land use

- Inferred from provided information
- Basis of 'reasonable estimate' range

		Global today				Global 2050						Global 2050
		ACRE Satellite Model (Min.)	ACRE Satellite Model (Max.)	FOLU LED & BECCS Scenarios	Others (*see sections*)	FOLU LED Scenario	FOLU BECCS Scenario	*IIASA EU waste & residue scaled*	ICCT	*ICCT: EU waste & residue scaled*	Others (*see sections*)	**Reasonable estimate**
Biomass from dedicated land	**Food Crops**	0	0	3		5[1]	5[1]	-		-		*Low to zero*
	Non-Food Crops	1	8	0		5	56	-	75	-		~5-10
	Subtotal	1	8	3		10	61	-	75	-		**~5-10**

The sustainable biomass supply **values** we have used here are **on the lower end** in order to **avoid competition with food** and **safeguard biodiversity**.

(1) 1st generation energy supply included to account for current targets, but its contribution is assumed to be small and remain negligible going forward

Source # 2: Biomass from waste and residual sources

Topics		Key questions addressed
1. Biomass from dedicated land use	Land for climate mitigation	▪ How much **land can be dedicated to climate mitigation** among other land uses (food production, habitation, biodiversity conservation)?
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What criteria must be considered when determining low-carbon, sustainable biomass from forest residues?

Types of forests used to source wood (e.g., **protected lands excluded** to safeguard biodiversity)

Residues considered eligible
(e.g., only from new growth)

Amount of residues that should be left on the land (e.g., for soil health)

Lack of availability due to **competing demand** or **uneconomic collection**

Deep dive on following slides

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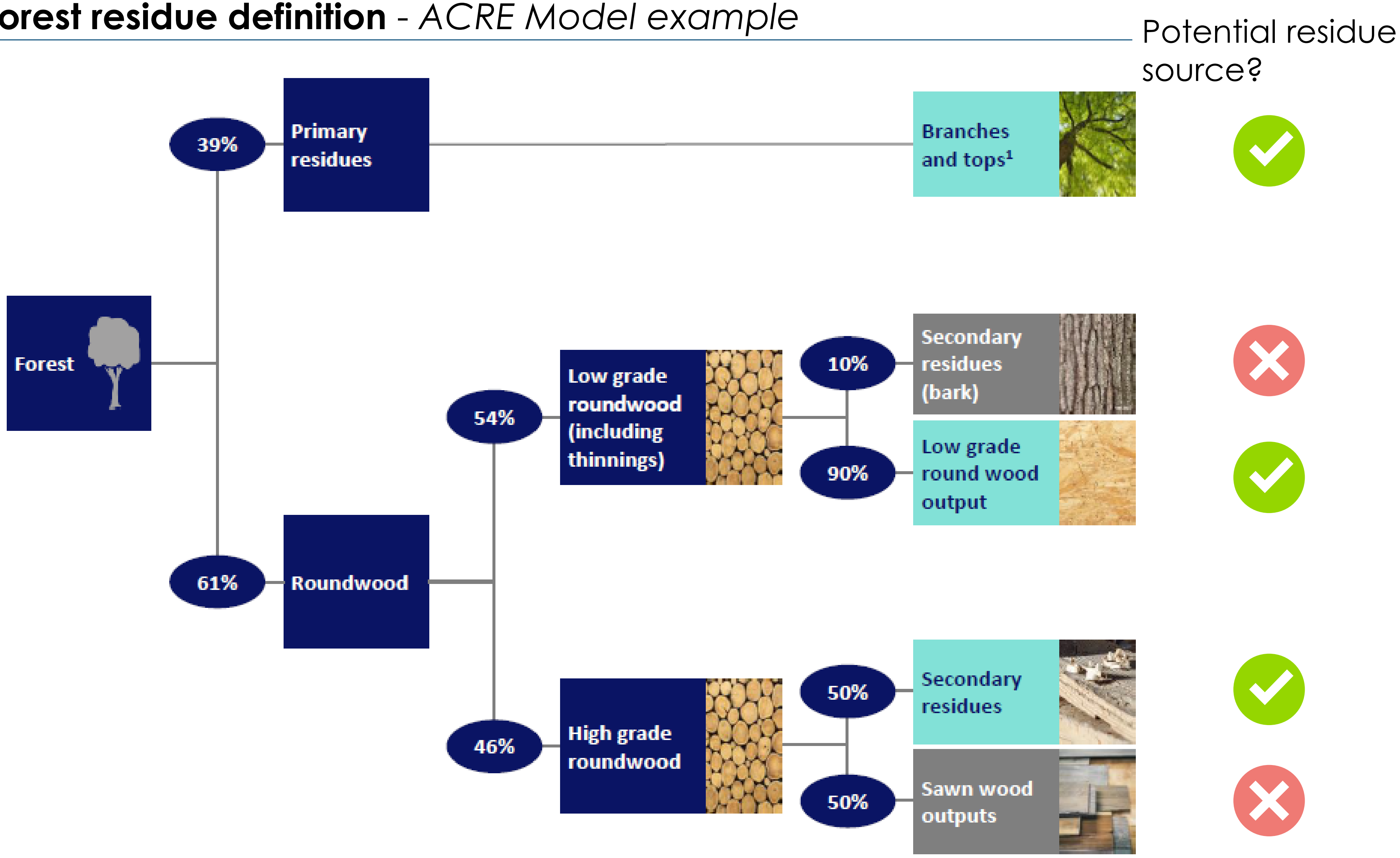
Note: more details in appendix

Which residues are eligible for sustainable use?

2 Biomass from waste and residues
A Forest residues

Determination of scope of residues from forests considered eligible as a source of sustainable biomass, including at different points along the value chain (e.g. logging residues, black liquor, industrial by-products or recycled wood).

Forest residue definition - *ACRE Model example*



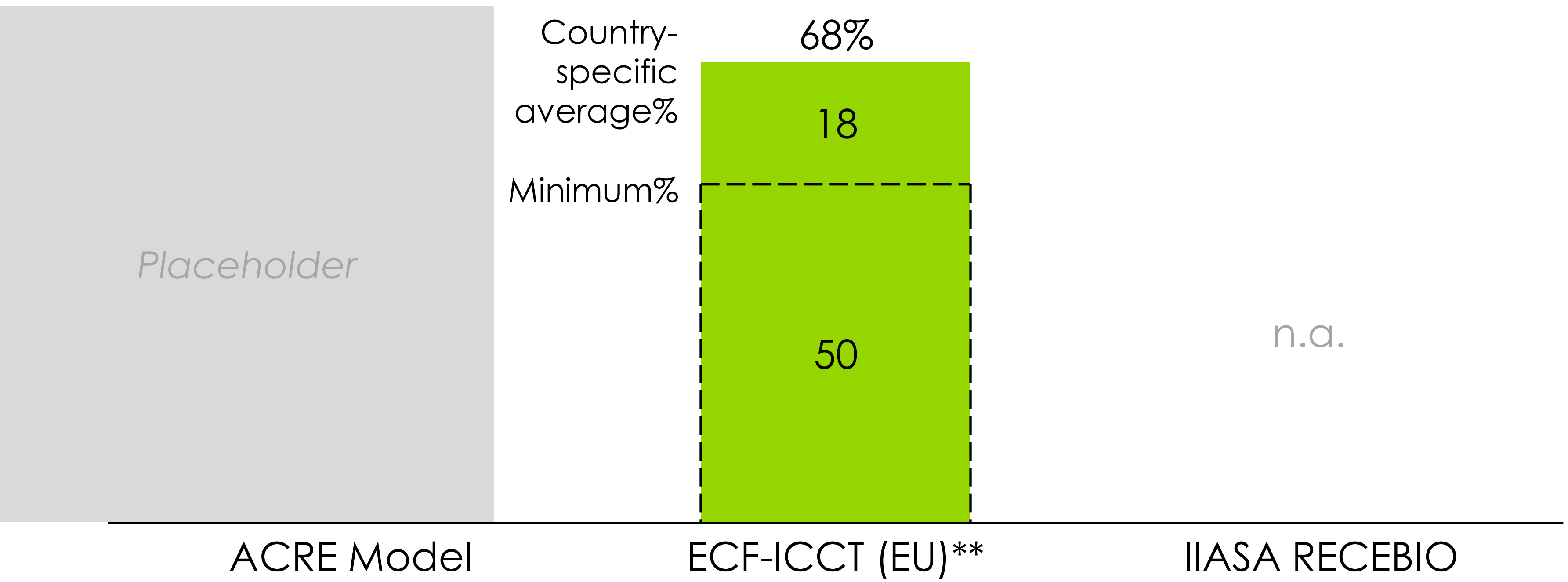
Note: * ACRE model estimates depend on the scenario (low vs. high GAI) and relate only to pixels considered suitable for residue collection..

How much residual biomass can be taken without compromising soil and forest health?

Safeguarding proportion of biomass residues assumed necessary to retain for soil health and forest health:

- soil organic carbon levels, topsoil depth
- exclusion of steep areas due to soil erosion risks
- Species of forest

Biomass Left on Soil to Maintain Soil Health
% Total Available (Residue) Biomass



Considers only new forest growth – % of residues retained for soil health & erosion from available residues

Considers total forestry / logging residues

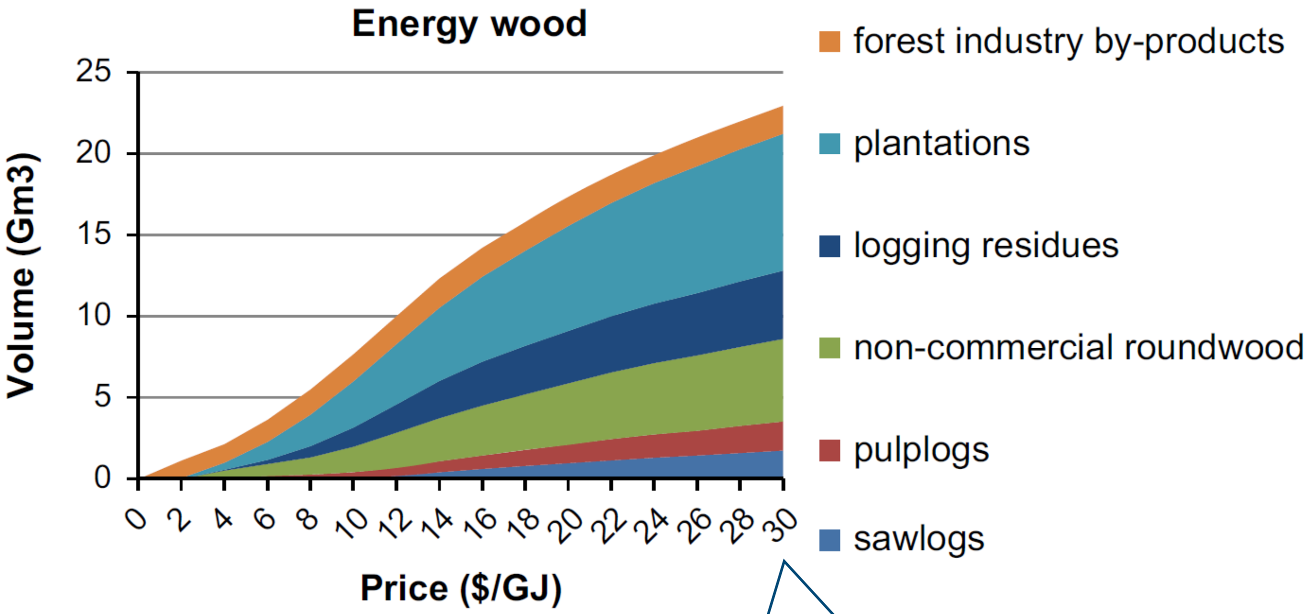
Soil health considerations applied per area unit mapped, rather than in aggregate – including soil organic carbon, topsoil depth, erosion risk, species of forest)

Note: * ACRE model estimates depend on the scenario (low vs. high GAI) and relate only to pixels considered suitable for residue collection..

