ETC 2020 analytical deepdives: Bio-economy

Determining the nature and scale of sustainable bio-resources supply

ENERGY TRANSITIONS COMMISSION

Appendix, Workshop 8th June 2020 – UPDATED MATERIALS

Contents

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Deprioritise

Summarise existing state of knowledge

Focus for ETC analysis

Developing the bio-economy in a truly sustainable way

Focus for June 8th workshop

		Production / Transformation	Collection / Transport	Use
What could be the realistic shape of zero-carbon energy generation ramp-up curves?		**What drives the range of estimates on the amount of land that could be dedicated to climate mitigation, given other land uses?** **What are the carbon trade-offs between alternative uses of this available land (renewables, sequestration, biomass production)?** **What drives the range of estimates on availability of waste and residues and of non-land-based biomass?** How fast can sustainable **supply of biomass** be scaled up? How fast can sustainable **supply of refined biomass** be scaled up, given technology readiness and lead time for industrial plants?	What is the cost of **collection/transportation** of different types of bio-resources (esp. wastes & residues)? How will that impact **use cases** across regions, localisation and size of **biorefineries**, and **international trade** of biomass/bio-products?	What is the **optimal use** of scarce sustainable bio-resources supply across different sectors (considering alternative decarbonization options & LCA analysis)?
		How are biomass prices likely to evolve given evolutions of both supply and demand? How could that differ depending on the type of bio-resource and on geography? What are the potential risks of price fluctuations during the scale-up phase?		
What will it take to achieve these ramp-up curves?	Technology	What are the critical technology developments required to both expand the range of usable sustainable biomass sources and to improve the efficiency of the transformation process?		
	Finance	What is the **type and scale of investments** required from 2020 to 2050 in both the **supply** of sustainable biomass and the **transformation value chain** for new use sectors?		
What actions can be taken to deliver?	Industry	Where do the biggest **business opportunities** lie in the development of a sustainable biomass value chain? What **critical steps** can industry players take in the 2020s to seize these opportunities?		
	Policy	**What public policies are required to ensure a truly sustainable supply of biomass without undercutting the bio-economy?** What types of incentives can be put in place to encourage an **optimal allocation/prioritization** of biomass across sectors?		

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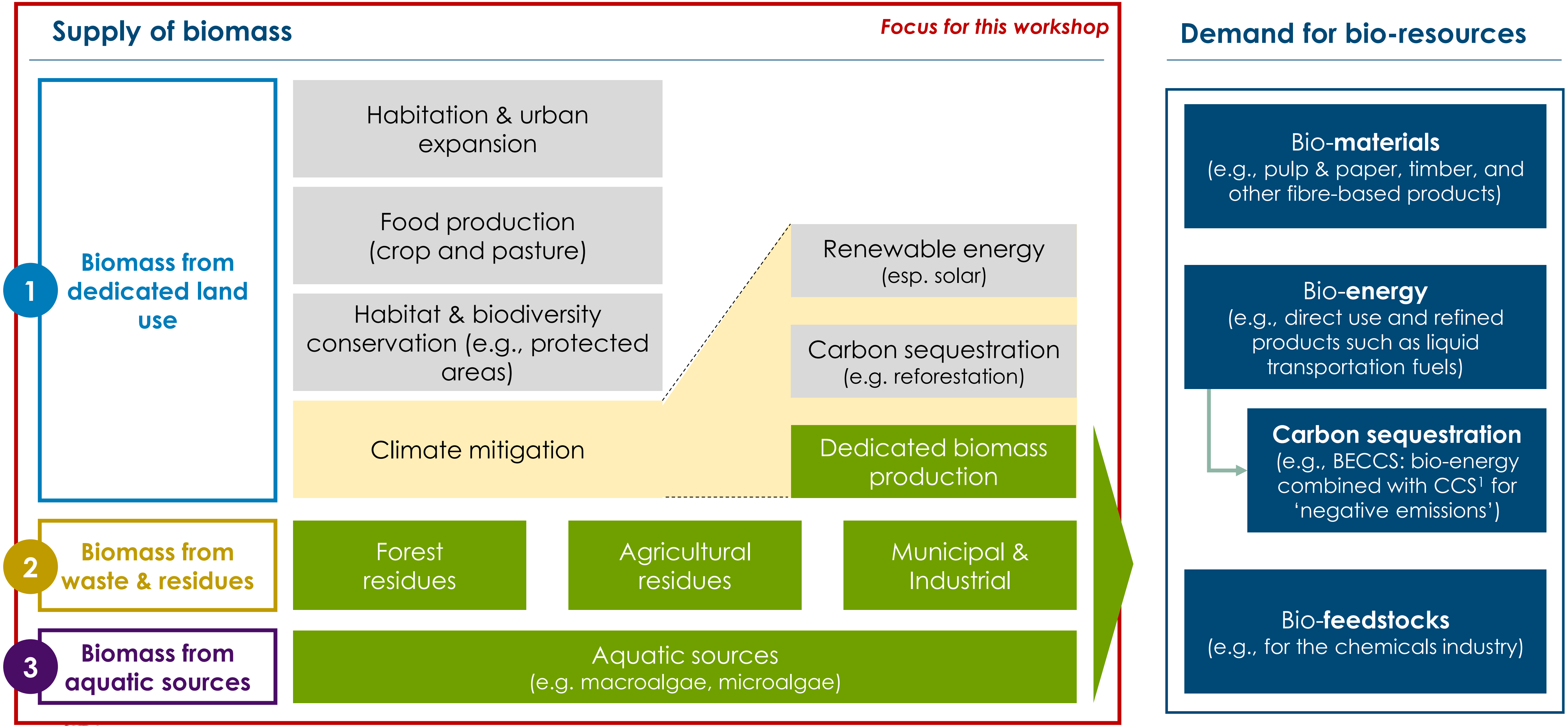
Competing uses of land constrain biomass supply, for which there are numerous demands



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

Overview of key global studies shared in Workshop #1 (& additional ICCT study)

	ACRE Satellite Model ①	FOLU/IIASA: Low Energy Demand Scenario (LED) ②	FOLU/IIASA: 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
Key Assumptions	• Exclude 59% of the world's land area for sustainability reasons • Only consider degraded land for energy crops, avoiding any competition with existing agricultural or forest use • Considers residues from forests and agriculture	• 40% reduction in final global energy demand from 2020 to 2050 (2050 = 245EJ*) • 1.5°C compatible pathway, without the use of BECCs • Global food security needs met by 2030	• ~5% increase in global final energy demand from 2020 to 2050 (2050 = 449EJ*) • 1.5°C compatible pathway, negative emissions in 2050 from CCS are 4.2 Gt/yr. • Global food security needs met by 2030	• Excludes all land that is forest, wetlands, tundra, desert, cropland, or pastureland, leaving ~930 MHa of grass & shrublands for biofuels • Only consider residues from wood plantations • Assume only 20% of agricultural residues available
		• Land use change driven by diet shift, carbon price, technological improvements		

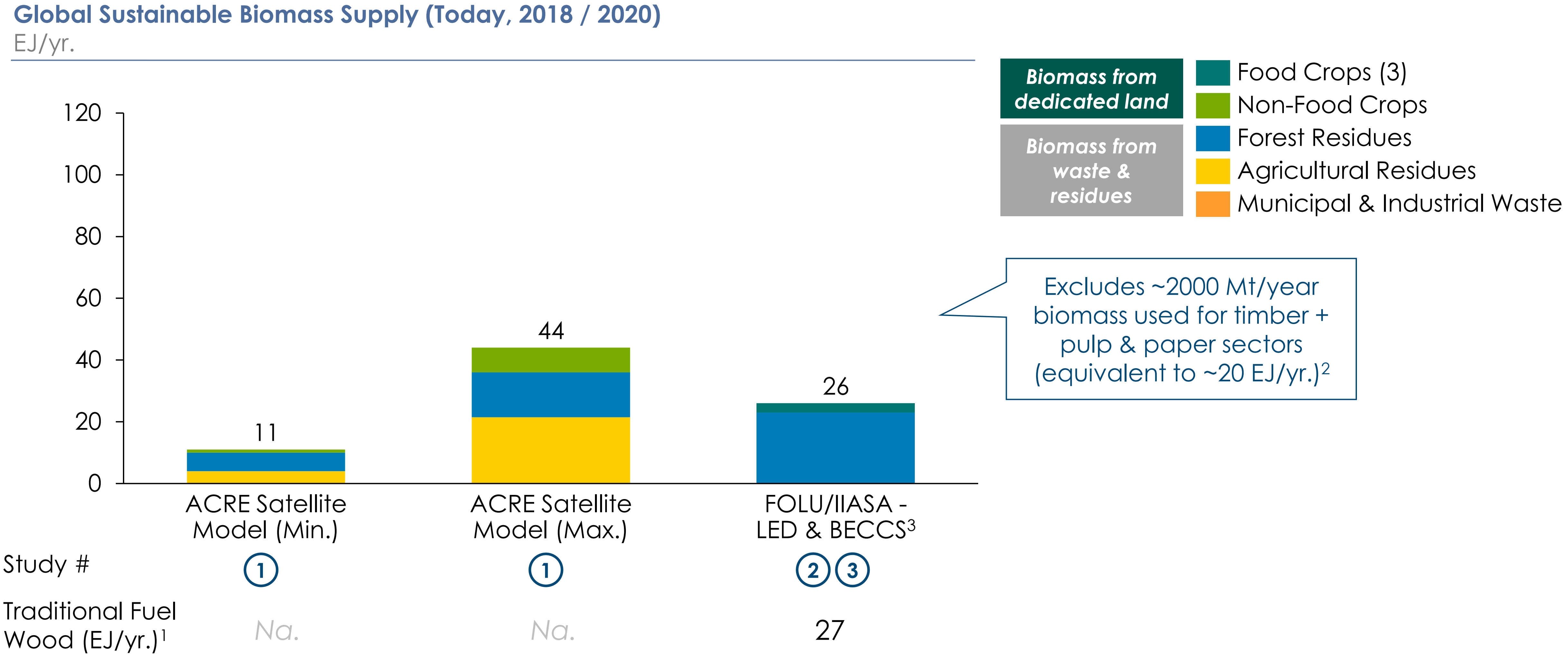
(*) First gen bioenergy not included in the total final energy demand because not a feature of the model.

In addition, 3 EU specific studies shared at Workshop #1

	IIASA		
	EU Commission Study (RECEBIO) 5	Land Use change impact of biofuels in EU (Valin et al. - ILUC) 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

Key Assumptions	• Agricultural & municipal sources not included in scope of study
	• Reporting on the EU Emission Reduction Scenario, assuming policy target of 80% reduction of GHG EU emissions by 2050
	• The increased use of biomass for energy has a direct impact on forest harvests, which are almost 9% higher than in the 2050 baseline
		• The EU 2020 Mix is about 90% food crop fuels, 10% woody biomass fuels
		• Reporting on the EU Biofuel Mix in 2020 scenario, based on the *National Renewables Energy Action Plan (NREAPs)*, this is not an economic analysis of potential.
		• 33-50% agricultural residue removal considered sustainable for soil health.
			• Waste + residue sources only
			• Sustainability criteria applied by category
			  • Only include residues from forestry products
			  • Assume minimum 50% forest residue retention for soil health
			  • Country specific ag residue retention ratios
			  • Waste streams are biogenic only

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



(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.

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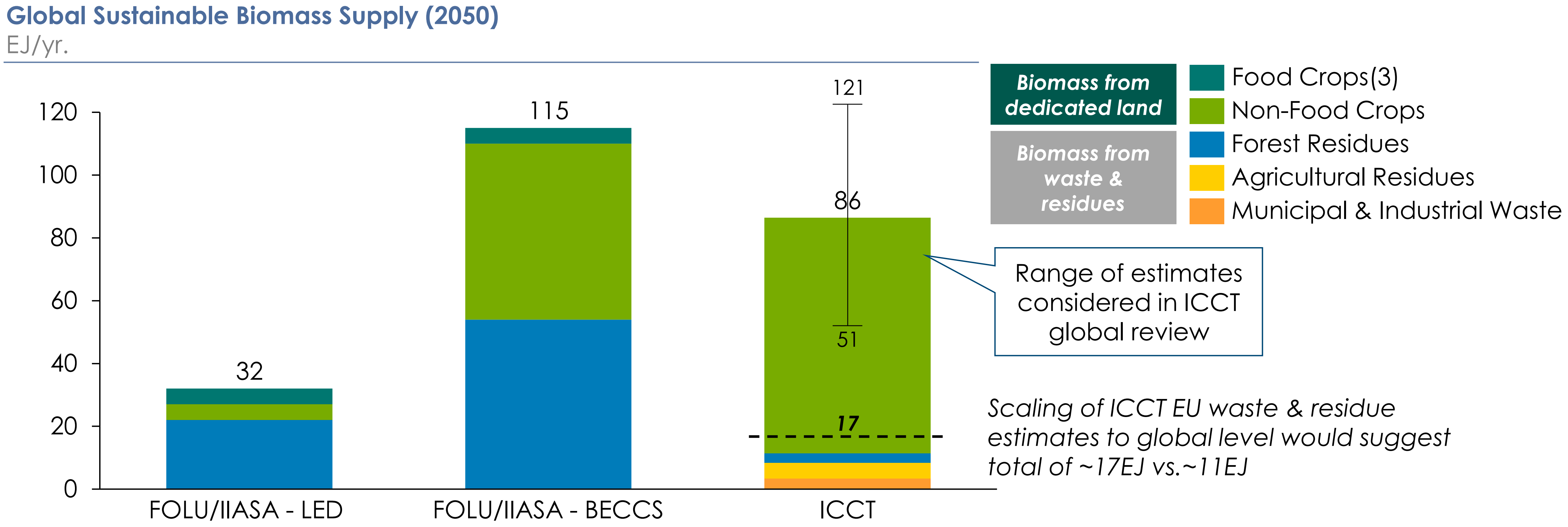
Supply in 2050: Global studies considered give range of ~40-120 EJ of sustainable biomass supply for energy and industrial use by 2050