How does collection economics and traditional demand from competing uses impact forest residue availability?

- **Economics of collection and processing** of residue sources improve as biomass prices increase, allowing access to additional volumes (e.g. larger collection radii)
- Studies reviewed took a range of assumptions and methodologies, e.g.
    - GLOBIOM: **Market price modelling** taking into account food, biomass and carbon prices to adjust allocation of land for food and bioenergy
    - ACRE: **25-30% of residues excluded** for uneconomic collection or competing uses, including fuelwood
- **Many existing alternative uses** of forest residues (including for heat and power), where possible assumptions concerning use-case prioritisation unwound, except for certain traditional uses (e.g. collection of firewood not included in estimates)

Impact of energy wood prices on global woody biomass supply in 2050



At $30/GJ, as much as 165EJ of forest residues would be mobilised each year

Source: IIASA; P. Lauri et al. / Energy Policy 66 (2014) 19–31

Illustrative example:
Stepped consideration of sustainability filters can rule out majority of biomass supply

Steps to achieve an estimate of sustainable woody biomass available

Start with the energy in all forests, then focus only on growth each year

Take this new growth and…

…exclude high grade round wood for timber products, consider only residues

…exclude areas designated as intact forest landscapes

...exclude peatlands

…exclude areas of high relative biodiversity

…exclude wetlands

…exclude protected lands

…exclude world database of key biodiversity areas

…leave 1000t per km of primary residues on the ground to maintain soil health

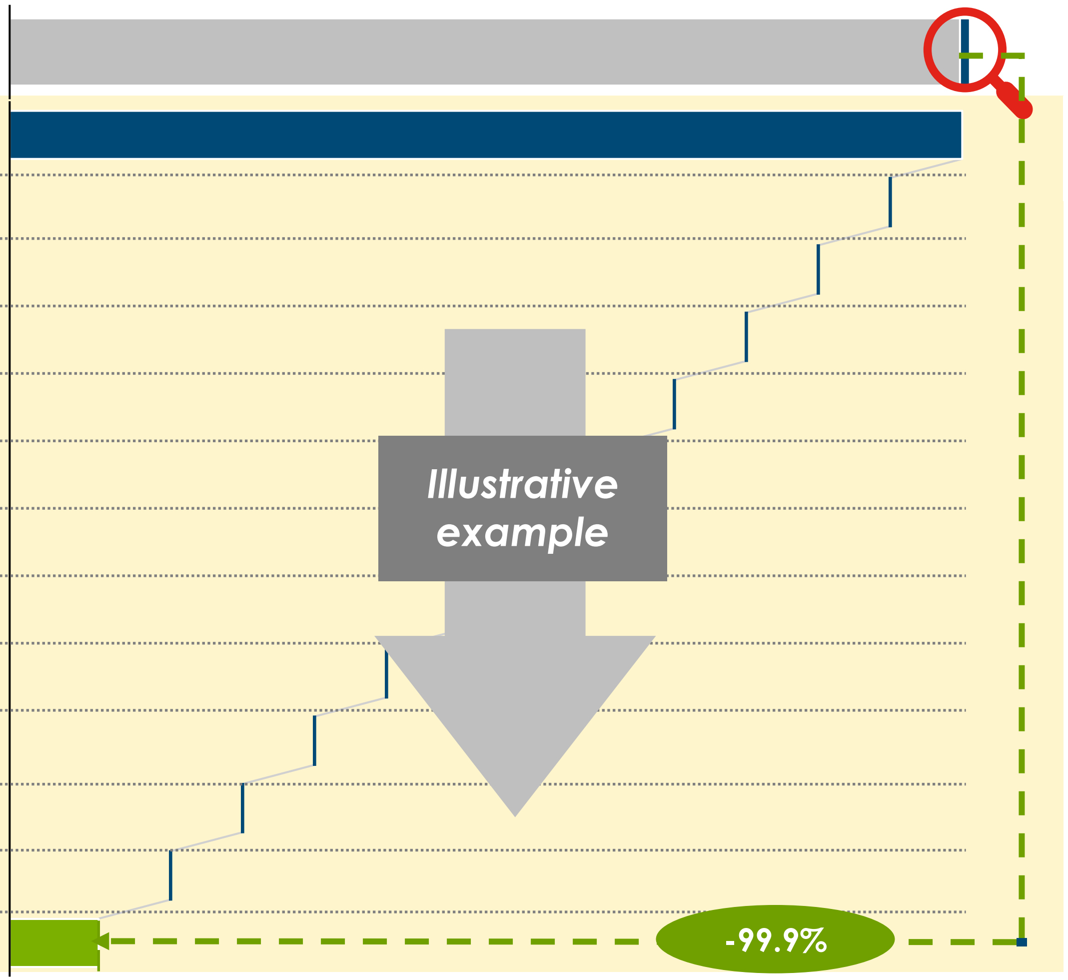
…exclude areas with a gradient higher than 25%

…of this, remove portions that are uneconomic to take or have competing uses

…exclude certain countries for reasons of corruption or slavery

…and you arrive at the sustainable woody biomass potential

Biomass energy at each step, EJ



Adapted from member presentation

Sustainable, low carbon supply subtotal: Forest residues

2 Biomass from waste and residues

Inferred from provided information

Basis of 'reasonable estimate' range

		Global today				Global 2050						Global 2050
		ACRE Satellite Model (Min.)	ACRE Satellite Model (Max.)	FOLU LED & BECCS Scenarios	Others (see sections)	FOLU LED Scenario	FOLU BECCS Scenario	IIASA EU waste & residue scaled	ICCT	ICCT: EU waste & residue scaled	Others (see sections)	Reasonable estimate
Biomass from dedicated land	Food Crops	0	0	3		5[1]	5[1]	-		-		Low to zero
	Non-Food Crops	1	8	0		5	56	-	75	-		~5-10
	Subtotal	1	8	3		10	61	-	75	-		~5-10
Biomass from waste and residues	Forest Residues	6	14.5	23		22	54	1.7-6.9	3	2.3		~10-20

Note: Traditional fuel wood and biomass for timber, pulp and paper sectors excluded (volumes equivalent to ~20EJ); (1) 1st generation energy supply included to account for current targets, but its contribution is assumed to be small and remain negligible going forward

What criteria must be considered when determining low-carbon, sustainable biomass from agricultural residues?

Amount of agricultural land from which residues can be sourced

Types of crops grown on land and the **expected residuals** from harvesting and processing

Amount of residues that should be left on the land (e.g., for soil health)

Lack of availability due to **competing demand** or **uneconomic collection**

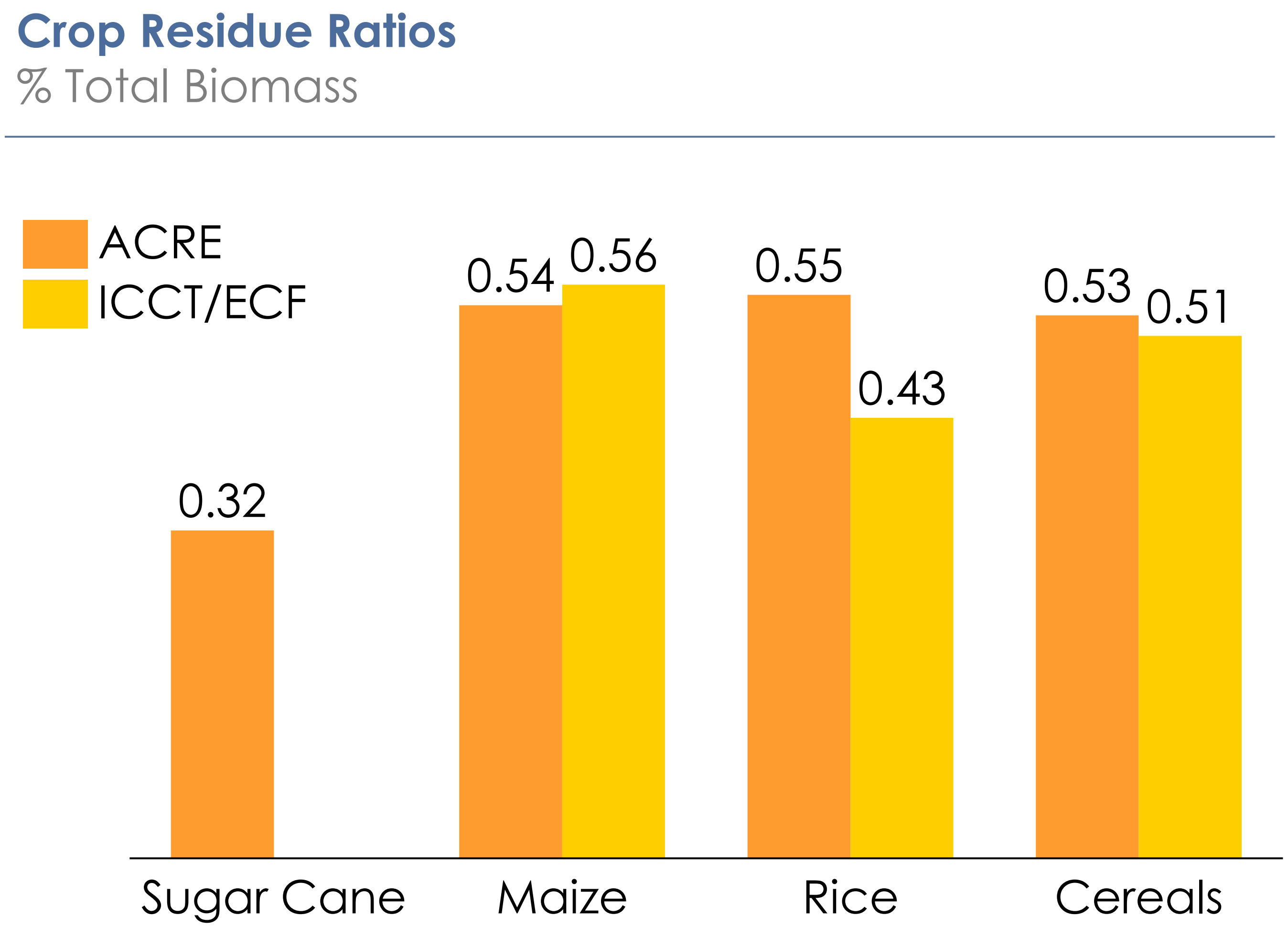
Deep dive on following slides

Note: more details in appendix

What crops will be grown and how much biomass will be left after harvesting and processing?

After assessing the **agricultural land area**:

Determination of range of **crop types** expected to be grown on agricultural land, **which residues** will be included (e.g., primary vs secondary/processing residues) and expected **ratios of biomass leftover as residues**



Note: Only displaying top 5 crops – cereals include both Wheat and Barley.

How much residual biomass can be taken without compromising soil health?

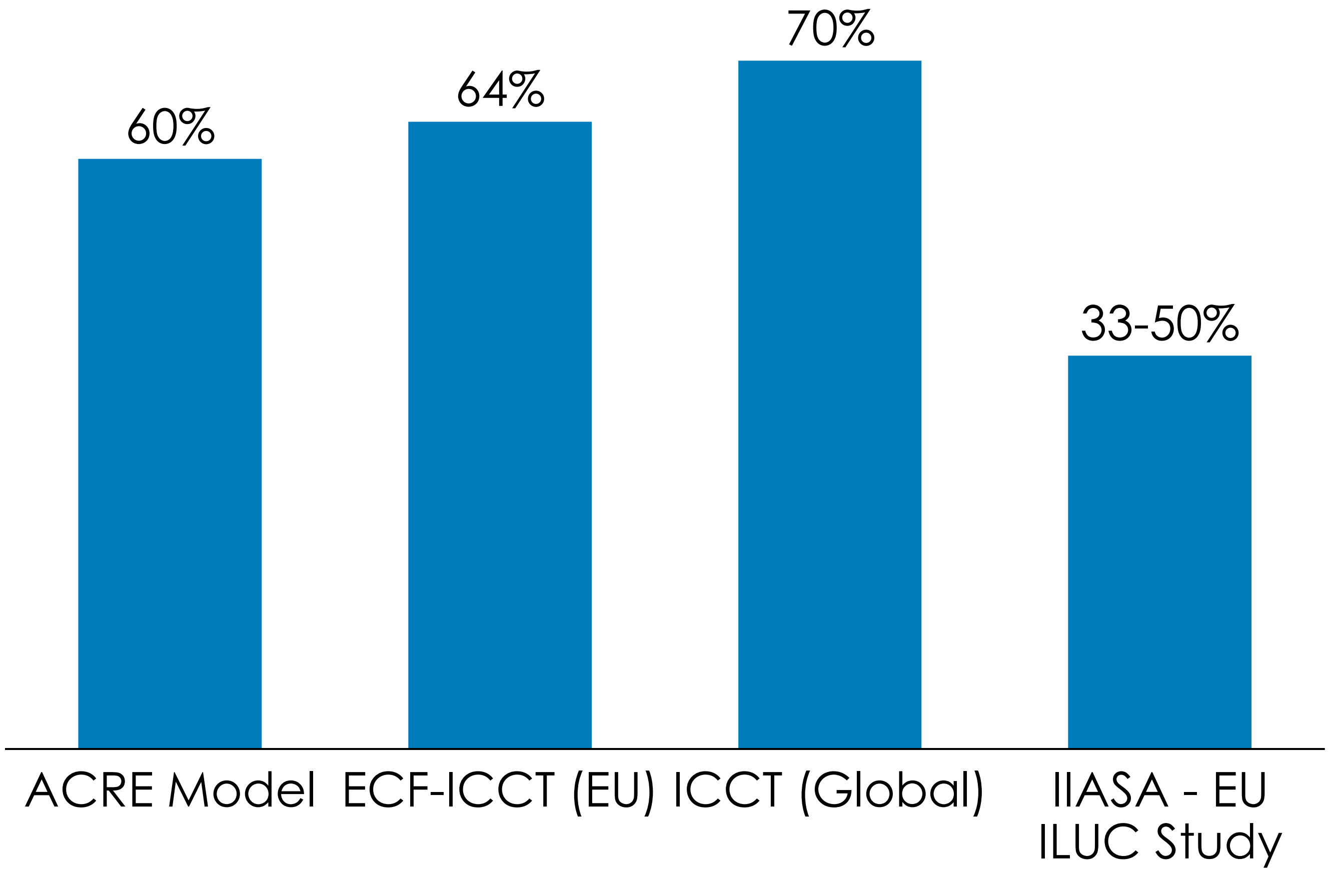
2 Biomass from waste and residues

B Agricultural residues

Safeguarding proportion of biomass residues assumed necessary to retain **for soil health**, including soil organic carbon, and to **prevent other nutrient loss and soil erosion**.

Biomass Left on Soil to Maintain Soil Health

% Total Available Biomass



Note: Assume yield of 5.8 tons/ha for ECF figures.
Note: Biomass assumed removed is considered baseline assumption depending the region

Sustainable, low carbon supply subtotal: Agricultural residues

2 Biomass from waste and residues

- Inferred from provided information
- Basis of 'reasonable estimate' range

		Global today				Global 2050						Global 2050
		ACRE Satellite Model (Min.)	ACRE Satellite Model (Max.)	FOLU LED & BECCS Scenarios	Others (see sections)	FOLU LED Scenario	FOLU BECCS Scenario	IIASA EU waste & residue scaled	ICCT	ICCT: EU waste & residue scaled	Others (see sections)	Reasonable estimate
Biomass from dedicated land	Food Crops	0	0	3		5[1]	5[1]	-		-		Low to zero
	Non-Food Crops	1	8	0		5	56	-	75	-		~5-10
	Subtotal	1	8	3		10	61	-	75	-		~5-10
Biomass from waste and residues	Forest Residues	6	14.5	23		22	54	1.7-6.9	3	2.3		~10-20
	Agricultural Residues	4	21.5	0		0	0	5.1-12.4	5	11.3		~5-12

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Note: Traditional fuel wood and biomass for timber, pulp and paper sectors excluded (volumes equivalent to ~20EJ); (1) 1st generation energy supply included to account for current targets, but its contribution is assumed to be small and remain negligible going forward

What criteria must be considered when determining low-carbon, sustainable biomass from <u>municipal & industrial waste (MISW)</u>?

Waste should be minimised through efficient material use and material recovery (e.g., by developing a **circular economy**)

Residual waste (i.e., after recycling and composting) **contains non-renewable materials** (i.e., large proportion of plastics) – *although could improve in time*

Use of residual waste raises **greenhouse gas concerns** (e.g., emissions from waste incineration and landfills)

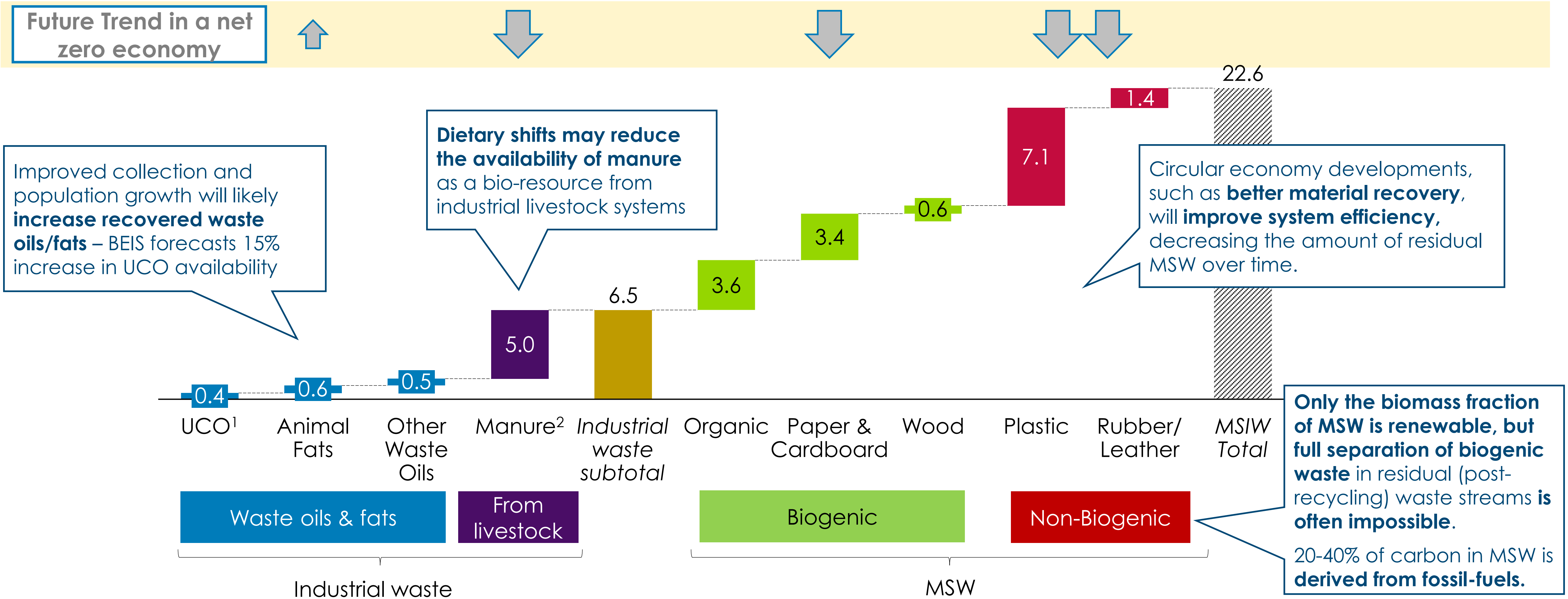
Deep dive on following slides

Note: more details in appendix

At current recovery rates, MSIW streams contain ~23 EJ potential energy, but in a net-zero economy we would expect a significant reduction

Current potential enegy from residual MSW (after recycling and composting)

EJ/yr.



Note: Removes proportion of MSW that is recycled or composted, using regional weighted average of 17% total MSW. (1) UCO – used cooking oils. (2) Global potentials for biomass energy is about 5EJ/year from intensive livestock systems. Source: ETC, IEA, World Bank (2018), CST Analysis (2020), Kalt et al. (2020) Greenhouse gas implications of mobilizing agricultural biomass for energy: a reassessment of global potentials in 2050 under different food system pathways. Environ. Res. Lett. 15 034066

Residual MISW waste streams contain both organic and non-organic materials, with separation process technically difficult and costly

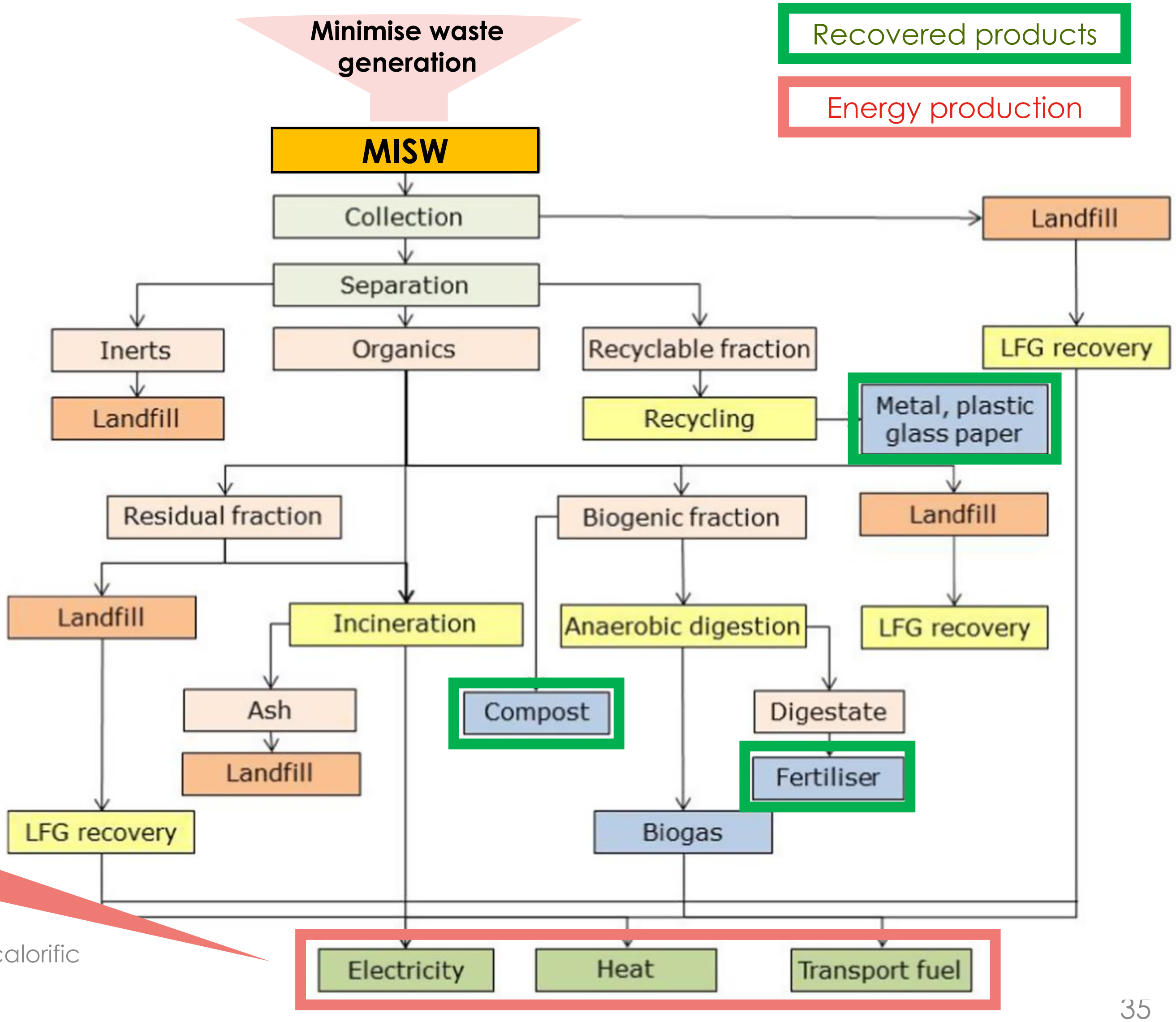
2 Biomass from waste and residues

C Municipal & Industrial waste

- Once products enter the waste stream, **separation technically difficult and costly**
- Currently using **MISW for energy as last resort** if recycling / separation is economically infeasible or environmentally unsound
- Given separation challenges **waste stream contains non-renewable materials (i.e., large proportion of plastics)** therefore not a low carbon source of energy
- Policies should aim to limit waste creation and encourage maximum material recovery via **improvements to collection and separation processes –** this would improve stream purity allowing allow organic waste to be made into low carbon bio-energy

We should aim to **maximise circular economy** practices and **minimise waste for energy**

Current waste separation process



Note: LFG – landfill gas; Typically, a tonne of MSW has about 1/3rd of the calorific value of coal (8-12 MJ/kg) and can yield approx. 600 kWh of electricity
Source: IEA, Scarlat et al. (2015).