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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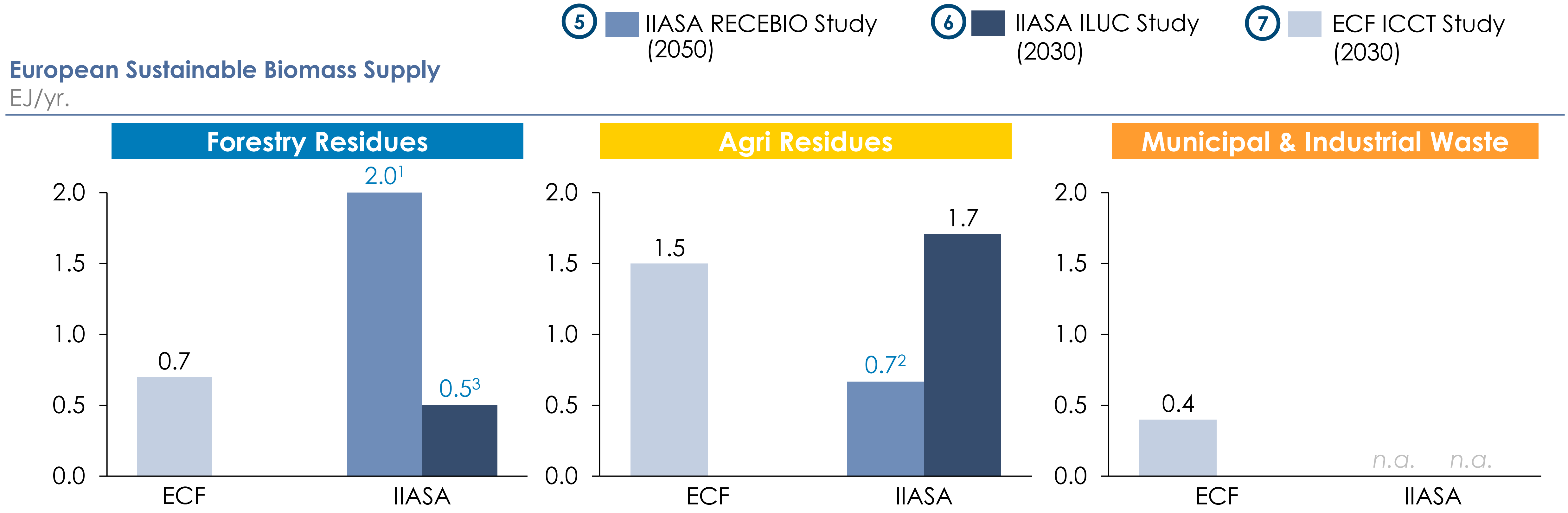
European studies focused on waste & residues sources in detail, and in some areas suggest higher availability than equivalent ICCT and IIASA global studies



Illustrative scaling of EU waste and residue estimates to a global level

	Forestry Residues			Agri Residues			Municipal & Industrial Waste		
EU as % of global	*29%*			*14%*			*14%*		
EU scaled to global (EJ)	2.3	6.9	1.7	11.3	5.1	12.4	3.1	*n.a*	*n.a*

Note: Assuming conversion factors of 17 and 20 GJ/ton for agricultural and forest residues, respectively. EU ILUC study only considers wheat straw for agri residues. ((1)Forestry residues in RECEBIO Study assumed to include Black Liquor, industrial by-products and forest residues; conversion factor applied for woody biomass (16 GJ/t); 2)Assuming 1 Mtoe = 5.8 Mm3; Ag residues for RECEBIO for 2030 drawn from 2014 EU Commission Impact Assessment Report, pg 62 ; (3) The sustainable potential estimated to be 73Mm3 (note, not considered therefore to be economic potential based on residue prices, which would be lower).

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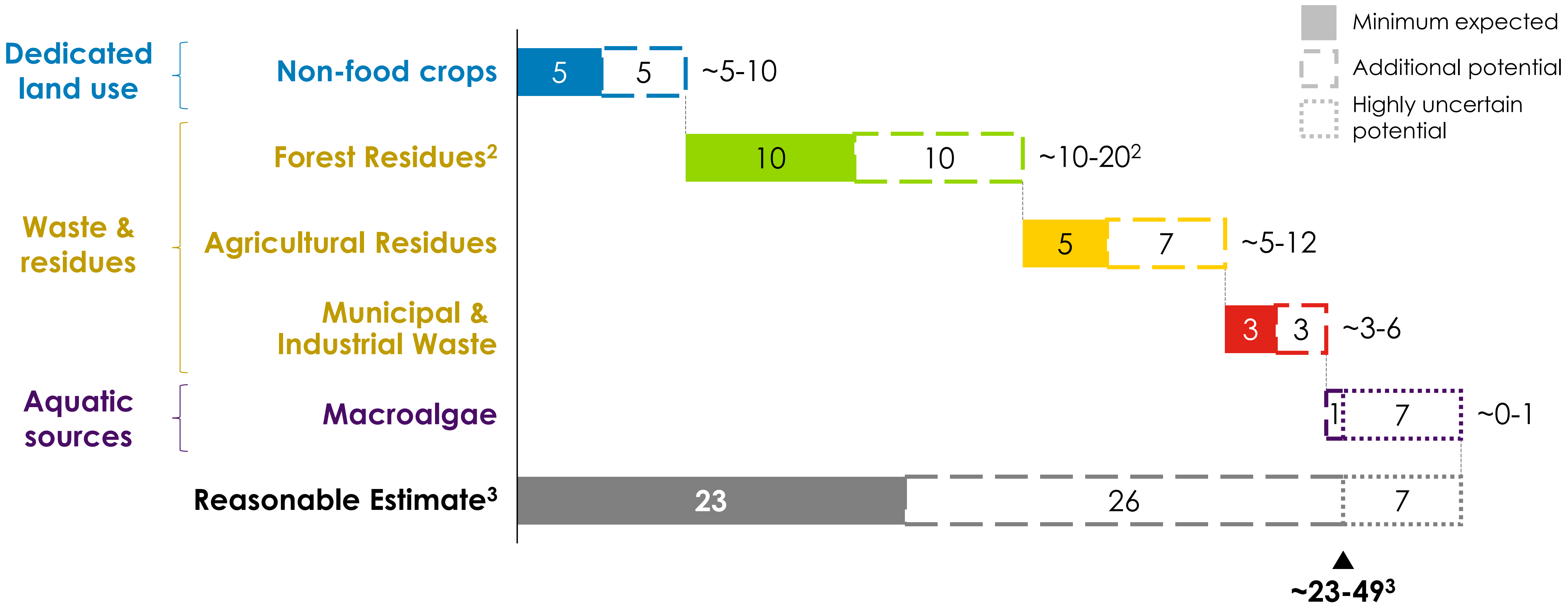
Sustainable biomass supply is likely to be constrained in 2050 - a 'reasonable estimate' across studies suggests ~25-50 EJ/yr primary energy could be available for energy and industrial uses in 2050

Global sustainable biomass[1] supply (2050)

EJ/yr



(1) The term 'sustainable biomass' is used to describe organic material that is renewable, has a life-cycle carbon footprint equal or close to zero (including considerations for the opportunity cost of land), and for which the cultivation and harvesting practices used are mindful of ecological considerations such as biodiversity and health of the land and soil. (2) Supply estimates exclude traditional fuelwood as well as biomass for the timber and pulp & paper sectors (~14 EJ/yr today (FAO Industrial Roundwood minus by-products used for energy)). (3) Stated range of Reasonable Estimate excludes ~7 EJ/yr of highly uncertain potential from macroalgae.

The studies reinforce the scarcity of low carbon, sustainable biomass supply and suggest ~25-50EJ 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*	5*	n.a.	n.a.	n.a.		*Low to zero*
	Non-Food Crops	1	8	0		5	56	n.a.	75	n.a.		~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					5.1-12.4	5	11.3		~5-12
	Municipal & Industrial Waste				6-14				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	Macroalgae				0.1						~1-8**	~0-1**
	Microalgae				<<1						<1	0
	Subtotal				0.1						0-1**	**~0-1****
	Total	**11**	**44**	**26**	**6-14**	**32**	**115**	**6.8-19.3**	**86.4**	**16.7**	**3-7**	**~25-50**

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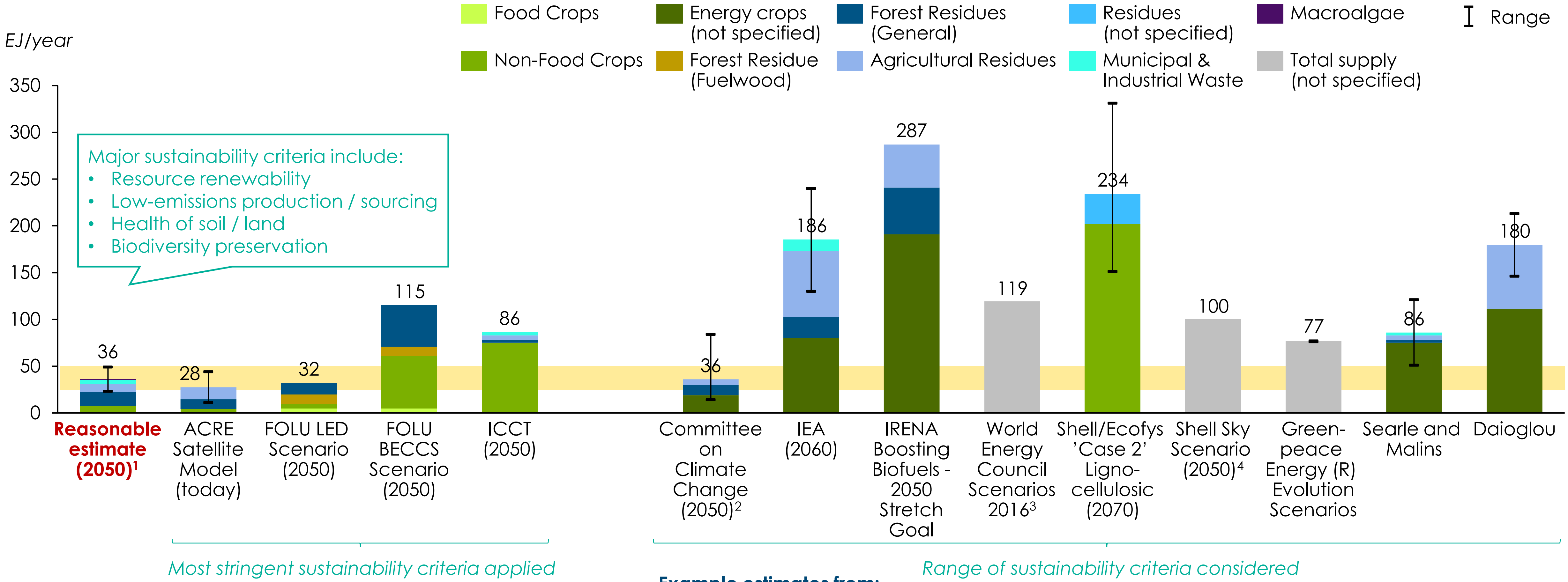
Note: Traditional fuelwood as well as biomass for the timber and pulp & paper sectors excluded; (*) 1st generation energy supply included to account for current targets, but its contribution is assumed to be small and remain negligible going forward; (**) Highly uncertain potential, majority excluded from total.

A 'reasonable estimate' of ~25-50EJ per year of primary energy from biomass is consistent with other sustainability-focused estimates but lower than many others



Example estimates from:

Sustainability studies reviewed in detail in our evaluation of biomass supply

Energy agencies | **Industry** | **NGOs** | **Academia**

(1) Reasonable Estimate: midpoint of range; excludes ~7 EJ/yr of highly uncertain potential from macroalgae; excludes traditional fuelwood as well as biomass for the timber and pulp & paper sectors (~14 EJ/yr today (FAO Industrial Roundwood minus by-products used for energy)). (2) Mid scenario. (3) Unfinished Symphony Scenario. (4) Excludes traditional uses of biomass (fuelwood, charcoal and dung used in the residential sector, predominantly in developing countries).