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Currently three options for use of residual MISW; liquid fuel production likely to be most sustainable route for long-term development

2 Biomass from waste and residues

C Municipal & Industrial waste

Residual waste streams (post-recycling) typically contain a 20-40% non-biogenic (i.e. plastic, rubber) component that is currently economically and/or technically infeasible to separate out

1 **Landfilling**	• Decomposing organic material in landfills produces **landfill gas (LFG)**, composed of approximately equal proportions of **CO_2 and methane** • In the US, MSW landfills accounted for 15% of total methane emissions in 2018 • **Landfilling is progressively being phased out** via policy in many regions, e.g. UK landfill gate fee, Scotland 2022 landfill ban.
2 **Electricity Generation**	• Producing electricity from MISW has high LCA GHG emissions – typically higher than the grid average in EU countries • **Energy from waste offers considerably worse GHG emissions profiles than renewable electricity generation**
3 **Liquid Fuel Production**	• Not net-zero due to residual plastic content of mixed waste streams, but offers **carbon savings vs. use of other liquid fuels** – e.g. kerosene • **Initial volumes required to scale technology** and attain learning curve effects • As recycling technology improves, **capacity will be established to maximise biogenic MISW for fully renewable liquid fuels**

Source: EPA, E4Tech.

Sustainable, low carbon supply subtotal: Municipal & Industrial Waste

2 Biomass from waste and residues

- Inferred from provided information
- Basis of 'reasonable estimate' range

		Global today				Global 2050						Global 2050
		ACRE Satellite Model (Min.)	ACRE Satellite Model (Max.)	FOLU LED & BECCS Scenarios	Others (see sections)	FOLU LED Scenario	FOLU BECCS Scenario	IIASA EU waste & residue scaled	ICCT	ICCT: EU waste & residue scaled	Others (see sections)	Reasonable estimate
Biomass from dedicated land	Food Crops	0	0	3		5[1]	5[1]	-		-		Low to zero
	Non-Food Crops	1	8	0		5	56	-	75	-		~5-10
	Subtotal	1	8	3		10	61	-	75	-		~5-10
Biomass from waste and residues	Forest Residues	6	14.5	23		22	54	1.7-6.9	3	2.3		~10-20
	Agricultural Residues	4	21.5	0		0	0	5.1-12.4	5	11.3		~5-12
	Municipal & Industrial Waste	0	0	0	6-14	0	0	-	3.4	3.1	3-6	~3-6

While the technical availability of energy from municipal and industrial waste is substantial (>20EJ), **the sustainable biomass supply values we have used here are on the lower end** due to the nature of MSW containing substantial **non-biogenic material** and an anticipated reduction in supply due to **circular economy advances** and **dietary shifts**.

Note: Traditional fuel wood and biomass for timber, pulp and paper sectors excluded (volumes equivalent to ~20EJ); (1) 1st generation energy supply included to account for current targets, but its contribution is assumed to be small and remain negligible going forward

Sustainable, low carbon supply subtotal: waste and residues

2 Biomass from waste and residues

Inferred from provided information

Basis of 'reasonable estimate' range

		Global today				Global 2050						Global 2050
		ACRE Satellite Model (Min.)	ACRE Satellite Model (Max.)	FOLU LED & BECCS Scenarios	Others (see sections)	FOLU LED Scenario	FOLU BECCS Scenario	IIASA EU waste & residue scaled	ICCT	ICCT: EU waste & residue scaled	Others (see sections)	Reasonable estimate
Biomass from dedicated land	Food Crops	0	0	3		5[1]	5[1]	-		-		Low to zero
	Non-Food Crops	1	8	0		5	56	-	75	-		~5-10
	Subtotal	1	8	3		10	61	-	75	-		~5-10
Biomass from waste and residues	Forest Residues	6	14.5	23		22	54	1.7-6.9	3	2.3		~10-20
	Agricultural Residues	4	21.5	0		0	0	5.1-12.4	5	11.3		~5-12
	Municipal & Industrial Waste	0	0	0	6-14	0	0	-	3.4	3.1	3-6	~3-6
	Subtotal	10	36	23	6-14	22	54	6.8-19.3	11.4	16.7	3-6	**~20-40**

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Note: Traditional fuel wood and biomass for timber, pulp and paper sectors excluded (volumes equivalent to ~20EJ); (1) 1st generation energy supply included to account for current targets, but its contribution is assumed to be small and remain negligible going forward

Source # 3: Biomass from aquatic sources

Topics		Key questions addressed
1. Biomass from dedicated land use	Land for climate mitigation	▪ How much **land can be dedicated to climate mitigation** among other land uses (food production, habitation, biodiversity conservation)?
	Climate mitigation alternatives	▪ What are the **carbon trade-offs between alternative uses of land** available for climate mitigation (e.g. renewables, sequestration, biomass production for bio-products or bio-energy)? ▪ What does this imply for level of **biomass supply**?
2. Biomass from waste and residual sources	Forest	
	Agriculture	
	Municipal & Industrial	
3. Biomass from aquatic sources		▪ What is the **availability of biomass** from each of these sources? ▪ What drives the range of estimates? ▪ How will this evolve over time? ▪ What is the cost of collection/ transportation?

Two main sources of aquatic biomass: macro- and micro-algae

A Macroalgae

- Seaweed
- Grown suspended longlines
- Uncontrolled environment in the ocean
- **Requires no inputs to grow**
- High sugar
- Used for food, hydrocolloids, and cosmetics
- Could provide nutrient absorption and carbon sequestration benefits

B Microalgae

- Grown in ponds or photobioreactors
- Controlled environment
- Requires energy and nutrient input to grow
- **High lipid content** under certain growth conditions
- Globally produced in small volumes today

Photo credit: Microalgae Jillian D. Young-Lorenz, Macroalgae – the Seaweed site
I.S. Tan et al. 2020 *Chemical Journal of Engineering*

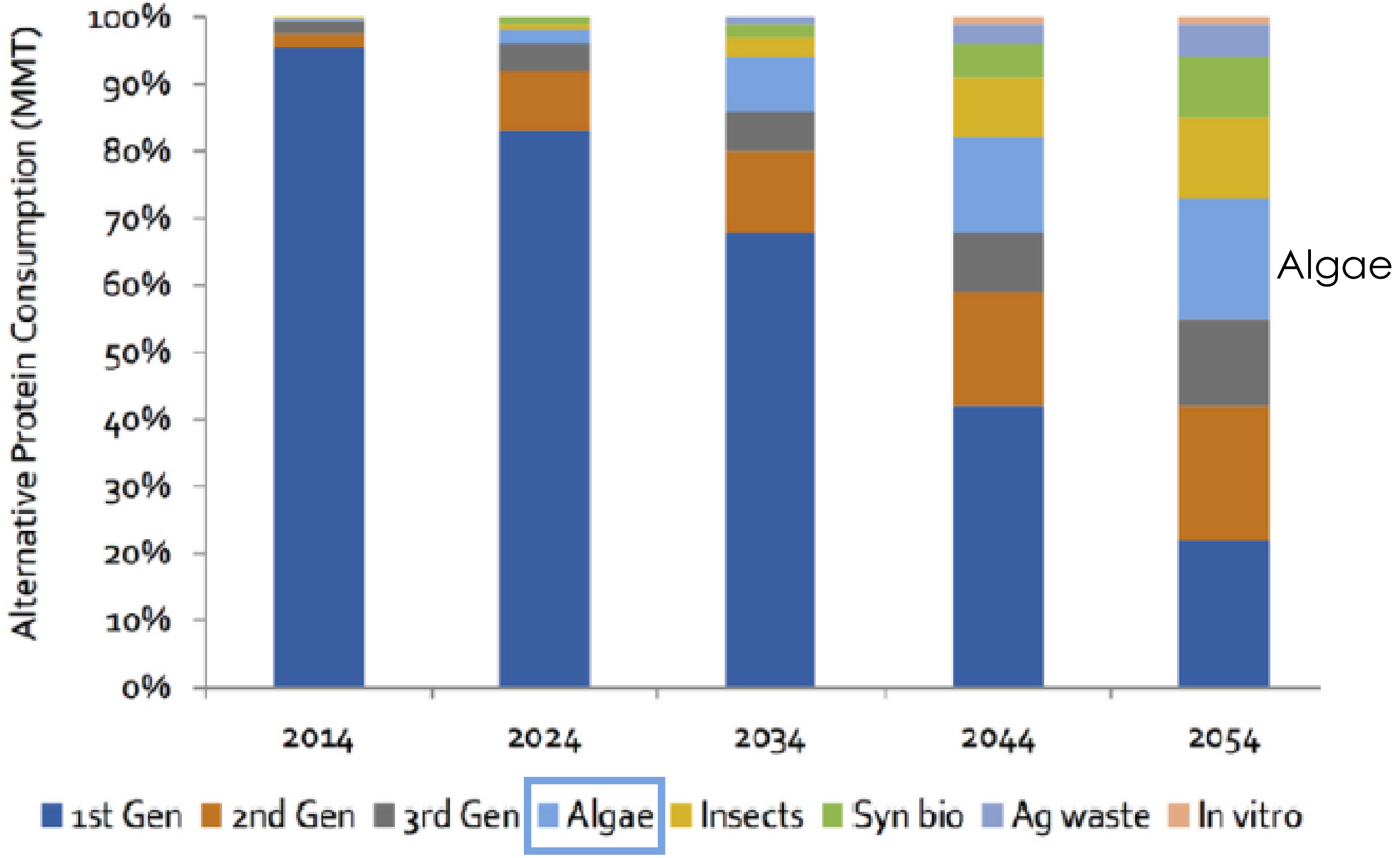
Energy and industrial demands for sustainable aquatic biomass will likely compete with those of the food sector

- **2/3 farmed seaweed today is for human food products** and hydrocolloid[2] production
- **Aquaculture**, including **algae production**, is one of the world's **fastest growing food-producing sectors**[1] (FAO)
- By mid-century, global **protein consumption of algae could increase to 56 MMT[1], ~12-15x today's production**.

A viable ocean macroalgae economy will have to accommodate **competing demands from the food, energy, and industrial sectors**.

However, limiting factor will likely not be biological potential, but economically viable farming capacity.

Global market proportions of protein consumption



Note: (1) Algae particularly promising as a feedstock for finfish aquaculture. (2) Gels and thickening agents
Source: European Commission, *Sustainable, Safe and Nutritious Foods*, Business Innovation Observatory; Seaweed Manifesto 2020
(1) Million Megatons; equivalent to approximately 370 MMT Dry weight, assuming approx. 15% protein content; https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6585948/

What criteria must be considered when determining low-carbon, sustainable biomass from macroalgae?