Sources: ACRE, FOLU/IIASA, ICCT, Deng et al. Country-level assessment of long-term global bioenergy potential. Biomass & Bioenergy 74 (2015) 253-267.; IEA Technology roadmap: Delivering Sustainable Bioenergy (2017); IEA 2017 Technology Perspectives (and sources within); Committee on Climate Change Biomass in a low-carbon Economy (2018); Shell Sky Scenario (2018)

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

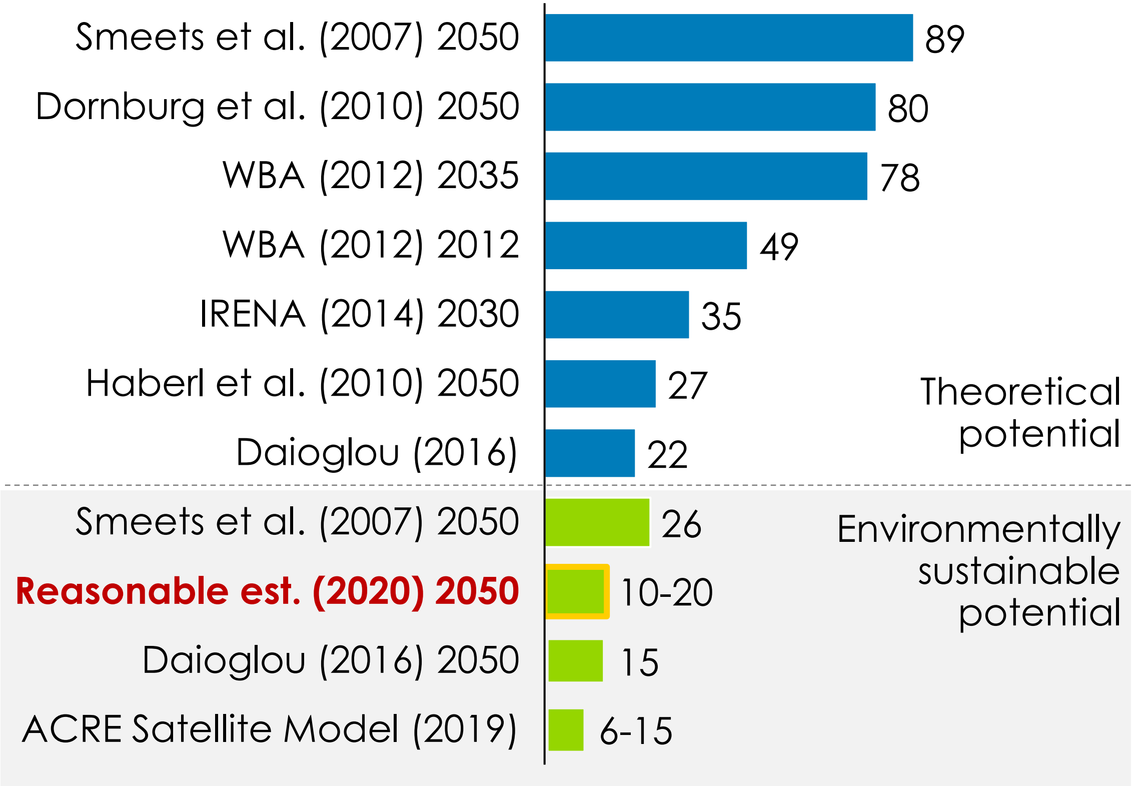
	Ecofys / Shell (2015)	International Energy Agency (IEA, 2017)
Mid-century bio-resources potential	**130-400 EJ** primary energy (2070) ▪ Dedicated land – energy crops (3/4ths) ▪ Forestry and agricultural residues (1/4th)	**130-240 EJ** primary energy (2060) ▪ Dedicated land (60-100 EJ) ▪ Forest residues (15-30 EJ) ▪ Agricultural residues (46-95 EJ) ▪ Municipal waste (10-15 EJ)
Key differences in sustainability criteria	▪ **Crop biomass prioritised over biodiversity preservation** in assessing the potential use of land available for climate mitigation ▪ **Cropland productivity not reduced** for abandoned cropland	▪ **Agricultural land considered in scope** for bio-resource production (i.e., dedicated land includes non-marginal land that is appropriate for agriculture (but where current production is low) as well as pasture landscapes) ▪ **Municipal waste supply includes** inseparable non-biogenic material (e.g., **plastic waste**)

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*

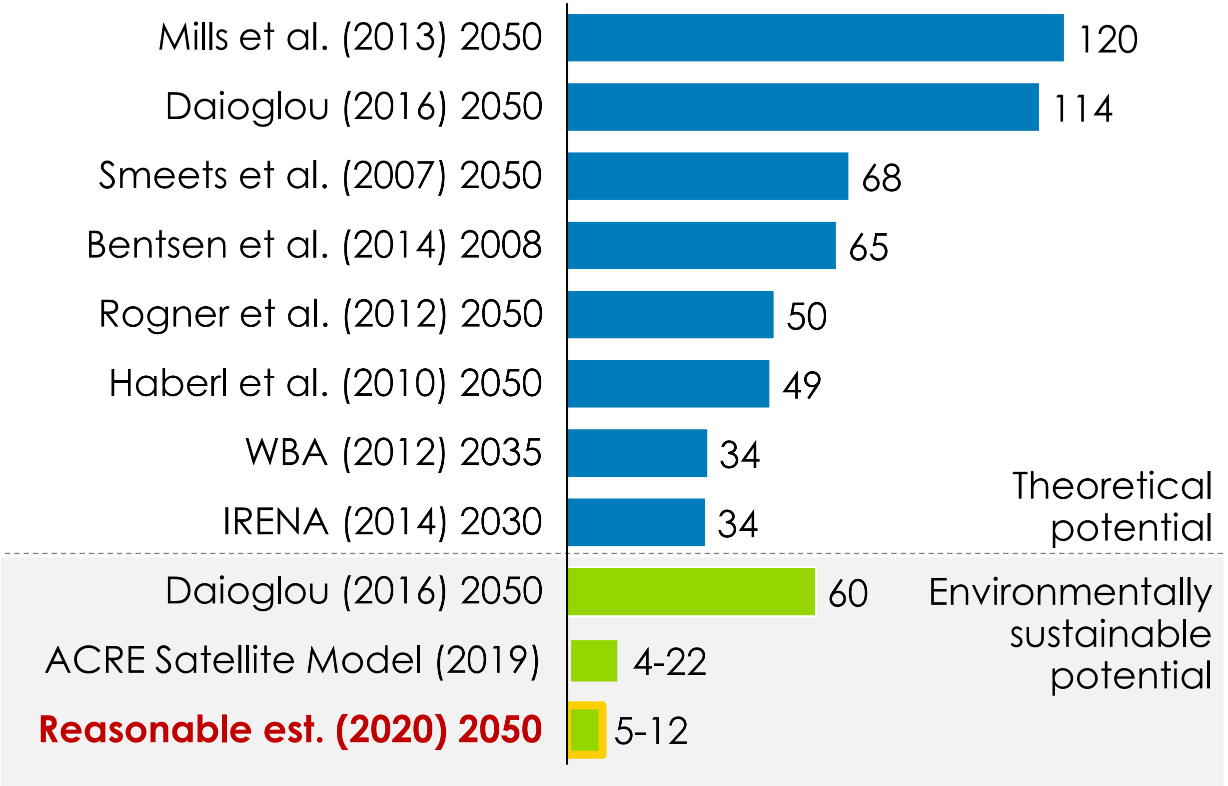
The reasonable consensus falls within a similar range as other studies looking at environmentally sustainable biomass potential

Theoretical potential | Environmentally sustainable potential | **This review of studies**

Energy potentials in this analysis versus literature (*forests*)
Global energy potential of forest biomass, EJ



Energy potentials in this analysis versus literature (*agriculture*)
Global energy potential of agriculture residue biomass, EJ



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

Sources of biomass		Key sustainability questions considered
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		

Source material for referenced studies

	Study	Coverage	Source material
1	**ACRE** Satellite Model	Global 2018	*Proprietary*
2	Food and Land Use Coalition (**FOLU**) / **IIASA**: *Low Energy Demand* (***LED***) *Scenario*	Global 2020-2050	• https://www.foodandlandusecoalition.org/wp-content/uploads/2019/09/FOLU-GrowingBetter-GlobalReport.pdf; • https://www.foodandlandusecoalition.org/wp-content/uploads/2019/09/FOLU-GR-IIASA-Supplementary-Paper_final.pdf; • https://www.nature.com/articles/s41560-018-0172-6
3	Food and Land Use Coalition (**FOLU**) / **IIASA**: ***BECCS***[1] *Scenario*		
4	**ICCT**	Global 2050	• https://onlinelibrary.wiley.com/doi/full/10.1111/gcbb.12141
5	**IIASA: EU** Commission Study (RECEBIO)	EU 2020-2050	• http://pure.iiasa.ac.at/id/eprint/14006/; • http://ec.europa.eu/environment/enveco/resource_efficiency/pdf/bioenergy/KH-02-16-505-EN-N%20-%20final%20report.pdf
6	**IIASA**: Land Use change impact of biofuels in **EU**	EU 2020-2030	• http://pure.iiasa.ac.at/id/eprint/12310/; • https://ec.europa.eu/energy/sites/ener/files/documents/Final%20Report_GLOBIOM_publication.pdf
7	**ECF EU** study conducted by **ICCT**	EU 2018-2030	• https://pubag.nal.usda.gov/catalog/5267579
	Shell / Ecofys	Global 2070	• https://www.sciencedirect.com/science/article/pii/S0961953414005340
	International Energy Agency (IEA)	Global 2060	• https://www.iea.org/reports/technology-roadmap-delivering-sustainable-bioenergy

(1) BECCS = bioenergy with carbon capture and storage

Overview of key studies

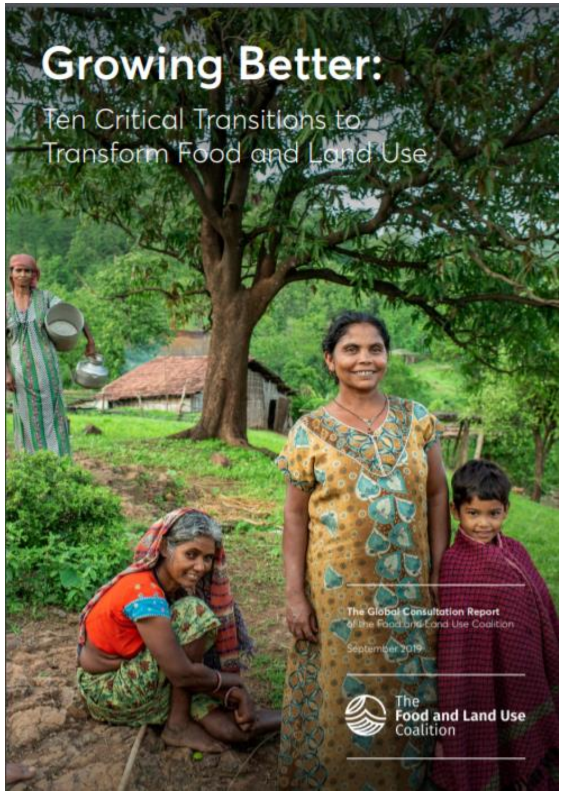
- Food and Land Use Coalition (FOLU)
- International Institute for Applied Systems Analysis (IIASA)
- European Climate Foundation (ECF)
- ACRE study

Growing Better: Ten Critical Transitions to Transform Food and Land Use

The Food and Land Use Coalition

The FOLU Global Consultation Report, 2019

- The first **integrated, global assessment** of the social, economic and health benefits of transforming our food and land use systems, and the large, growing costs and risks of inaction.
- Identifies that there are no systemic trade-offs between: 1) better **environment**, 2) better **human health**, 3) more **inclusive development** and 4) enhanced **food security.**
- Describes a **systemic reform agenda** and how this might be applied through ten critical transitions, the delivery of which result in an economic prize of **$5.7 trillion a year** in avoided damage to people and the planet by 2030, more than 15 times the investment cost of **$300-350 billion a year.**
- It is "**consultation report**": it aims to trigger action, but also to inspire dialogue and debate across the world, supporting a shared journey of learning, creativity & societal change.



Find online here: https://www.foodandlandusecoalition.org/global-report/

Economic Prize
$5.7 trillion economic prize by 2030 and $10.5 by 2050 based on avoided hidden costs

Investment Requirements
$300-$350 billion required each year for the transformation of food and land use systems to 2030

Business Opportunity
$4.5 trillion annual opportunity for businesses associated with the ten critical transitions by 2030