Environmental impacts (e.g., greenhouse gas emissions accounting, protection of biodiversity)

Technological readiness and **economic feasibility** (i.e., ability to scale)

Deep dive on following slides

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Note: more details in appendix

Sustainable macroalgae farming has many environmental and social benefits

3 Biomass from aquatic sources

A Macroalgae

Applications

- Nutritious and healthy food
- Pharmaceutical's and nutraceuticals
- Cosmetics
- Food additives and ingredients
- Animal feed
- Bioplastics
- Biofuels
- Fertilisers

Environmental benefits

- No need for freshwater
- No need for cleared land (and deforestation)
- No need for (chemical) fertilisers
- Carbon sequestration (“blue sink”)
- Absorption of excess nitrogen
- Habitat creation

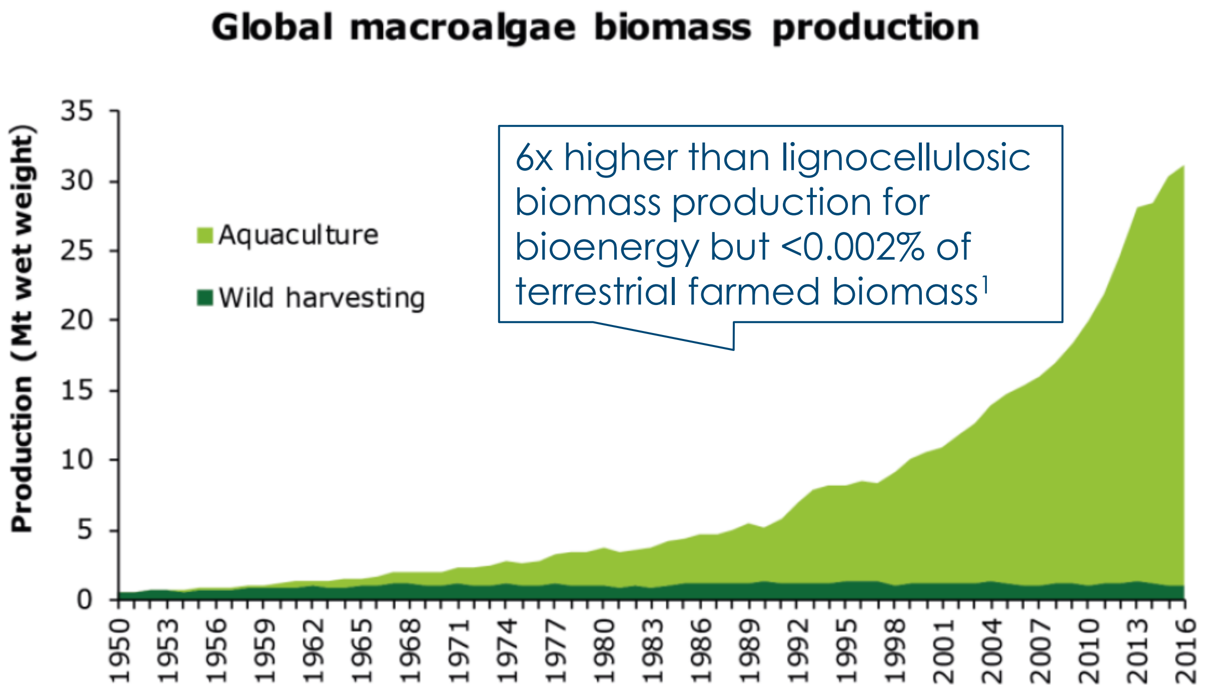
Social benefits

- Job creation
- Employment during winter months
- Upskilling
- Accessible to youth and low skilled workers

Source: SYSTEMIQ Oceans Team

Offshore farmed macroalgae production is growing fast, but has not yet reached scale or technical maturity for viable biorefinery

Macroalgae production (mainly for food) doubled in past decade, but small proportion of global biomass



Although growing rapidly, macroalgae farming is still too expensive at scale for biorefining uses

- Production and processing costs of macroalgae must decrease for biorefinery production to be viable
- Scale-up challenges include:
  - Energy intensive dewatering & processing steps
  - High transportation costs for offshore production
  - Carbohydrate content of many species not yet high enough for economic bioenergy production
  - Use of biomass for biofuels would general small revenues/ton despite large demand
- Increasing policy support for research to achieve cost reductions, including in China, Norway, EU, USA.

Note: (1) Seaweed farmed fresh weight
Source: I.S. Tan et al. 2020 *Chemical Journal of Engineering;* Buschmann et al, 2017; Lehahn et al., 2016; EU Commission *Brief on Algae Biomass Production* 2019 (Figure)

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Biomass supply subtotal: aquatic sources

Preliminary; in review with experts

3 Biomass from aquatic sources

- Inferred from provided information
- Basis of 'reasonable estimate' range

		Global today				Global 2050						Global 2050
		ACRE Satellite Model (Min.)	ACRE Satellite Model (Max.)	FOLU LED & BECCS Scenarios	Others (see sections)	FOLU LED Scenario	FOLU BECCS Scenario	IIASA EU waste & residue scaled	ICCT	ICCT: EU waste & residue scaled	Others (see sections)	Reasonable estimate
Biomass from dedicated land	Food Crops	0	0	3		5[1]	5[1]	-		-		Low to zero
	Non-Food Crops	1	8	0		5	56	-	75	-		~5-10
	Subtotal	1	8	3		10	61	-	75	-		~5-10
Biomass from waste and residues	Forest Residues	6	14.5	23		22	54	1.7-6.9	3	2.3		~10-20
	Agricultural Residues	4	21.5	0		0	0	5.1-12.4	5	11.3		~5-12
	Municipal & Industrial Waste	0										~3-6
	Subtotal	10										~20-40
Biomass from aquatic sources[2]	Macroalgae				0.1						10-18	~10

While the maximum estimated technical availability of energy from macroalgae could be substantial (>18EJ), the **sustainable biomass supply values we have used here are on the lower end** to acknowledge **technological and economic limitations** of seaweed farming as well as **competing demands for biomass use as food**.

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Note: Traditional fuel wood and biomass for timber, pulp and paper sectors excluded (volumes equivalent to ~20EJ); (1) 1st generation energy supply included to account for current targets, but its contribution is assumed to be small and remain negligible going forward; (2) Preliminary, in review with experts

What criteria must be considered when determining low-carbon, sustainable biomass from microalgae?

Land use implications (e.g., carbon trade-offs)

Environmental impacts (e.g., greenhouse gas emissions accounting, protection of biodiversity)

Resource requirements (e.g., energy, water, nutrients)

Technological readiness and **economic feasibility** (i.e., ability to scale)

Deep dive on following slides

Note: more details in appendix

Production of microalgae uses land, but can be extremely resource efficient and low-carbon

Promising new developments[1] demonstrate that microalgae:

- Can grow faster than terrestrial plants, **using 1/10th of the land** to produce an equivalent amount of biomass
- Can be very **resource efficient** and **low-carbon,** produced **without relying on agricultural land, freshwater, or addition of nutrients** (i.e., by utilising desert lands and providing growth requirements via pumping in nutrient-rich ocean water)

Other features of interest include:

- Some strains have **naturally high oil content**[2]
- Potential for industrial **carbon sequestration**[3]

Limitations include:

- **Land use** requirements
- Production today is for **food and niche chemicals**
- Grown in a **controlled environment**, adding to **expense**
- Has **not reached scale** or technical maturity; biomass **production is currently very low (<<1EJ/year)**

Placeholder

(1) Data presented and sustainability claims relevant for SuSeWi microalgae production specifically; not representative of other industry players.
(2) Note however that microalgae produce high oil content under nutrient-stressed conditions where they grow more slowly. (3) Carbon can be captured from fossil-fuel combustion if CO_2-rich flue gasses are bubbled through a photo-bioreactor; the higher concentration vs ambient air also aids their growth.

Sources: SuSeWi; ETC team research

Microalgal production has not yet reached scale, but its global potential for sustainable, resource-efficient biomass supply is low

3 Biomass from aquatic sources
B Microalgae

SuSeWi case study

	Biomass potential (fresh weight) *MT/year*	**Biomass potential** (dry weight) *MT/year*	**Land requirement** (desert) *M hectares*	**Energy content** *EJ/year*
2020	0.000450[1]	0.000015[1]	0.000003[1]	<<1[1]
Near-term (~2026)	2.1[1]	0.07[1]	0.006[1]	<<1[1]
Medium term	4.5[1]	0.15[1]	0.012[1]	<<1[1]
2050	15[1]	0.5[1]	0.036[1]	<<1[1]
2050 global potential*	**990**	**33**	**2.8**	**~1**

Due to its **limited scale relative to macroalgae** (when restricted to sustainable, low-carbon, resource-efficient methods), microalgal production is **best suited to meet food and niche chemical demands** rather than used for energy or other industrial needs

*Global estimation assumes 14,000km of global coastline (flat unused deserts near the sea with deep ocean) where resource-efficient, sustainable microalgal production is possible.

(1) Single company example; (2) Assumed 23-32 MJ/kg Dry Weight
Source: SuSeWi; Milledge et al. 2014

Biomass supply subtotal: aquatic sources

Preliminary; in review with experts

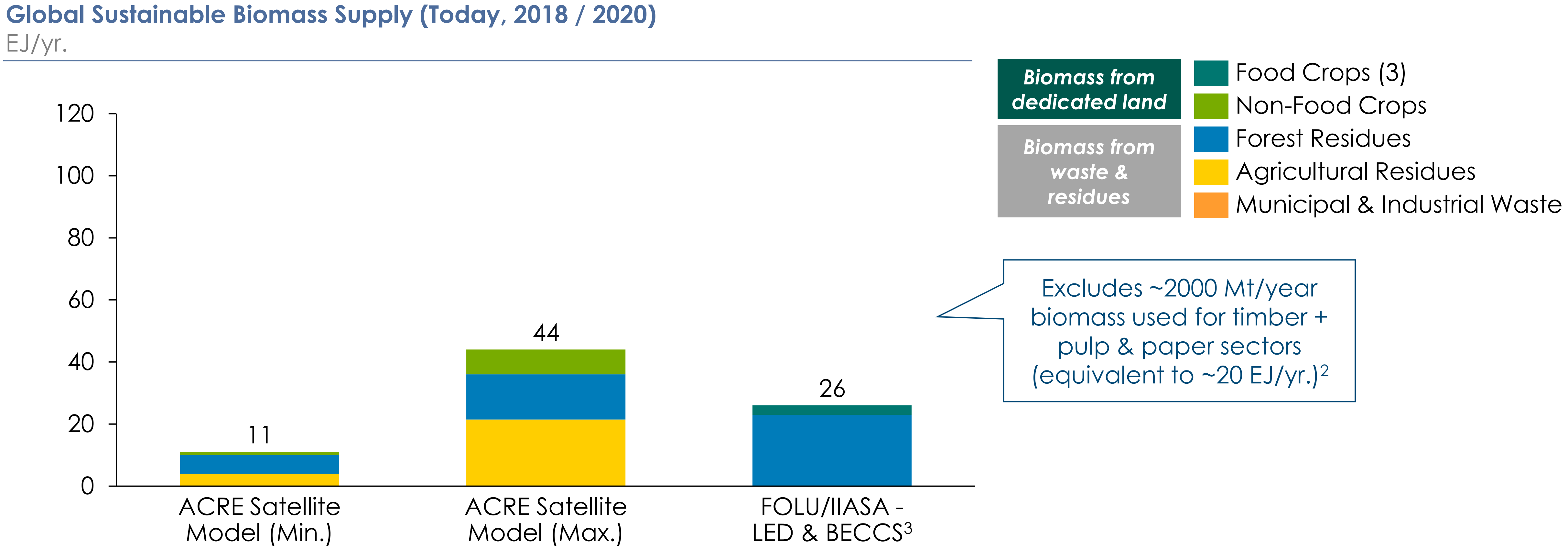
3 Biomass from aquatic sources

- Inferred from provided information (green)
- Basis of 'reasonable estimate' range (yellow)