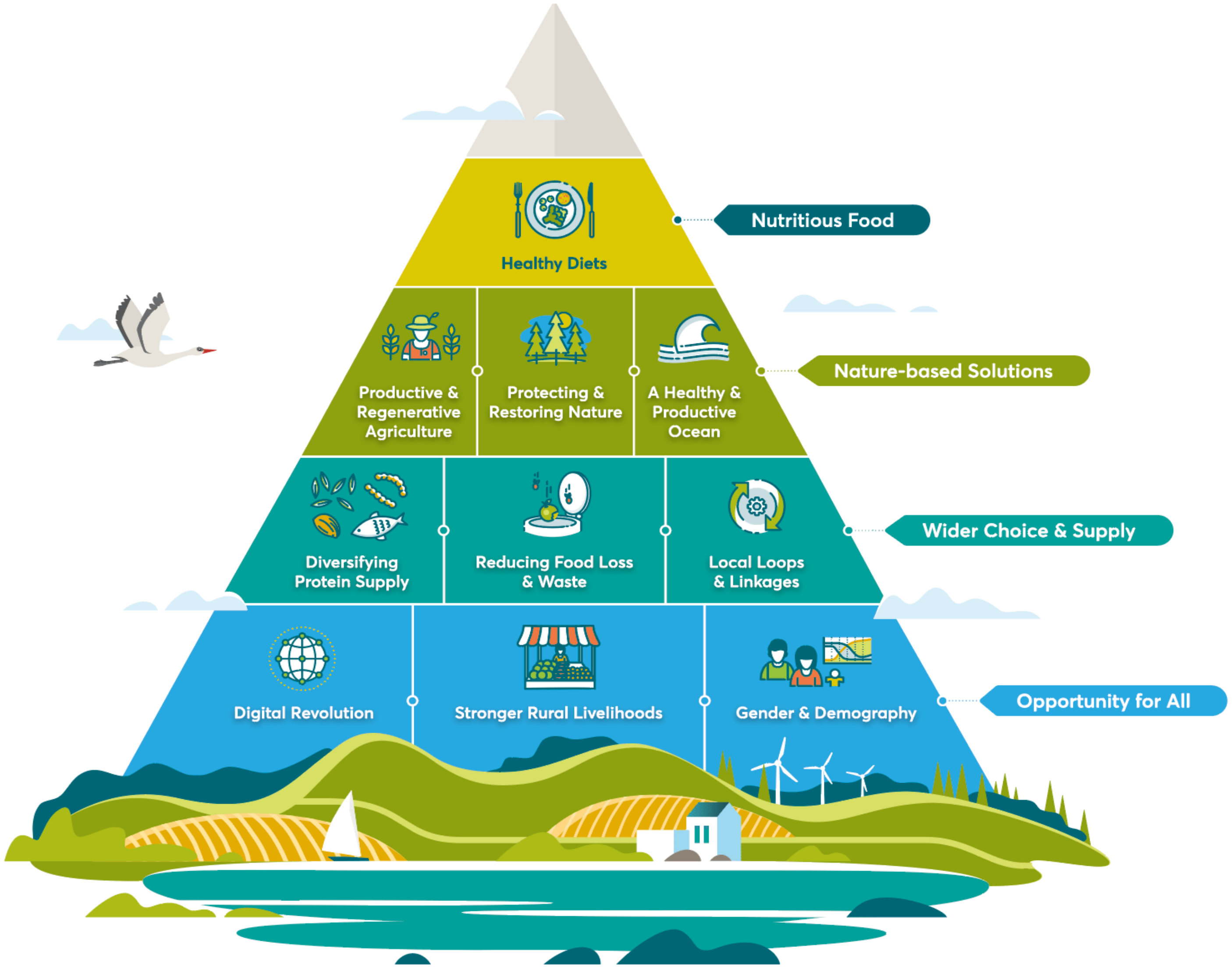
Coalition partners:

AGRA Growing Africa's Agriculture; EAT; gain Global Alliance for Improved Nutrition; IIASA International Institute for Applied Systems Analysis; Sustainable Development Solutions Network – A Global Initiative for the United Nations; SYSTEMIQ; wbcsd; World Resources Institute; World Farmers' Organisation

Supported by:

MAVA Fondation pour la Nature; Gordon and Betty Moore Foundation; NICFI; UKaid

The “Better Futures” scenario can be realised through action towards Ten Critical Transitions



Nutritious food:

- Transitioning toward diets that are conducive to good human and planetary health.
- Empowering consumers to make better-informed decisions that are healthier for them and for the planet ignites the whole reform agenda.

Nature-based solutions (NBS):

- NBS are mobilised to create more productive, regenerative techniques of food production, new approaches to protecting forests and other critical ecosystems, and new ways to manage the ocean in order to protect ocean life and increase ocean protein production.

Wider choice and supply:

- Expanding consumer choice and supply, especially of resource-intensive, healthy foods such as proteins.
- Accelerating the diversification of protein supplies, reducing food loss and waste and creating more local supply chains, together with tighter resource looping.

Opportunity for all:

- Ensuring that digitisation empowers people rather than concentrates data, that investment is made in the talent, infrastructure and social systems needed for a rural renaissance, and that women are supported in making choices that are better for themselves, their families and communities.

Source: Food and Land Use Coalition, 2019

The Food and Land Use Coalition

The "Better Futures" scenario models key drivers to realise the Ten Critical transitions

Better environment.

Food and land use systems are net carbon-neutral, contributing up to one-third of the mitigation needed to stay within 1.5°C; biodiversity loss halted; ocean fish stocks restored; 80% reduction in food and land use system air pollution.

Better health.

Eliminate under-nutrition and halve the disease burden associated with consuming too many calories and unhealthy food.

Inclusive development.

Boost income growth for the bottom 20% of the rural population, increase yields of low-productivity smallholders, create over 120 million extra decent rural jobs and contribute to a more secure future for indigenous and local communities.

Food security.

Increase food security significantly by helping to stabilise or even lower real food prices, to supply enough food of the right quality and quantity and to improve access for the poorest and most vulnerable.

Overview of the Food and Land Use Coalition

The Food and Land Use Coalition

Overview of the Coalition

Launched in 2017, FOLU brings together stakeholders to accelerate the transformation of food and land-use systems to deliver the SDGs, Paris Agreement & Aichi Biodiversity Targets.

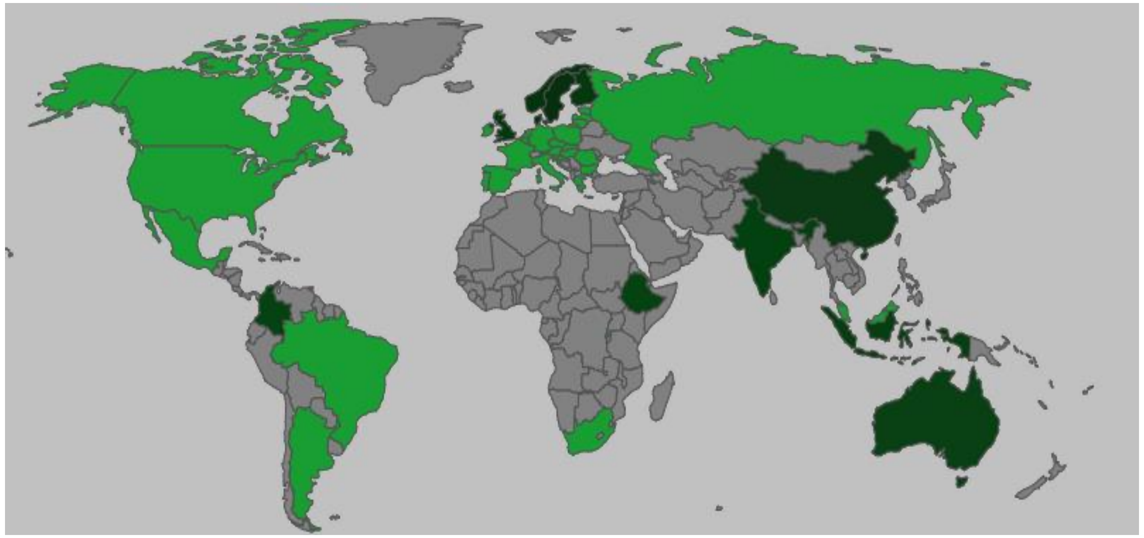
- A self-governed coalition of diverse institutions
- With an expansive & influential network
- Reaching across global & national levels
- Delivering a robust evidence base for action

Our mission is to:

- Protect & restore the planet's natural resources & ecosystems
- Build a more resilient, prosperous rural economy for farmers & fishers
- Shift food & land use systems so they become a net GHG sink
- Find a healthier, less wasteful way to feed 9+ billion people by the 2030s
- Build stronger international collaboration on food and land use, specifically with EU and China

Country Work

- Create social, environmental & economic case for change
- Break down silos for systemic solutions
- Set long-term targets & ambition, through FABLE Consortium
- Access top-level political leaders
- Build domestic stakeholder support
- Strengthen high ambition coalitions



FABLE countries | FOLU country platforms

Coalition partners:

AGRA Growing Africa's Agriculture · EAT · GAIN Global Alliance for Improved Nutrition · IIASA International Institute for Applied Systems Analysis · Sustainable Development Solutions Network · SYSTEMIQ · wbcsd · World Resources Institute · World Farmers' Organisation

Supported by:

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Indicator	2050: CURRENT TRENDS scenario		2050: BETTER FUTURES scenario	
Deforestation	Deforestation continues at a rate of 6.7 million hectares (Ha) per year	6.7 mHa/yr	Deforestation reduces to a rate of 0.2 million hectares (Ha) per year	0.2 mHa/yr
Agricultural land	The area of land dedicated to agriculture increases by 400 million Ha (12% of area today)	400 mHa	The area of land dedicated to agriculture decreases by 1200 million Ha (37% of area today)	1200 mHa
Restored natural land	225 million Ha are restored to natural ecosystems since 2010.	225 mHa	1300 million Ha are restored to natural ecosystems since 2010.	1300 mHa
Biodiversity	Biodiversity loss continues to decline at a rate similar to the last 40 years.	-3.2% loss	Biodiversity recovers by 0.2% compared to 2010.	0.2% recovery
Food and land use emissions	Emissions account for 12-13 $GtCO_2e$ putting a 1.5 degree future pathway out of reach.	12-13 $GtCO_2e$/yr	Emissions from food and land use systems reduce to net zero.	Net Zero
Food insecurity (2030)	By 2030 the number of food insecure people globally is 475 million.	475 million	Enough food is produced to completely eliminate food insecurity.	Sufficient Production
Death due to high Body Mass Index	10.1 million people die prematurely each year due to high body mass index (BMI)	10.1 million	5.6 million people die prematurely each year due to high BMI – 50% compared to current trends	5.6 million
Ocean food economy	Wild catch declines by 15% due to overfishing leading to continued decay of global fish stocks	15% decline	Wild catch improves by 24%as all fisheries are managed within maximum sustainable yield.	24% increase

International Institute for Applied Systems Analysis
IIASA www.iiasa.ac.at

science for global insight

Towards sustainability pathways for the agriculture and food system

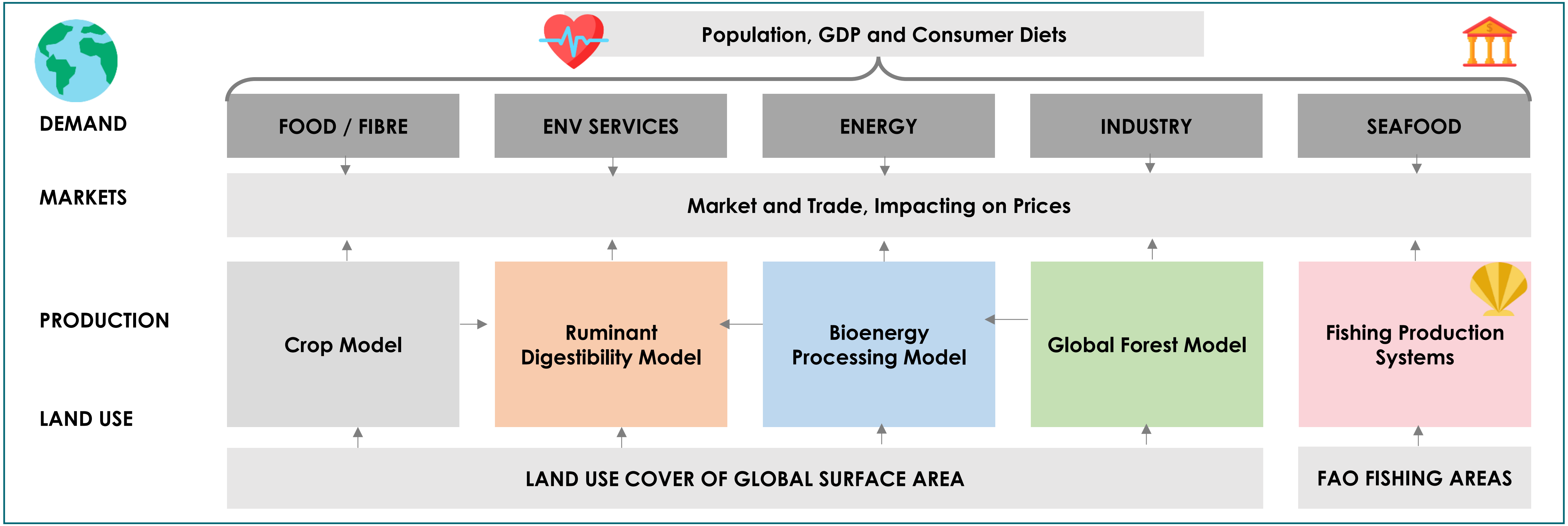
GLOBIOM modelling for FOLU

Andre Deppermann, Hugo Valin, Mykola Gusti, Frank Sperling, Miroslav Batka, Jinfeng Chan, Stefan Frank, Pekka Lauri, David Leclere, Amanda Palazzo, Marcus Thomson,
Petr Havlik, Michael Obersteiner

IIASA modelled integrated sustainability pathways for the agriculture and food system using GLOBIOM, creating the FOLU Better Futures scenario

The Food and Land Use Coalition

GLOBIOM model



Other modelling inputs:

University of Washington: Global Burden of Disease

- Population inputs

University of Santa Barbara: emLAB

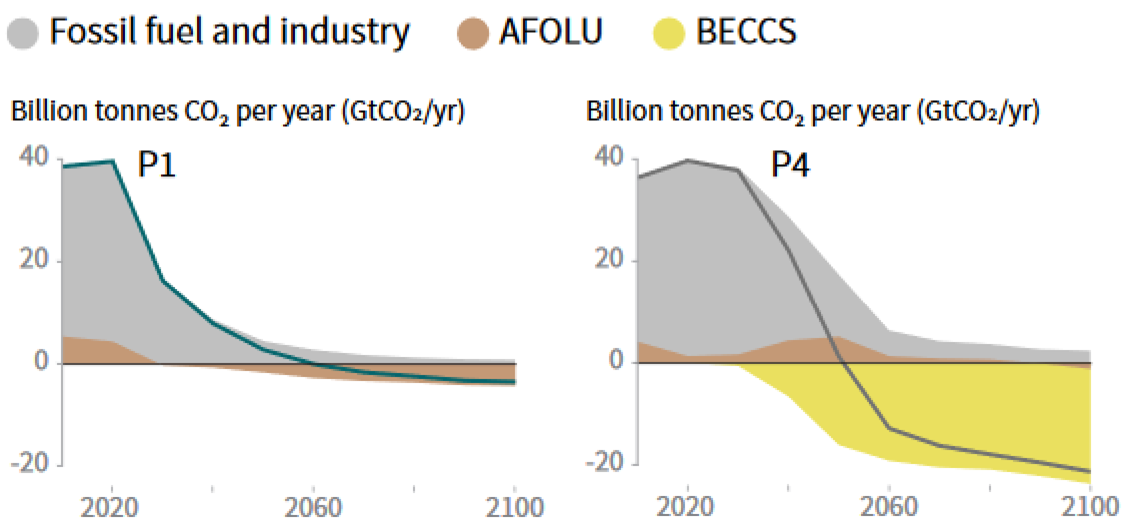
- Potential for ocean proteins

World Bank: Shockwaves Model

- Income distribution and skilled employment in urban / rural sectors.

Core modelling features of the FOLU/GLOBIOM Better Futures Scenario

Key Features of the FOLU/GLOBIOM Better Futures Scenario	
Climate Mitigation	• 1.5 ° C mitigation target • Follows the IIASA Low Energy Demand Scenario
Biodiversity	• Protects biodiverse rich areas using a subsidy • Drives restoration of degraded and pasture land
Food Security	• Zero hunger (SDG2) by 2030, less than <1% global population at risk of hunger
Healthy, Sustainable Diets	• Global convergence towards an EAT-Lancet diet by 2050
Zero Net Deforestation	• Global NET deforestation from 2030 onwards
Significant technological progress	• 10% higher increase in technical progress (productivity) than baseline. • 25% of the yield gap reduced
Trade Facilitation	• Increase of trade between the 37 GLOBIOM regions (trade costs increase) • 50% trade cost reduction within Sub-Saharan Africa
Oceans Productivity	• Half of wild caught fisheries are sustainably reformed by 2050 • Technological improvements see a scale up in aquaculture production

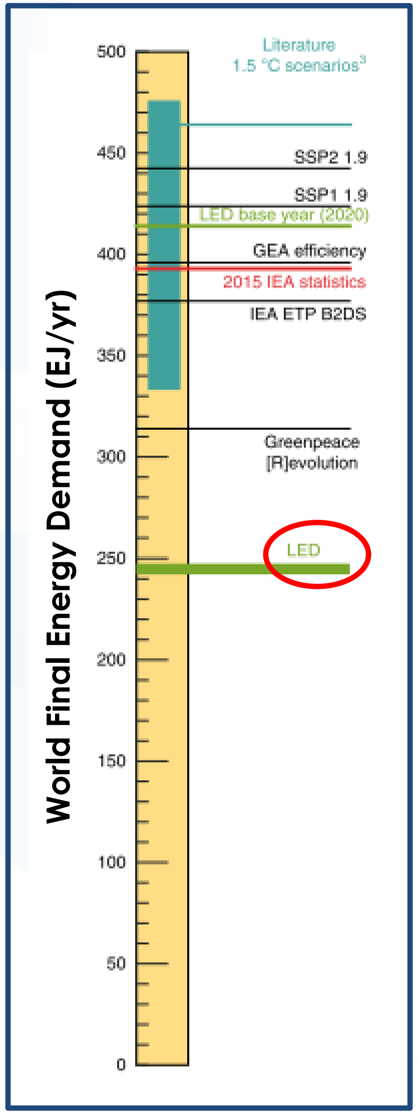


Source: IPCC Special 1.5°C report

Two Scenario Paradigms

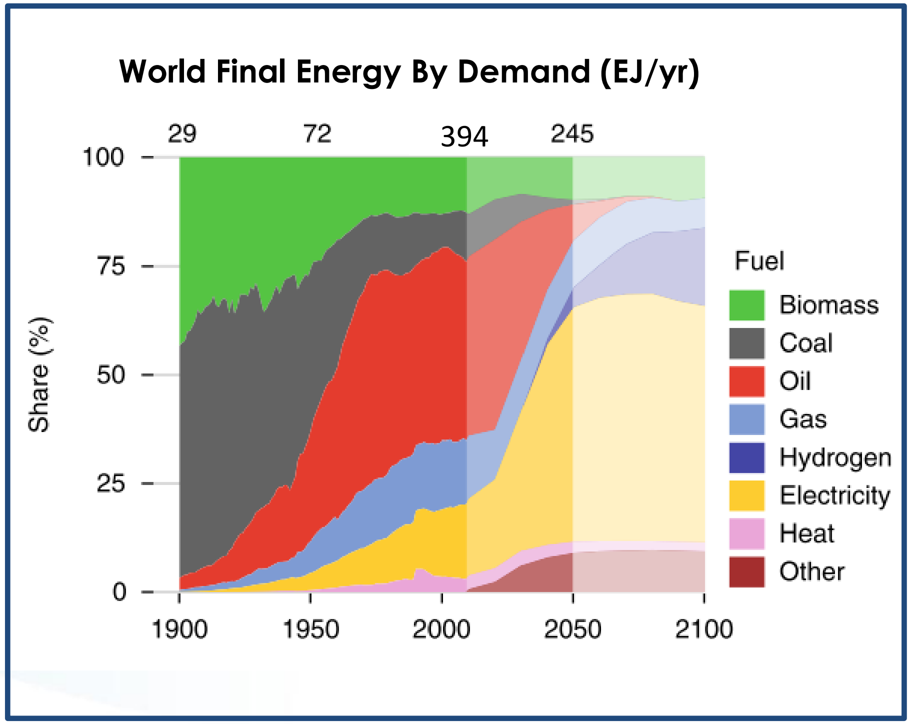
Better Future: 1.5 C Low Energy Demand Scenario (no BECCs)	Better Future: 1.5 C (includes BECCs)
40% reduction in energy consumption from the 2020 baseline to 2050. → Primary scenario- reported in *Growing Better* (does not rely on BECCs).	**~5%** increase in energy consumption from the 2020 baseline to 2050. → Secondary scenario (not reported)

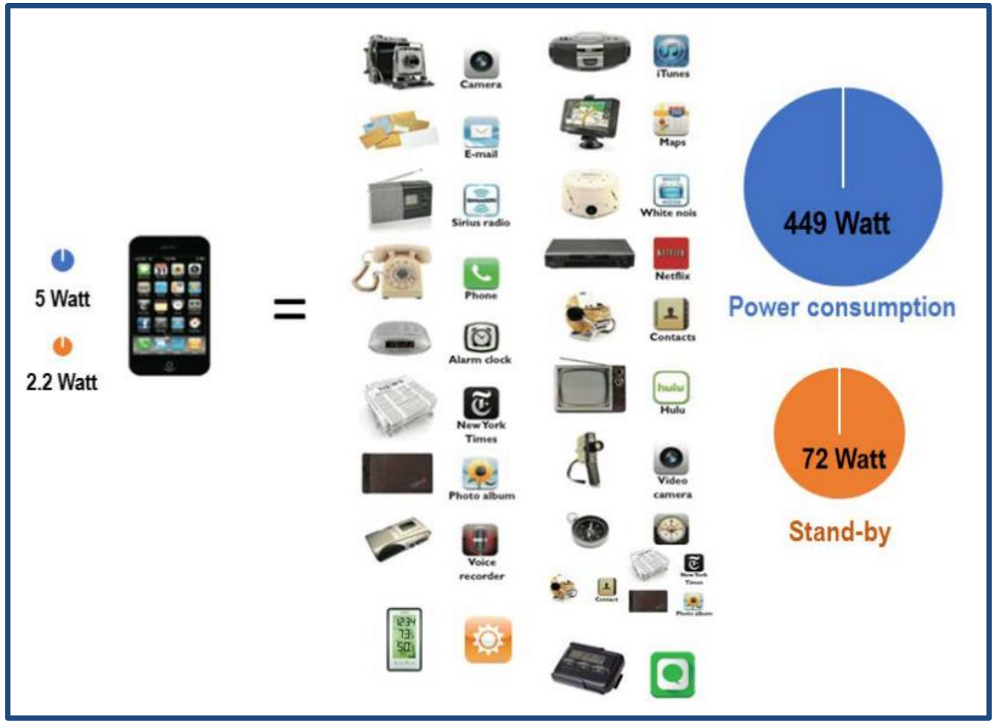
Underlying assumptions for the IIASA Low Energy Demand (LED) Scenario



- The **LED Scenario** (Grubler et al., 2018) was developed to visualise a 1.5 C mitigation pathway without using as-yet unproven CCS.

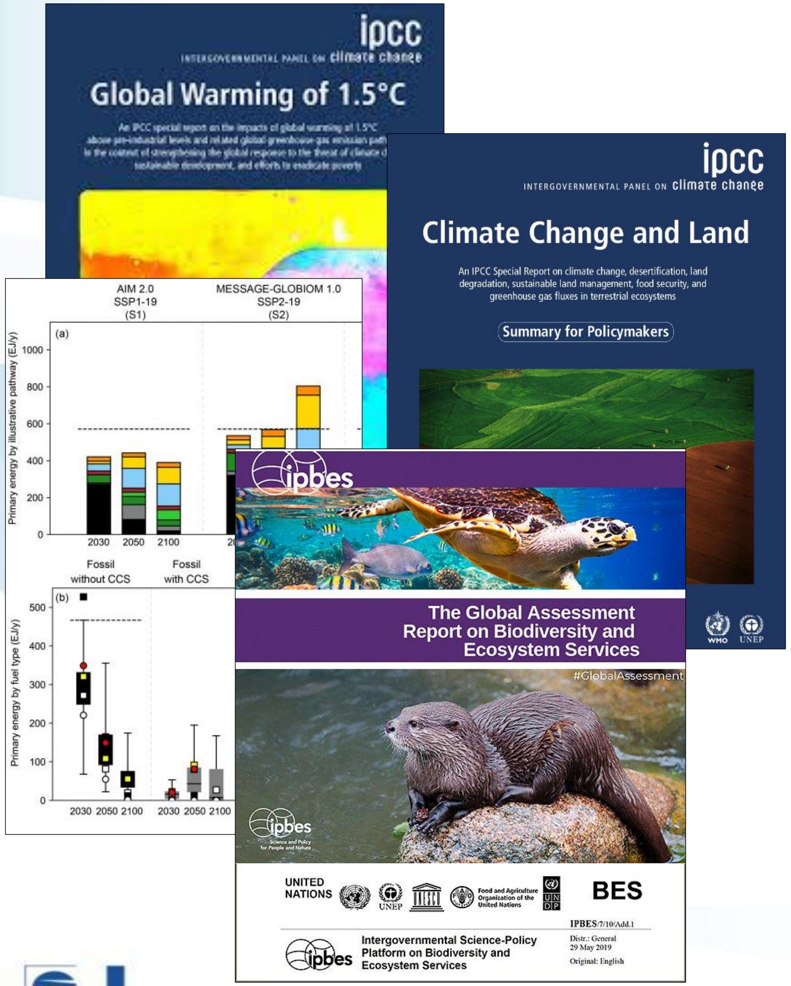
- It assumes a more radical shift in energy demand compared to conventional scenarios **(-40% for 2020-2050)** through:
  - scaling up of existing energy efficiency technologies for all sectors
  - large deployment of decarbonised energy sources.