		Global today				Global 2050						Global 2050
		ACRE Satellite Model (Min.)	ACRE Satellite Model (Max.)	FOLU LED & BECCS Scenarios	Others (see sections)	FOLU LED Scenario	FOLU BECCS Scenario	IIASA EU waste & residue scaled	ICCT	ICCT: EU waste & residue scaled	Others (see sections)	Reasonable estimate
Biomass from dedicated land	Food Crops	0	0	3		5[1]	5[1]	-		-		*Low to zero*
	Non-Food Crops	1	8	0		5	56	-	75	-		~5-10
	Subtotal	1	8	3		10	61	-	75	-		**~5-10**
Biomass from waste and residues	Forest Residues	6	14.5	23		22	54	*1.7-6.9*	3	*2.3*		~10-20
	Agricultural Residues	4	21.5	0		0	0	*5.1-12.4*	5	*11.3*		~5-12
	Municipal & Industrial Waste	0	0	0	6-14	0	0	-	3.4	*3.1*	3-6	~3-6
	Subtotal	10	36	23	6-14	22	54	*6.8-19.3*	11.4	*16.7*	3-6	**~20-40**
Biomass from aquatic sources[2]	**Macroalgae**				0.1						10-18	~10
	Microalgae				<<1						<1	0
	Subtotal				0.1						10-18	**~10**

Note: Traditional fuel wood and biomass for timber, pulp and paper sectors excluded (volumes equivalent to ~20EJ); (1) 1st generation energy supply included to account for current targets, but its contribution is assumed to be small and remain negligible going forward; (2) Preliminary, in review with experts

Supply today: Global studies considered give range of 11-44 EJ of sustainable biomass supply for energy and industrial use today

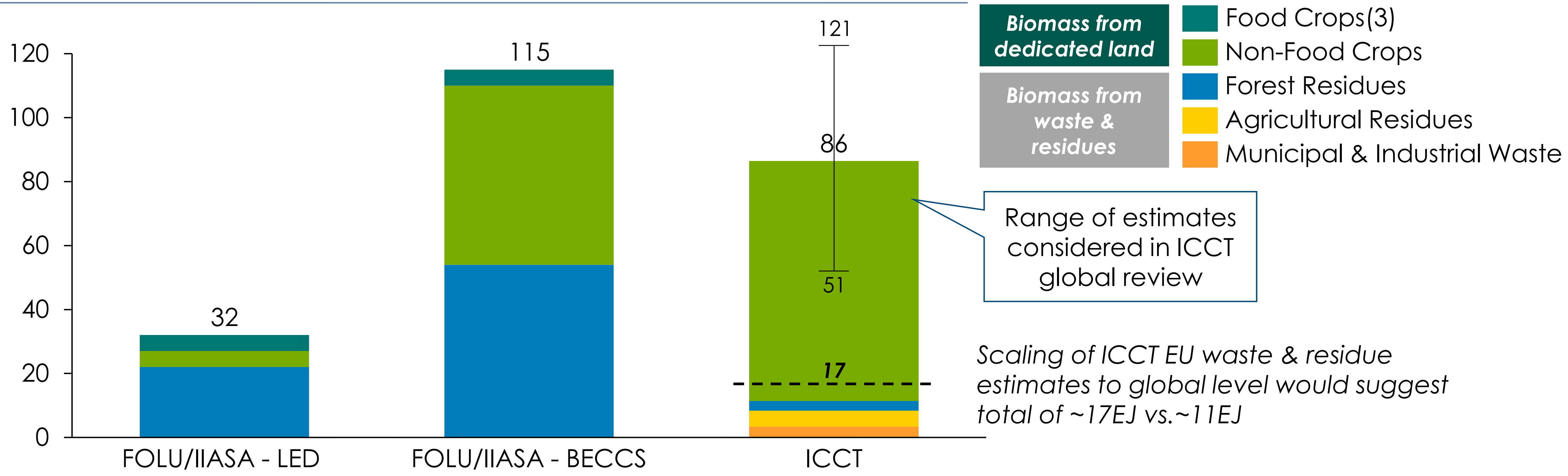


	ACRE Satellite Model (Min.)	ACRE Satellite Model (Max.)	FOLU/IIASA - LED & BECCS[3]
Study #	1	1	2 3
Traditional Fuel Wood (EJ/yr.)[1]	Na.	Na.	27

(1) Traditional fuel wood is defined as traditional sources of raw biomass primarily for home-based cookstoves, and therefore assumed to be unusable for industrial uses due to distributed way that it is collected; (2) Searchinger T. (2018), FAO http://www.fao.org/forestry/statistics/80938/en/; (3) Note: GLOBIOM doesn't model 1st Gen. food crops, but the modeling authors do acknowledge that there are approximately ~3EJ/yr being harvested today, which may increase to 5EJ/yr in 2050 based on current policy targets. This is not included in the model total for primary energy demand.

<u>Supply in 2050</u>: Global studies considered give range of ~40-120 EJ of sustainable biomass supply for energy and industrial use by 2050

Global Sustainable Biomass Supply (2050)
EJ/yr.



	FOLU/IIASA - LED	FOLU/IIASA - BECCS	ICCT
Study #	2	3	4
Traditional Fuel Wood (EJ/yr.)[1]	22	22	Na.

(1) Traditional fuel wood is defined as traditional sources of raw biomass primarily for home-based cookstoves, and therefore assumed to be unusable for industrial uses due to distributed way that it is collected; Modelling completed for BEIS in 2017 estimated 23 EJ / year from biomass sustainably available by 2050, with 7 EJ/yr. from energy crops, 9 EJ/yr. from forest residues and 6 EJ/yr. from agri residues. (3) Note: GLOBIOM doesn't model 1st Gen. food crops, but the modeling authors do acknowledge that there are approximately ~3EJ/yr being harvested today, which may increase to 5EJ/yr in 2050 based on current policy targets. Not included in modelled total primary energy demand

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The studies reinforce the scarcity of low carbon, sustainable biomass supply and suggest ~35-60EJ of primary energy could be available for energy and industrial uses in 2050

- Inferred from provided information
- Basis of 'reasonable estimate' range

		Global today				Global 2050						Global 2050
		ACRE Satellite Model (Min.)	ACRE Satellite Model (Max.)	FOLU LED & BECCS Scenarios	Others (see sections)	FOLU LED Scenario	FOLU BECCS Scenario	IIASA EU waste & residue scaled	ICCT	ICCT: EU waste & residue scaled	Others (see sections)	Reasonable estimate
Biomass from dedicated land	Food Crops	0	0	3		5[1]	5[1]	-		-		*Low to zero*
	Non-Food Crops	1	8	0		5	56	-	75	-		~5-10
	Subtotal	1	8	3		10	61	-	75	-		**~5-10**
Biomass from waste and residues	Forest Residues	6	14.5	23		22	54	1.7-6.9	3	2.3		~10-20
	Agricultural Residues	4	21.5	0		0	0	5.1-12.4	5	11.3		~5-12
	Municipal & Industrial Waste	0	0	0	6-14	0	0	-	3.4	3.1	3-6	~3-6
	Subtotal	10	36	23	6-14	22	54	6.8-19.3	11.4	16.7	3-6	**~20-40**
Biomass from aquatic sources[2]	Macroalgae				0.1						10-18	~10
	Microalgae				<<1						<1	0
	Subtotal				0.1						10-18	**~10**
	Total	**11**	**44**	**26**	**6-14**	**32**	**115**	**6.8-19.3**	**86.4**	**16.7**	***13-24***	**~35-60**

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Note: Traditional fuel wood and biomass for timber, pulp and paper sectors excluded (volumes equivalent to ~20EJ); (1) 1st generation energy supply included to account for current targets, but its contribution is assumed to be small and remain negligible going forward; (2) Preliminary, in review with experts

Studies with less rigorous sustainability criteria report greater bio-resource supply

	Ecofys / Shell (2015)	International Energy Agency (IEA, 2017)
Mid-century bio-resources potential	**130-400 EJ** primary energy (2070) ▪ Dedicated land – energy crops (3/4ths) ▪ Forestry and agricultural residues (1/4th)	**130-240 EJ** primary energy (2060) ▪ Dedicated land (60-100 EJ) ▪ Forest residues (15-30 EJ) ▪ Agricultural residues (46-95 EJ) ▪ Municipal waste (10-15 EJ)
Key differences in sustainability criteria	▪ **Protected areas not explicitly excluded** (but grassland availability kept <25%) ▪ **Cropland productivity not reduced** for abandoned cropland ▪ **Food crops considered** in addition to lignocellulosic crops ▪ **No exclusions for soil health** on proportion of residues available	▪ **Agricultural land considered in scope** for bio-resource production (i.e., dedicated land includes non-marginal land that is appropriate for agricultural (but where current production is low) as well as pasture landscapes) ▪ **Municipal waste supply includes** inseparable non-biogenic material (e.g., **plastic waste**)

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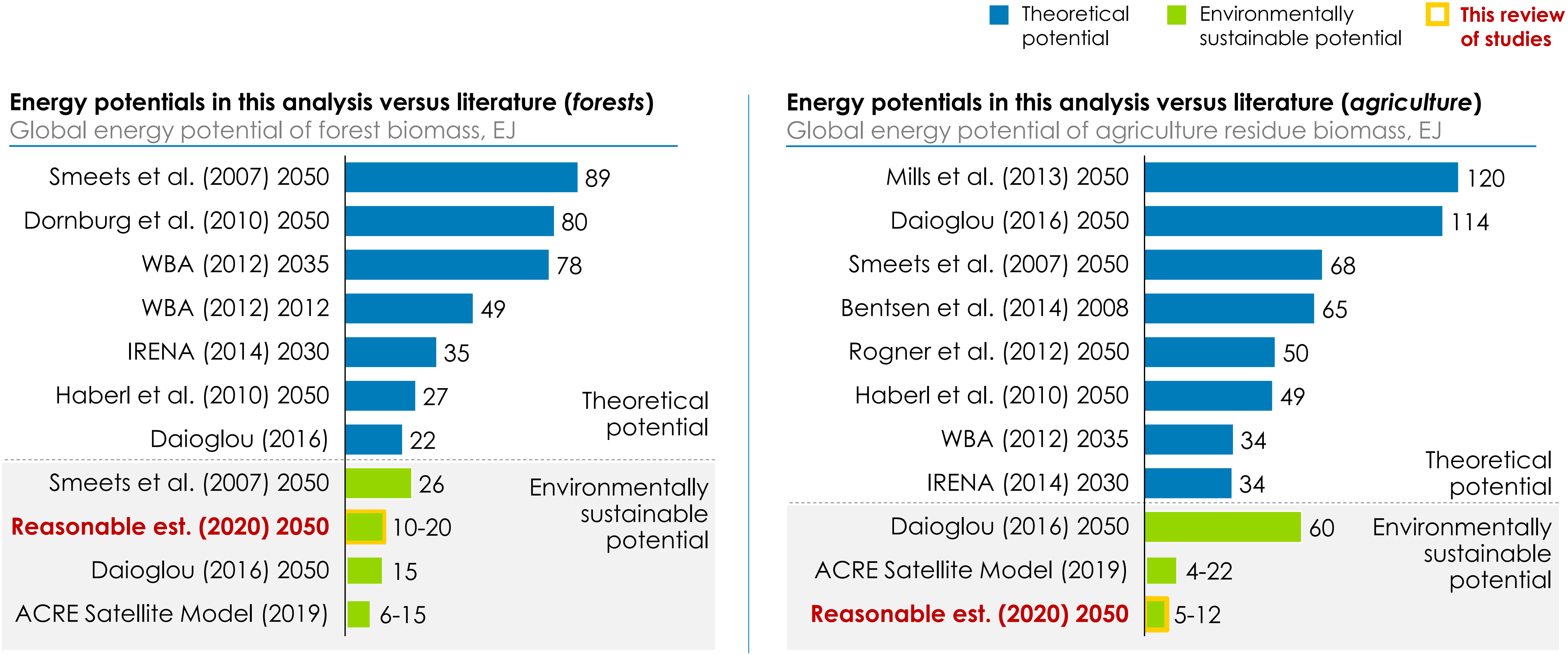
Deng et al. Country-level assessment of long-term global bioenergy potential. Biomass & Bioenergy 74 (2015) 253-267.
IEA, 2017, *Technology roadmap: Delivering Sustainable Bioenergy*