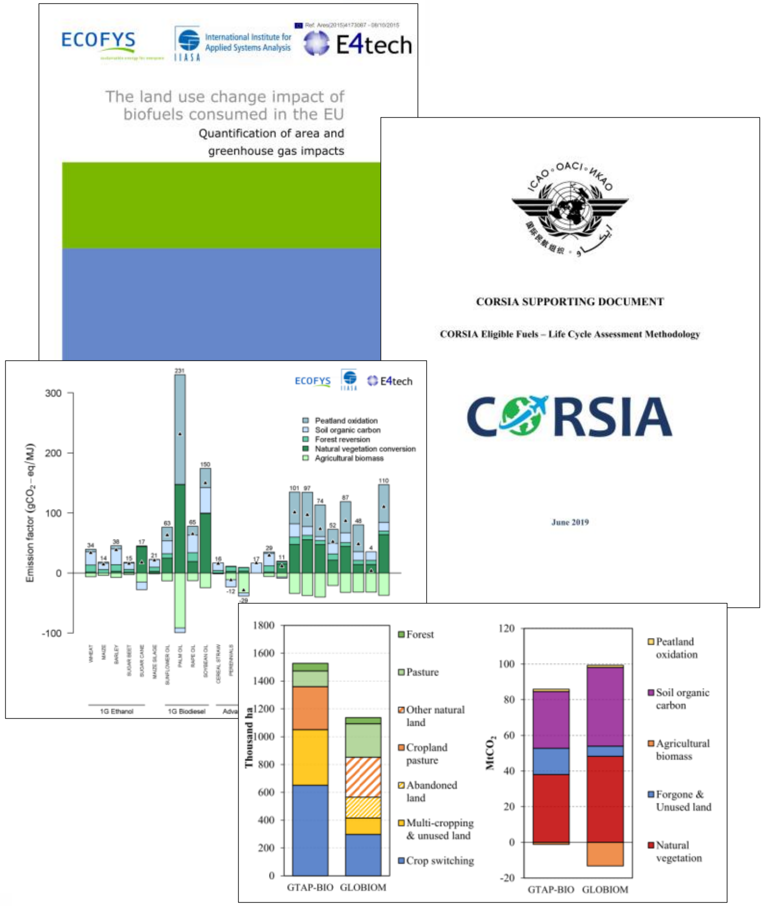


Bioenergy as part of the broader GLOBIOM team research/policy agenda

Integrated assessment for climate change mitigation



Sectoral consequential analysis for biofuels LCA



Policy support for Long term strategies modelling

IIASA – Summary of Bioenergy-related Studies

	Low Energy Demand (LED) Scenario	BECCS Scenario	FOLU *Growing Better* Study	EU Commission Study (RECEBIO)	Land Use change impact of biofuels in EU
Published Study Reference	Grubler et al. 2018	Grubler et al. 2018	FOLU *Growing Better* 2019	Forsell et al., 2016 Fulvio et al., 2016*	Valin et al., 2015
Primary Objective	To develop a climate mitigation scenario for 1.5 Celsius Pathway without relying on BECCS.	Demonstrating a 1.5C climate mitigation pathway along a middle of the road socioeconomic development pathway (SSP2).	To demonstrate that it is possible to meet targets of food security, climate mitigation and environmental restoration within planetary boundaries (SSP2)	To examine the resource efficiency implications of increased EU use of bioenergy for electricity and heat until 2050 via modelling of wood biomass production and use.	To provide new insights to the EUC about indirect carbon & land impacts from biofuels, with more details individual feedstocks than was done before (SSP2)
Description	GLOBIOM	GLOBIOM	GLOBIOM	G4M / GLOBIOM	GLOBIOM
Defining Assumptions	40% reduction in energy demand through energy efficiency strategies SSP2 Pathway	SSP2 Pathway	The primary FOLU Scenario built on the **LED scenario** (FOLU-LED). Sensitivity tested against BECCs scenario (FOLU-BECCS)	Reporting on the **EU Emission Reduction Scenario** which assumes the policy target of 80% reduction of GHG EU emissions by 2050. Agricultural remain constant** and municipal sources are not included.	Reporting on the **EU Biofuel Mix in 2020** scenario. The EU 2020 Mix is about 90% food crop fuels, 10% woody biomass fuels. 33-50% agricultural residue removal considered sustainable for soil health.
Geographic Scope	Global	Global	Global	Europe	Europe
Timeframe	10 year time steps 2000 - 2100	10 year time steps 2000 - 2100	10 year time steps 2000 - 2050	2050	2030

* Fulvio et al., drawn on for assumptions about thresholds for residue removal.
** 2014 Impact Assessment Report https://ec.europa.eu/smart-regulation/impact/ia_carried_out/docs/ia_2014/swd_2014_0015_en.pdf

Availability of wastes and residues for advanced biofuel in EU Member States

European Climate Foundation

THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

Policy context

- EU Renewable Energy Directive (RED) requires 10% of road transport fuels to be renewable by 2020
- iLUC Directive has been finalized
  - 7% cap on food-based fuels
  - iLUC reporting
  - 0.5% target for advanced biofuels made from e.g. wastes and residues
- Is the 0.5% advanced biofuel target achievable for EU Member States?

Scope of this study

- Estimate availability of wastes and residues in each EU MS
- Agricultural residues, forestry residues, biogenic wastes
- Present and projections to 2020 and 2030
- Sustainable availability without adverse impacts on existing uses, soil quality
- Number of biorefineries and jobs
- Total amount of advanced biofuel that could be produced in each MS compared to 0.5% target

ACRE: The biomass available for energy and industrial demands is limited by environmental, economic, and socio-political sustainability

Filters

a **Biologically** potential biomass

b **Environmentally** sustainable potential biomass

c Environmentally sustainable biomass after **economic/social** constraints

Methodology

- Using **satellite image data** to understand land use (e.g., global forest and cropland cover)
- Sizing the availability of **degraded land** for energy crops
- Calculating the amount of **additional biomass growth** each year in forests
- Assessing the availability of **agricultural and forestry residues**
- Adjusting for **yields**
- Converting to **energy density**

- **Excluding areas that do not meet sustainability criteria** (i.e., areas of high biodiversity, peatlands, wetlands, virgin forests, land with low soil health[1] or high erosion, and protected areas)
- **Reducing the amount** of wood and agricultural residues that can be taken to allow for **maintaining soil quality**[2]

- Filtering by **economic constraints**:
  – Competing demand
  – Logistics
  – Legal constraints
  – Difficult terrain
  – Affordability
- Filtering by **socio-political constraints**:
  – Corruption/ability to do business metrics[3]
  – Slavery[4]

1 Excluding land with <2% soil carbon 2 To obtain a minimum of 1000t/km2 left on the ground 3 Thomson Reuters Country Check; Transparency International Corruption Perceptions Index 4 Global Slavery Index SOURCE: Deng et al., 2015; global forestry (e.g., FAO) and agricultural databases (e.g., Phyllis2, ASA); Wu et al. (2017), Newbold et al (2016); CCI land cover data; Global Soil Erosion, JRC; SoilGrid.com; MapSpam; Bai et al. (2008); Xue et al. (2015);. Gibbs and Salmon (2015); Smeets and Faaij, 2007; Diaoglou et al., 2016; Bunting et al., 2018; Potatov et al., 2017; Sandeman et al., 2017; Mai-Moulin et al., 2018;

Source # 1: Biomass from dedicated land use

Sources of biomass		Key sustainability questions considered
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		

Biomass from dedicated land use: sustainability considerations

A Primary uses of land (A–D)

B Climate mitigation (D–F)

A) Land area dedicated to climate mitigation	Assessment of land area that can be dedicated to climate mitigation without ***competing with food production*** or ***affecting forest area/ high carbon stock land,*** either due to demand or quality of soil
B) Enabling assumptions on crop & pasture land	Assumptions on ***long-term demand*** (e.g. population growth, diets) ***and yield trends*** and the consequent amount of cropland & pasture required
C) Social factors	Other social factors considered, e.g. ***corruption and slavery*** risks associated with biomass sourced from specific countries
D) Biodiversity considerations	Exclusion of area based on high ***biodiversity value*** or other reasons for ***preservation,*** particularly pristine environments (e.g. natural landscapes and ecosystem services).
E) Carbon trade-offs	The perspective on ***carbon benefits and opportunity costs*** of using land for dedicated biomass production vs other uses (e.g., for renewable energy or reforestation)
F) Energy crop & yield levels	Assumptions on ***energy crop types*** and average ***biomass yield***, including adjustment if applied to degraded land

Biomass from dedicated land use: Comparison of method and assumptions

Inferred from information provided

	① ACRE Satellite Model *Global 2018*	② ICCT *Global 2050*	③ FOLU/IIASA – LED *Global 2050*	④ FOLU/IIASA – BECCs *Global 2050*
A Land which can be dedicated to energy crops	Subset of all degraded land globally[1] (33 M Ha)	All degraded grassland and shrubland globally (930 M Ha) after applying 75% accessibility factor [2]	25 (M Ha) *Land demand is low due to energy efficiency measures*	252 (M Ha) *Land demand for energy crops dependant on how much is needed for BECCs*
B Enabling assumptions on crop & pasture land	Degraded land category does not compete with forests and agriculture (i.e. cropland and pastureland excluded)	Assume 10% expansion of cropland and pasture by 2050 based on average of figures in lit review	Land use optimised for multiple demands (including global food security, ecosystem restoration, forest carbon sequestration) Population growth, global diet shift and improving crop yields considered to determine land required for food production	
C Biodiversity considerations	Existing forests and areas of high biodiversity excluded		Biodiversity indicators see a recovery in this scenario	Biodiversity indicators declines due to land demand for BECCs.
D Carbon trade-offs considered	Assume future role for BECCS		Sequestration provided via land use change.	Sequestration achieved via land use change and BECCs
E Energy crop & yield levels	Miscanthus: 13 t/ha	Miscanthus & SRC (poplar, eucalyptus): 7.5t/ha (incl. long term trends on crop yields)	Woody biomass such as short-rotation coppice (SRC) and fast growing wood plantations. SRC yield range = ~5-18 t/ha[3] Yield improvement increase over time in line with past trajectories.	
F Social factors	Exclude 41 countries based on corruption / slavery risk	Socio-political adjustment factor	Assumes social dietary shift and energy efficiency targets will be achieved through climate mitigation policies.	
Totals	**Global, 2018:** 1-8 EJ	**Global, 2050:** 40-110 EJ	**Global, 2050:** 5 EJ*	**Global, 2050:** 56 EJ*

(*)+ 5EJ final energy demand from 1st gen biofuels from food crops, maintained at current levels; (1) Land degradation defined as *"long-term loss of ecosystem function and productivity caused by disturbances from which land cannot recover unaided."* Bai et al. (2009); (2) 50% on degraded land; (3) Based on crop yields for SRC in GLOBIOM, note, EU ILUC study highlights heterogeneity in EU regions: *"Avg yield for miscanthus/switchgrass is assumed to be 10.5 t dry matter/ha in Northern Europe, 9.2 t dm/ha in Central Europe and 9 t dm/ha in Western Europe. Switchgrass is assumed yield of 7.4 t dm/ha in Southern Europe, 8.7 t dm/ha in Eastern Europe and 10.1 t dm/ha in Western Europe."*

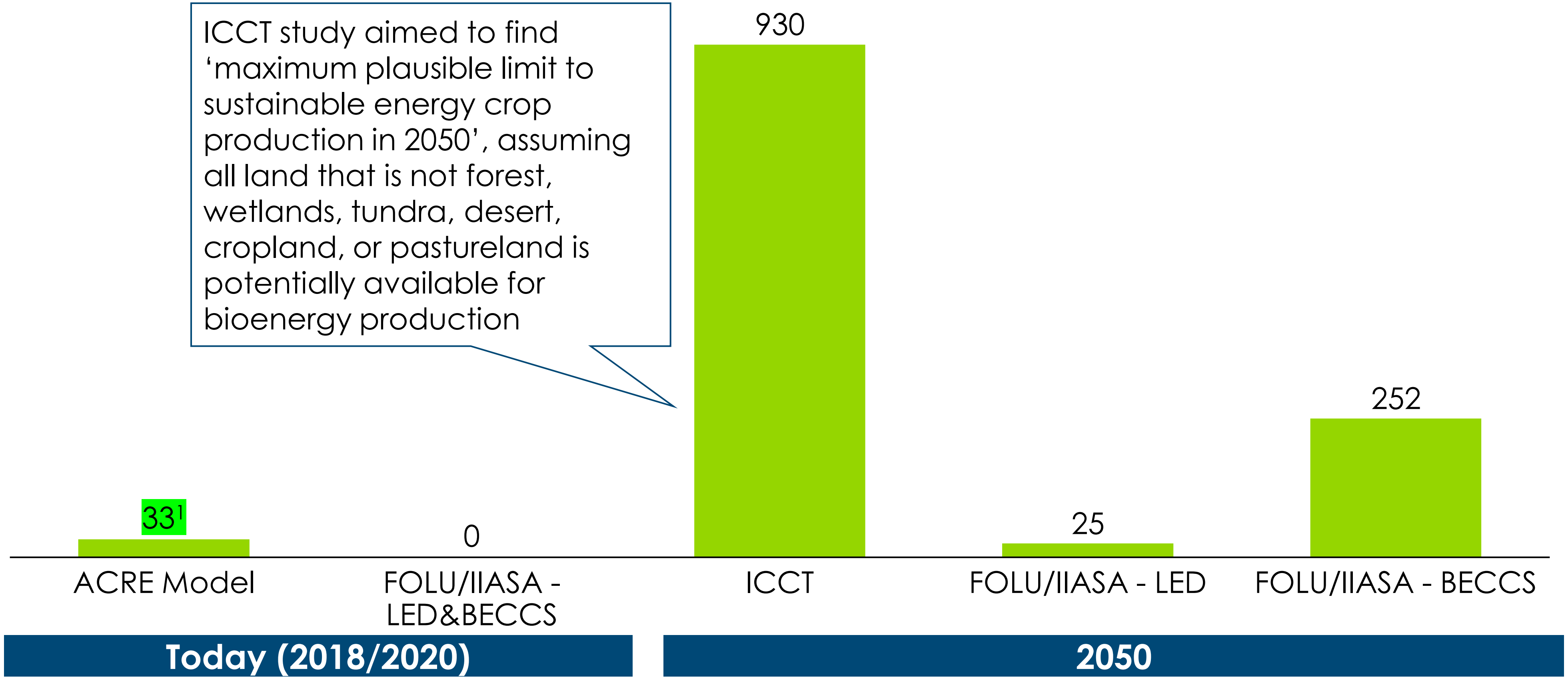
Comparison of sustainability studies: Key assumptions
Dedicated Land Area for Production of Biomass for Energy

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



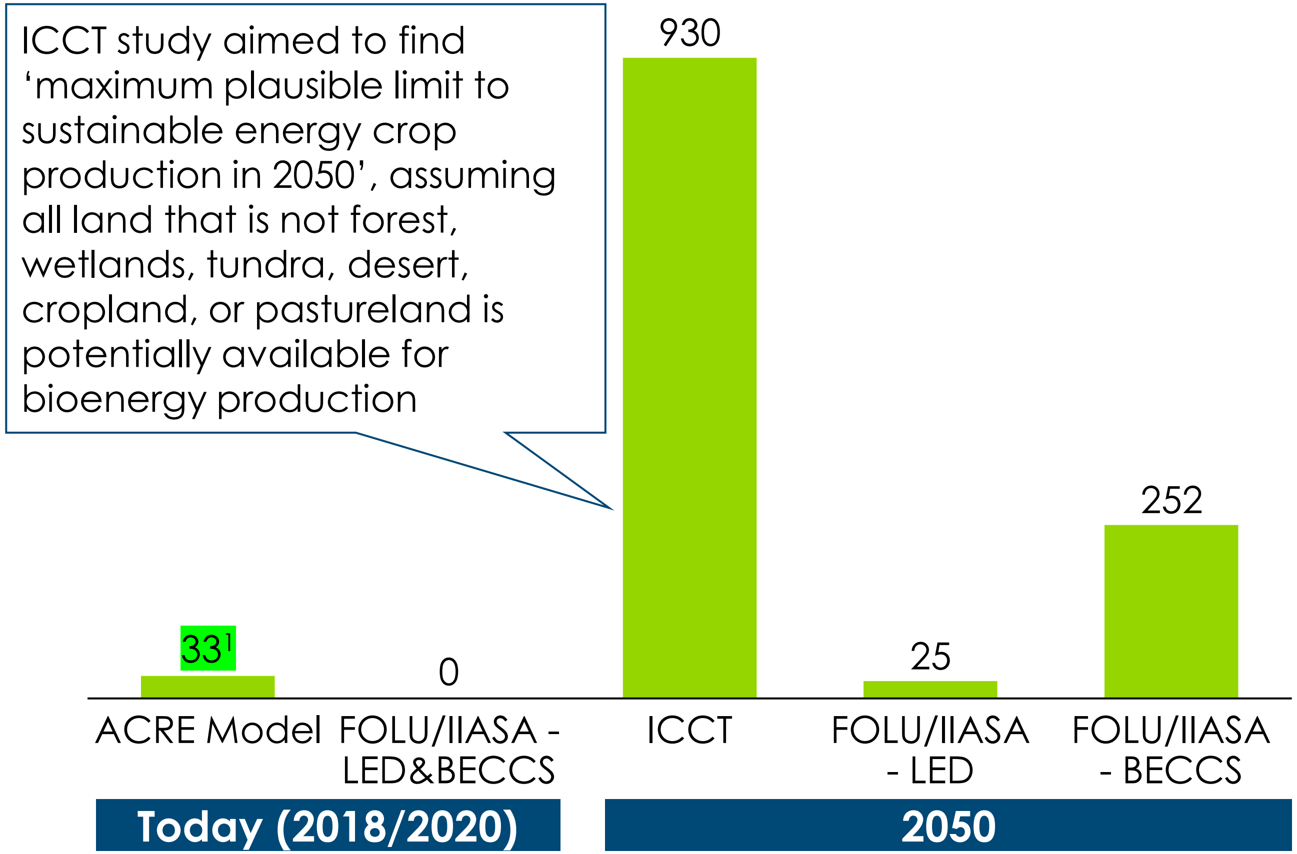
Cover and winter crops: Note, not covered in detail in the sustainability studies reviewed – Evidence currently limited on potential future supply, but likely to be limited as only applicable in Northern latitudes with winter season. Currently, major hurdles are that it is not economically attractive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

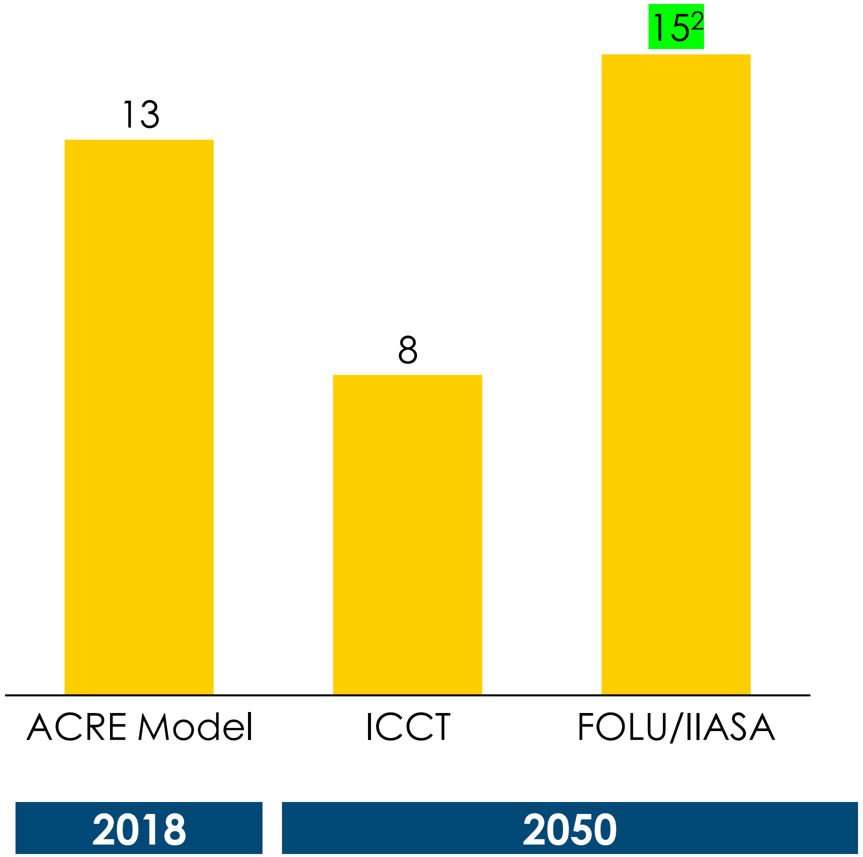
Biomass from dedicated land use: Key assumptions

Inferred from information provided

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



Energy Crop Yield
DM Tons/Ha/Yr.



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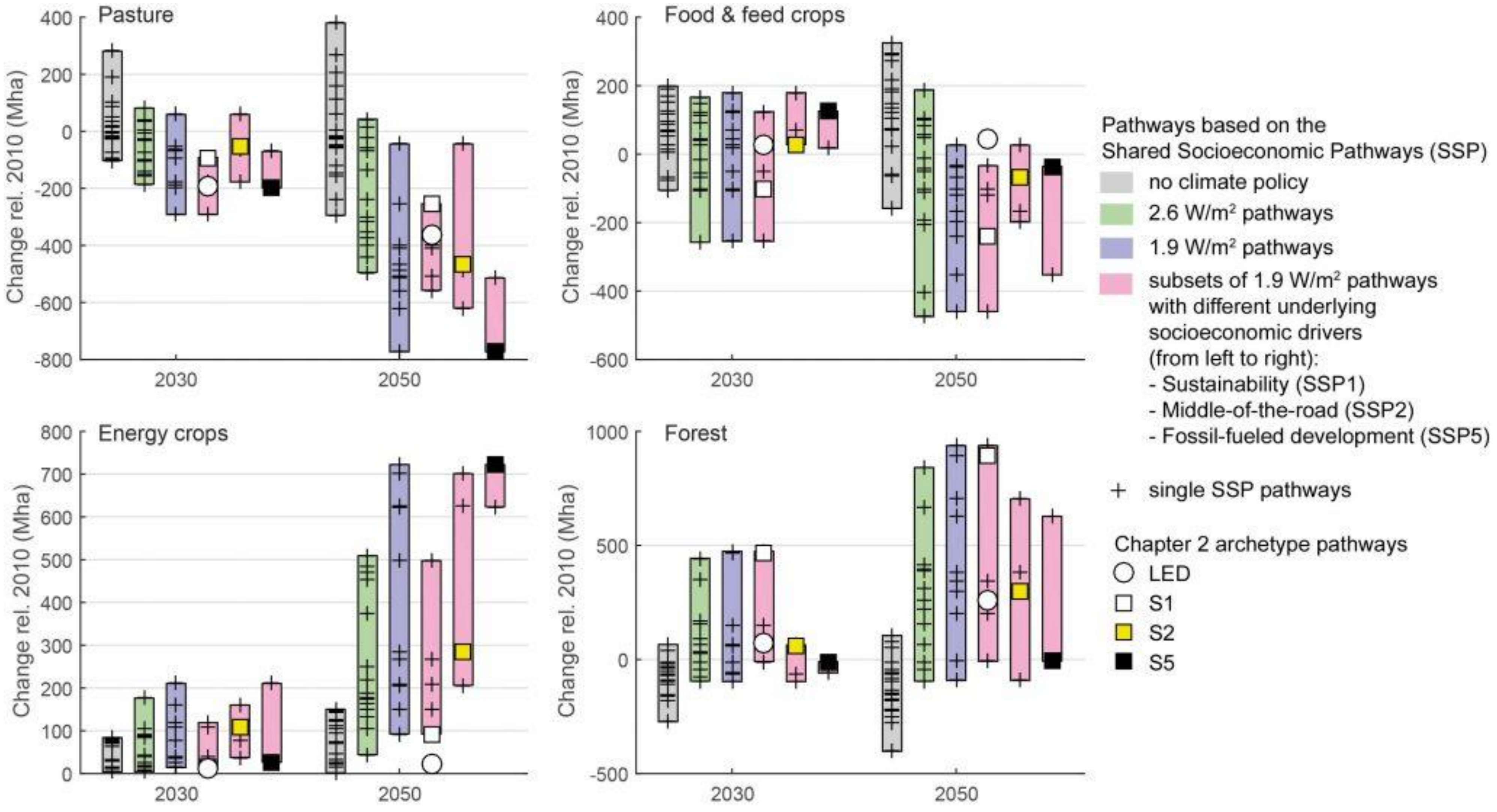
ENERGY TRANSITIONS COMMISSION

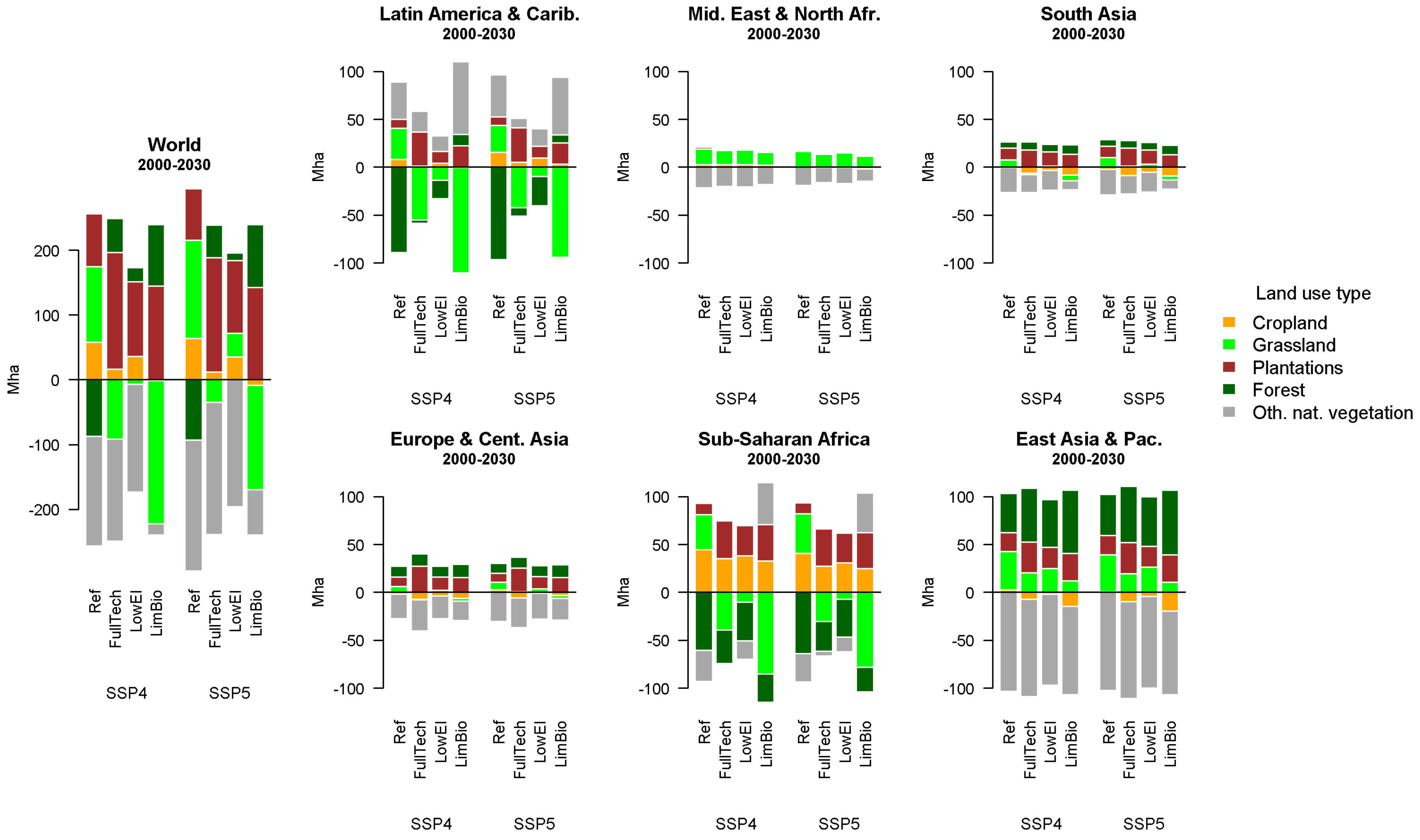
Land use requirements for CC mitigation (LED scenario)