The reasonable consensus falls within a similar range as other studies looking at environmentally sustainable biomass potential



Agenda for today

Sustainable, low-carbon biomass availability

Understand the range of estimates for the prudent **scale of bio-resources available** for industrial uses today and by mid-century, taking into account sustainability criteria and carbon trade-offs, considering

- Biomass from dedicated land use
- Biomass from waste and residual sources
- Biomass from aquatic sources

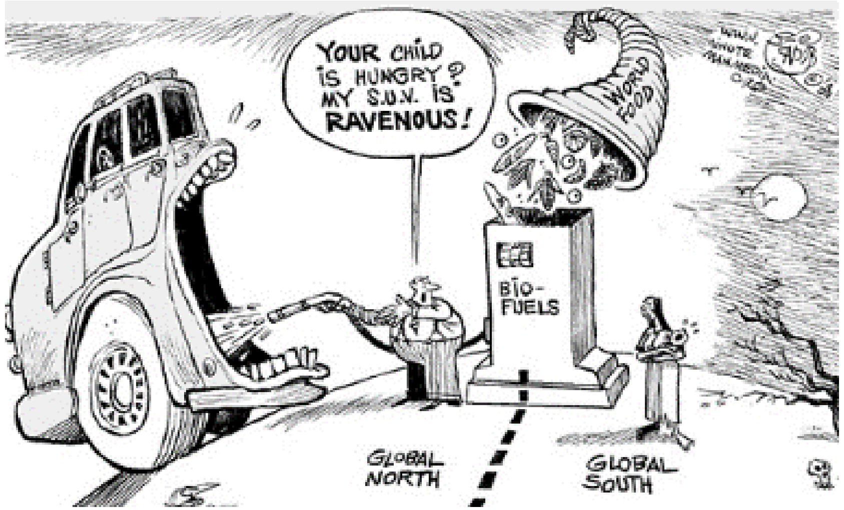
Actions to ensure sustainability

Discuss the **actions needed from policymakers and industry** to ensure the sustainability and low-carbon attributes of this biomass (e.g. regulations, standards)

Policymakers and industry must learn the lessons from previous failures

Food vs. fuel debate

Land grabbing debate



Source: IIASA presentation from April 2020

Actions must be taken from a policy and industry perspective to ensure bio-resources used in industry and energy sectors are truly sustainability and low-carbon

For discussion

Key Principles

1. Avoid **land use change effects**, especially in high biodiversity and carbon stock areas
2. Stabilise demand to reduce likelihood of **land-grabbing** and destruction of **traditional livelihoods**
3. Avoid competition with the production of **food & feed crops**
4. Maximize sustainable supply of bio-resources from **wastes & residues**
5. Ensure additional demand for biomass does not take resources from **competing sectors** without viable alternatives

Key Actions

A ▪ **Set clear sustainability and low carbon criteria** / standards, reflecting all complexities discussed today (e.g., do not source food crops, protect soil health)

B ▪ **Target low carbon opportunity cost land** for any dedicated biomass production – and build datasets to accurately identify and verify this land

C ▪ **Maintain high traceability** throughout the bio-resource supply chain (including community engagement)

D ▪ **Develop appropriate regulations and standards** to ensure compliance

E ▪ **Maximise use of waste and residue sources**, while safeguarding land and soil health; encourage circular economy efforts, including material recovery, waste collection & separation

F ▪ **Support critical innovations** (e.g. macroalgae development as it offers an alternative to biomass production on dedicated land)

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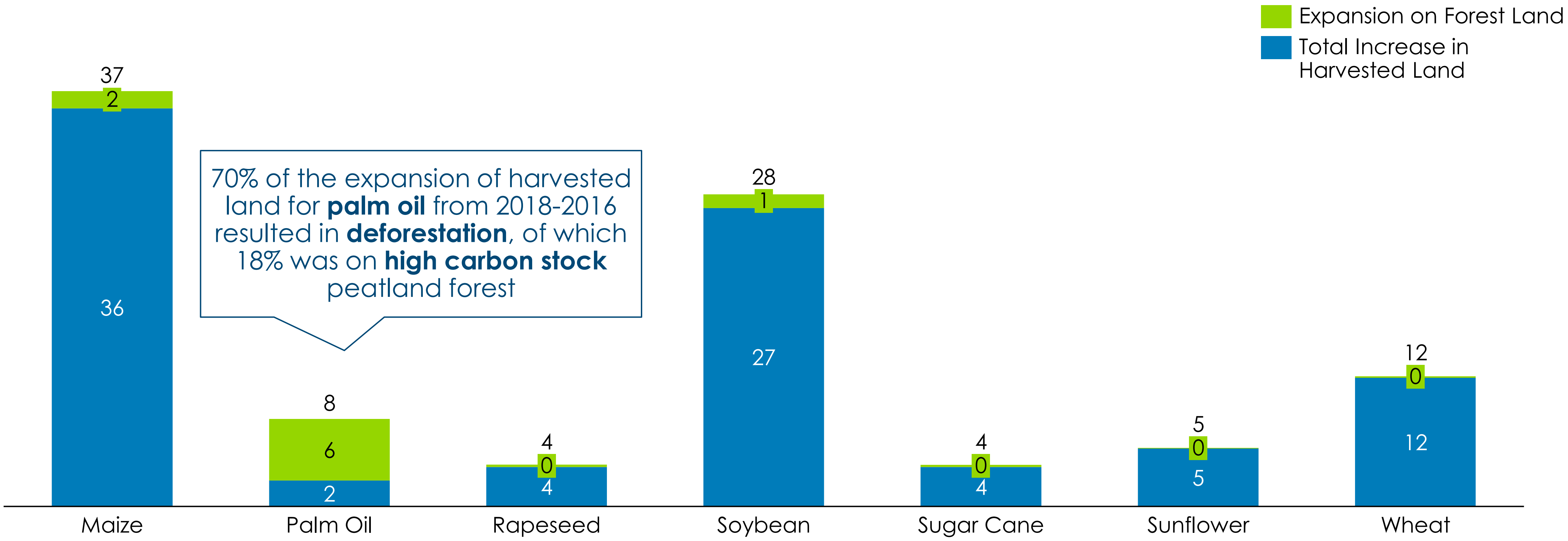
Source: European Commission (2019), IIASA (2015), USDA, FAOSTAT.

EU RED: The expansion of harvested land for energy crops has resulted in deforestation and is likely to continue despite efforts to exclude certain crops

A

Deforestation from Expansion of Harvested Land by Crop Type

Million hectares, 2008-2016



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Source: European Commission (2019), IIASA (2015), USDA, FAOSTAT.

Good policy is needed ensure that the supply of bio-resources is truly sustainable, as high demand can cause unintended consequences

A

Examples

Bad Policy

- The EU RED biofuels mandate resulted in the expansion of harvested land for energy crop cultivation, causing major deforestation
- 70% of the expansion for palm oil cultivation to meet the target from 2008-2016 was on forest land, of which 18% was on high carbon stock peatland forest

Good Policy

- In Sweden, effective forest governance laws & municipal-level financial support has led to the successful use of forest residues from the timber industry
- Bioenergy provided 37% of final energy use in Sweden in 2016, and wood biomass provides over 2/3rds of the fuel supply for district heating

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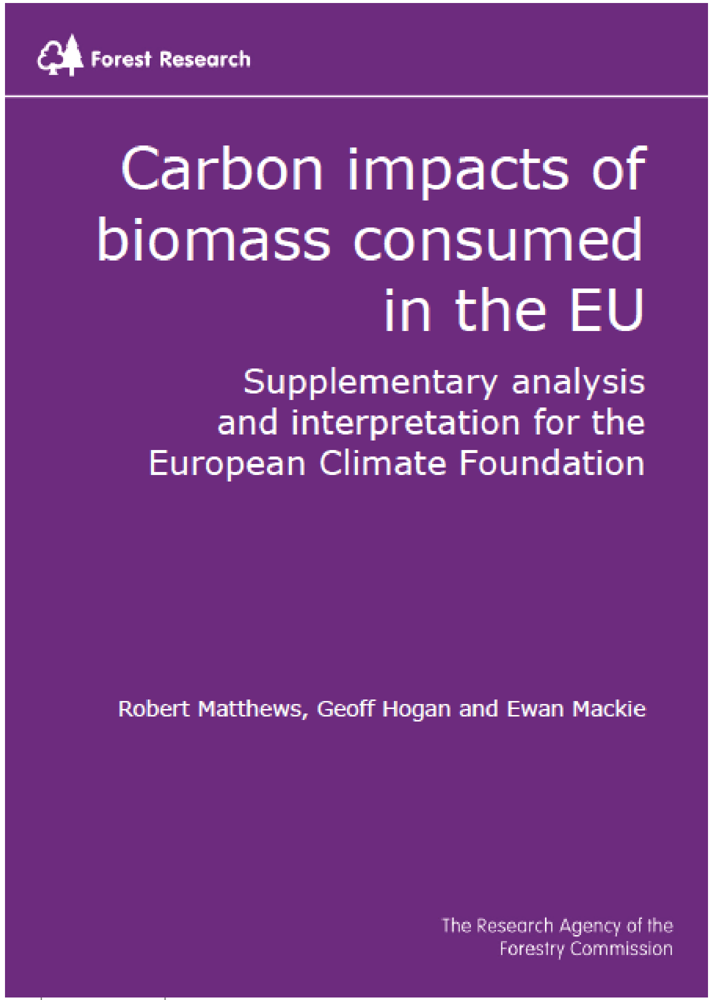
- The **first formulation of RED-II** (2010-2019) had **no limit on crops or land use criteria** and **resulted in land use changes**
- **RED-II** sets limits on **high-ILUC[1] risk** biomass, excluding feedstocks that have significantly expanded onto land with high carbon stock
- De facto, this means that **palm oil will be phased out by 2030**
- However, other feedstocks remain eligible from all regions (e.g. **soy, maize, sugar cane**)
- The EU biofuel mandate is projected to result in the conversion **8.8 million hectares of land**, approx. the size of Austria[2]
- This includes around **1 million hectares of tropical forest and peatlands**

Note: (1) ILUC = indirect land use changes ; (2) Figures refer to land use change modelling undertaken by IIASA (2015) for the European Commission.
Source: European Commission (2019), IIASA (2015), USDA, FAOSTAT.

Forest Research issued guidelines to maximize GHG savings

European Climate Foundation


Forest Research

Carbon impacts of biomass consumed in the EU

Supplementary analysis and interpretation for the European Climate Foundation

Robert Matthews, Geoff Hogan and Ewan Mackie

The Research Agency of the Forestry Commission

- Disallow sources linked to deforestation
- Avoid areas with low growth rates
- Favor sources linked to afforestation and increased stocks
- Favor thinnings versus felling
- Favor post-consumer waste, industrial residues, fast-decaying residues, salvage logging, early thinnings
- Avoid stumps and roots; roundwood or any sources suitable for sawn timber;

Suggested policies, incentives, and practices to limit future cropland expansion to lands with low environmental opportunity costs (from WRI)

A B

Generate a clearer understanding of what and where lands with low environmental opportunity costs are located:

- Agreeing on a clear **definition**.
- Applying our criteria to generate **maps**.
- **Identifying** cleared or abandoned agricultural lands where biophysical or human factors are blocking natural regeneration.

Facilitate use of lands with low environmental opportunity costs:

- Prioritizing lands with low environmental opportunity costs in participatory **spatial planning**.
- Clarifying and **strengthening land tenure** on lands with low environmental opportunity costs.
- Introducing **financial incentives** for farmers to use lands with low environmental opportunity costs.
- Improving **technical assistance** and rural extension for using such lands.
- Strengthening **community engagement** processes.

Discourage cropland expansion to lands with high environmental opportunity costs by making the financial, reputational, market access, or legal "cost" of converting natural ecosystems into cropland greater than the cost of expanding onto lands with low environmental opportunity costs:

- Introducing and enforcing **moratoriums** on converting natural ecosystems.
- Accelerating adoption of "deforestation-free" **supply chain commitments**.
- Implementing **monitoring** systems.

Source: Hanson, C. and T. Searchinger. 2015. "Ensuring Crop Expansion is Limited to Lands with Low Environmental Opportunity Costs." Working Paper. Installment 10 of Creating a Sustainable Food Future. *World Resources Institute*

Biomass sustainability governance

Managing Biomass Sustainability Risk

Strong regulatory framework, internal processes and external certification

Externally

- Strong regulatory framework – UK Renewables Obligation
- REDII – minimum standards that Drax exceeds

Drax

- Strong internal controls and external audits
- 92% of feedstocks used by Drax were certified by Sustainable Biomass Programme in 2018
- Close monitoring of supply chain and locations
- Close relationship and monitoring of suppliers

SBP
Sustainable Biomass Program

Regulator approved scheme demonstrating 100% compliance with regulation

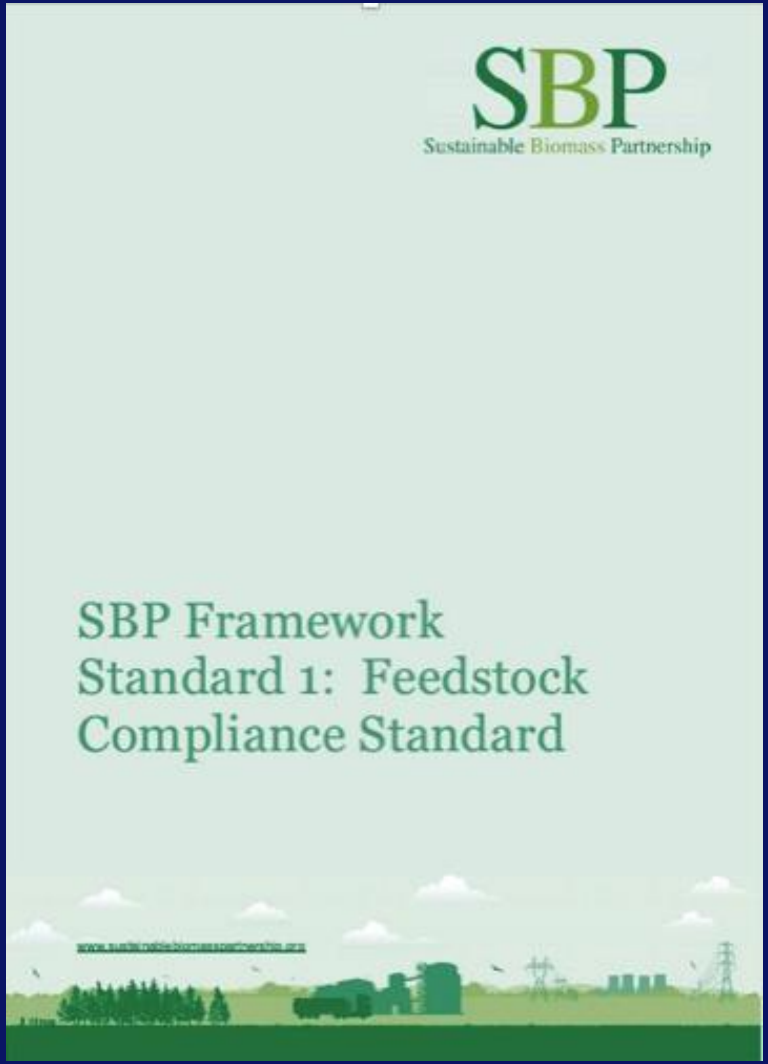
From industry origins has moved to multi-stakeholder governance in accordance with best practice

Standard revision process initiated, with stakeholder involvement.

Broad uptake of EU pellet industry players

- 9 Mt of SBP-certified pellets
- 65% of the EU-28 pellet consumption

SBP Framework Standard 1



C D

Principle 1. Biomass feedstock is legally sourced

Criterion 1.1: The Supply Base is defined.

Criterion 1.2: The forest owner and manager hold legal use rights to the forest (CPET[2] L1).

Criterion 1.3: There is compliance with the requirements of local, national and applicable international laws, and the laws applicable to Forest Management (CPET L2).

Criterion 1.4: All applicable royalties and taxes have been paid (CPET L3).

Criterion 1.5: There is compliance with the requirements of CITES (CPET L4).

Criterion 1.6: Harvesting does not violate traditional or civil rights.

Principle 2. Biomass feedstock is sustainably sourced

Criterion 2.1: Management of the forest ensures that features and species of outstanding or exceptional value are identified and protected (CPET S8c).

Criterion 2.2: Management of the forest ensures that ecosystem function is assessed and maintained through both the conservation/set-aside of key ecosystems or habitats in their natural state, and the maintenance of existing ecosystem functions throughout the forest (CPET S5 & 8b).

Criterion 2.3: Management of the forest ensures that productivity is maintained (CPET S6).

Criterion 2.4: Management of the forest ensures that forest ecosystem health and vitality is maintained (CPET S7).

Criterion 2.5: Management of the forest ensures that legal, customary and traditional tenure and use rights of indigenous peoples and local communities related to the forest, are identified, documented and respected (CPET S9).

Criterion 2.6: Appropriate mechanisms are in place for resolving grievances and disputes, including those relating to tenure and use rights, to Forest Management practices, and to work conditions (CPET S10).

Criterion 2.7: The basic labour rights of forest workers are safeguarded (CPET S11).

Criterion 2.8: Appropriate safeguards are in place to protect the health and safety of forest workers (CPET S12).

Criterion 2.9: Regional carbon stocks are maintained or increased over the medium to long term.

Criterion 2.10: Genetically modified trees are not used.

Beyond Regulation: Drax responsible sourcing policy for woody biomass

C D

Using:	Only using roundwood that:	Not using:
• Responsibly sourced sawmill residues • Forest residues from regions with high rates of decay, or where this material is extracted to roadside as part of standard harvesting practice. • Thinnings that improve the growth, quality or biodiversity value of the forest	• Helps to maintain or improve the growing stock, growth rate and productivity of the forest. • Helps to improve the health and quality of the forest, for example by using storm, pest or fire damaged wood. • Is not merchantable for use as sawn timber products	• Biomass that drives harvesting decisions that would adversely affect the long-term potential of the forest to store and sequester carbon. • Biomass that increases harvesting above the sustainable capacity of the forest • Biomass that displaces solid wood product markets • Biomass that comes from stumps

65

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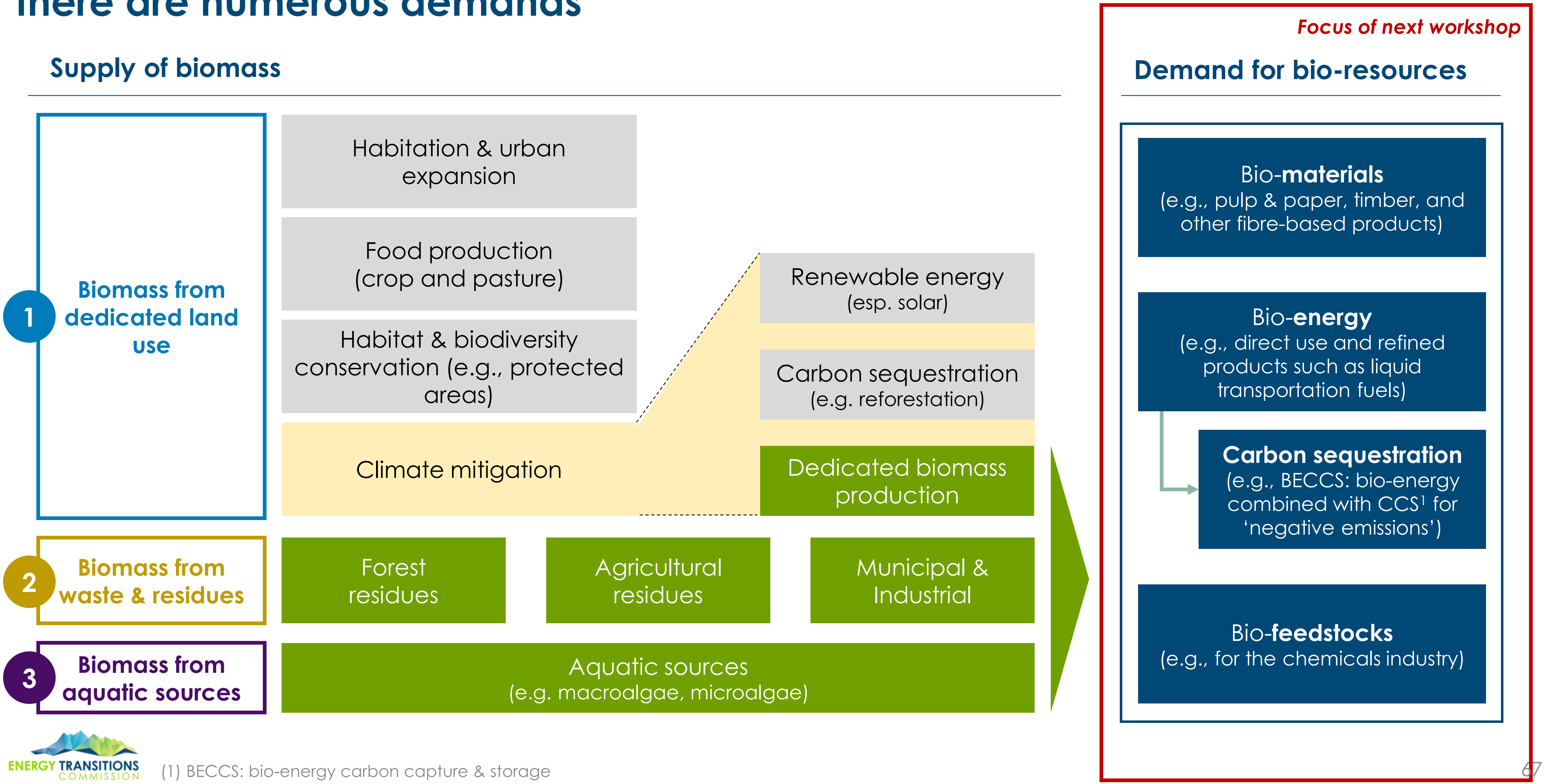
Source: European Commission (2019), IIASA (2015), USDA, FAOSTAT.

Next-steps: Competing uses of land constrain biomass supply, for which there are numerous demands



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(1) BECCS: bio-energy carbon capture & storage

Future workshops will shift focus to use-cases of biomass and how to align demand with limited supply

- **Review potential uses of biomass** in a net-zero economy (both for energy and as materials), and estimates of potential scale
- **Map alternative decarbonisation options** by use case (e.g. via electrification, use of synthetic fuels, or continued use of fossil fuels with CCS) and potential cost trends
- **Review technological readiness** of different forms and conversion technologies for bio-resources, and potential future cost trends

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The Energy Transitions Commission is hosted by SYSTEMIQ Ltd.