ENERGY TRANSITIONS COMMISSION

Source: IPCC, 1.5°C report

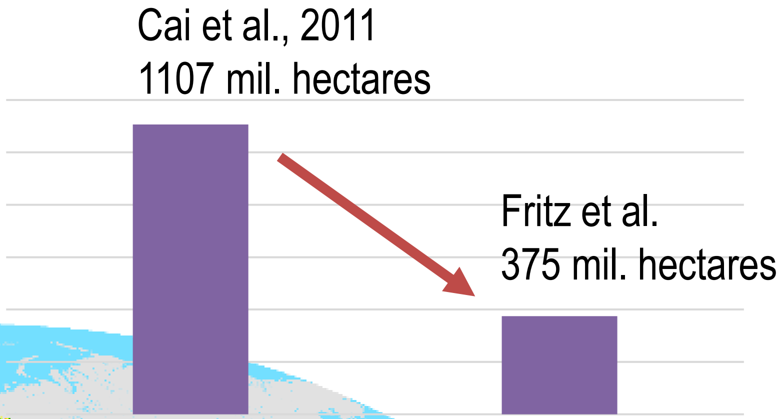
Regional implications by 2030…

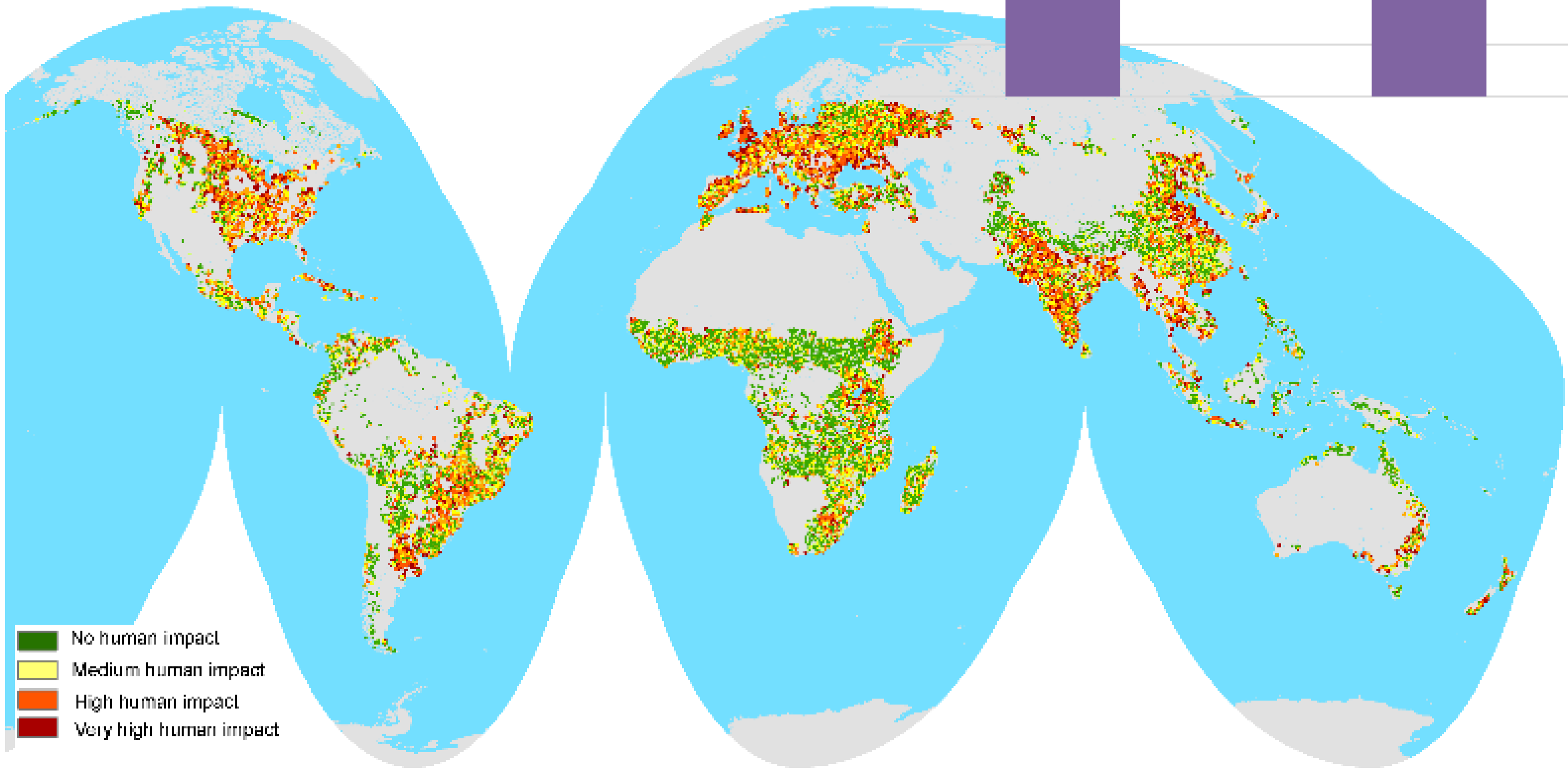


Source: Havlik et al., 2015

Verifying land availability

Revising recent estimates of
land availability using crowdsourcing



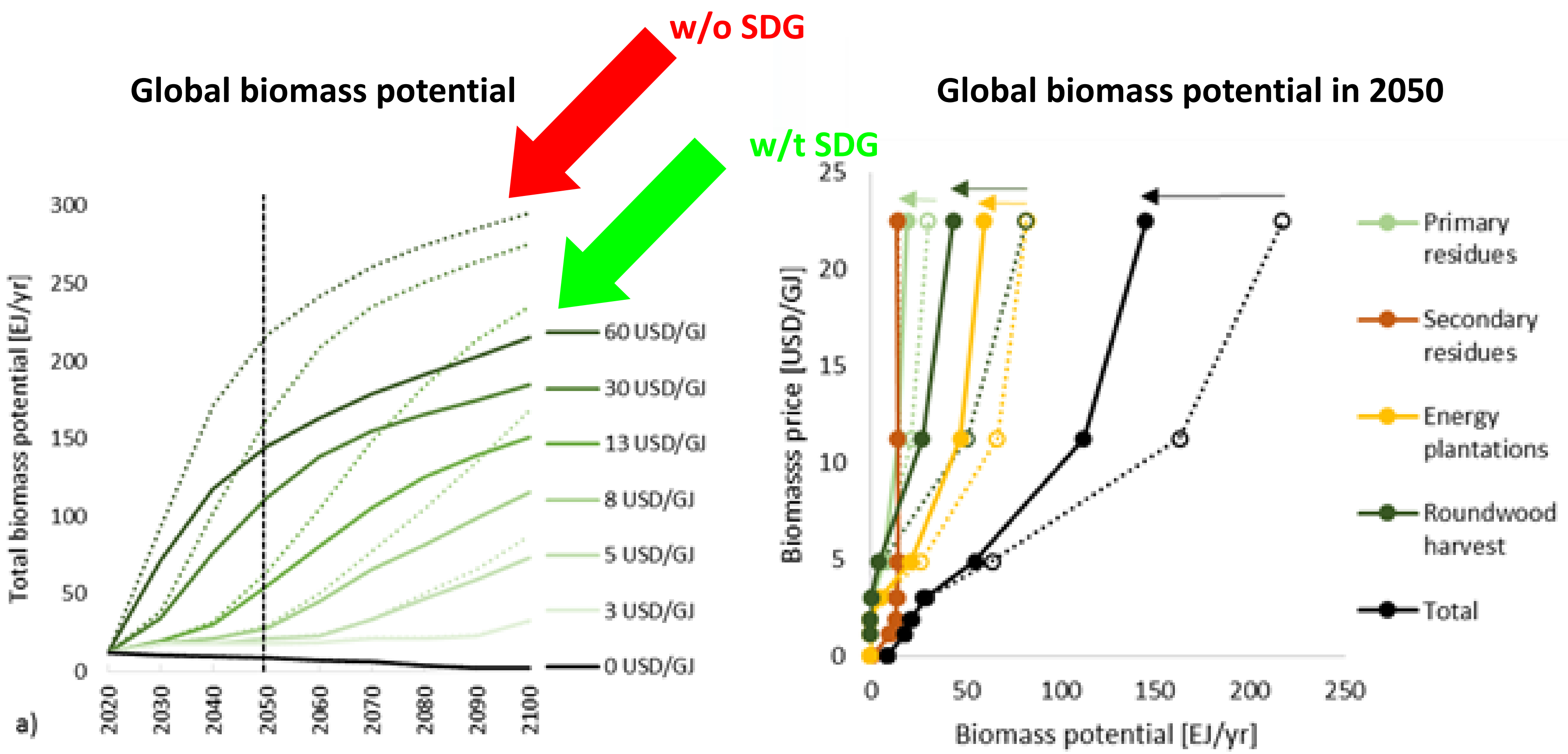


Source: Fritz et al, 2013, Environmental Science and technology

SDG compatible land mitigation potential

- *Food security (SDG2)*
  - Developing countries reach minimum total calorie intake levels that limit undernourishment below 1% by 2030
- *Dietary preferences (SDG12)*
  - Based on USDA recommendations for healthy diets and animal calorie intake decreased to 430 kcal/capita/day by 2030.
  - Halving current food waste by 2030
- *Sustainable water use (SDG6)*
  - Irrigation water consumption in agriculture does not conflict with ecosystem services and environmental flows
- *Biodiversity protection (SDG15)*
  - Achieving the AICHI Biodiversity target 11 and increase total surface of protected areas to 17% by 2030
  - No conversion of highly biodiverse areas

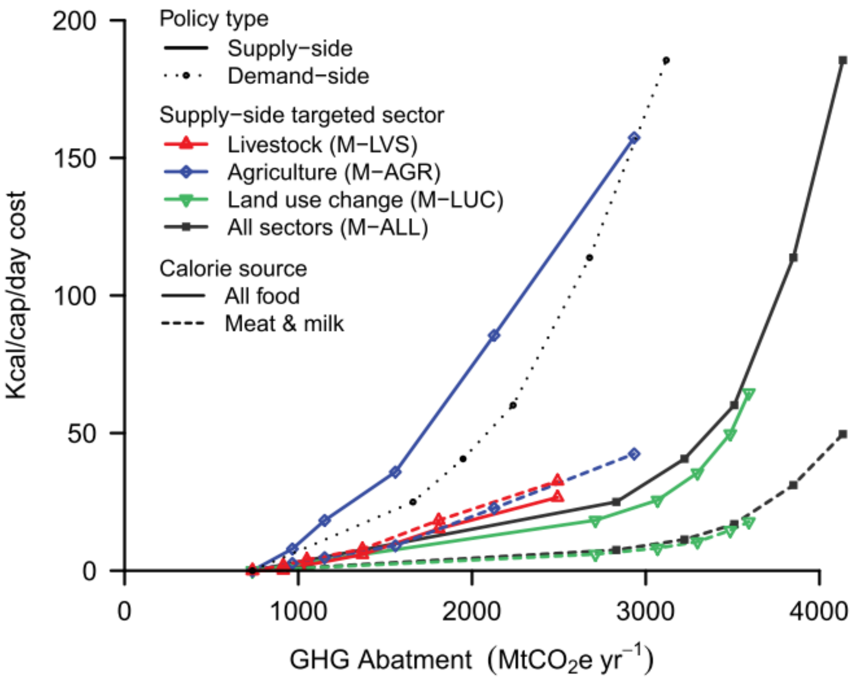
SDG compatible land mitigation potential



Source: Frank et al. forthcoming

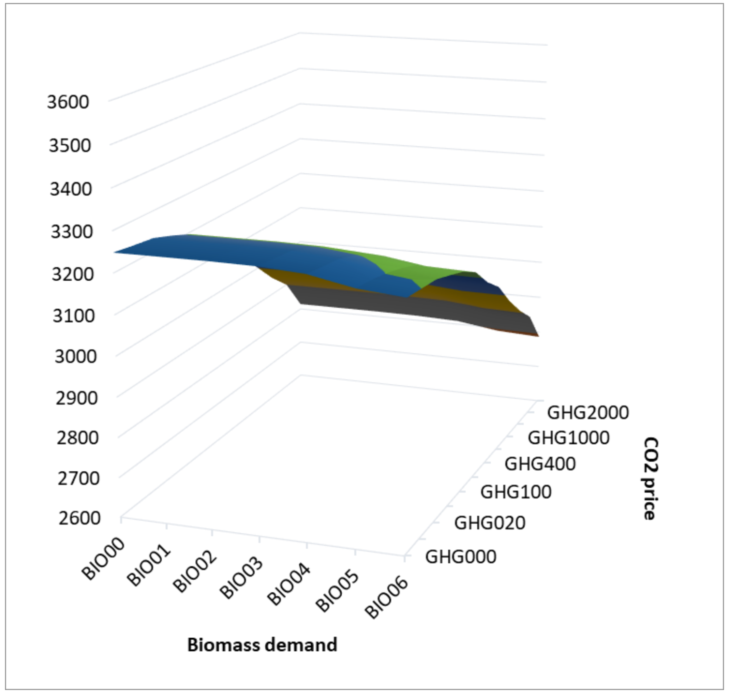
Focus on food security

Taxing deforestation CO_2 emissions (green) less impactful than taxing non-CO_2 (red and blue)



Source: Havlik et al., 2014

Increased bioenergy demand (x-axis) has only marginal impact on calories compared to carbon tax (y-axis)

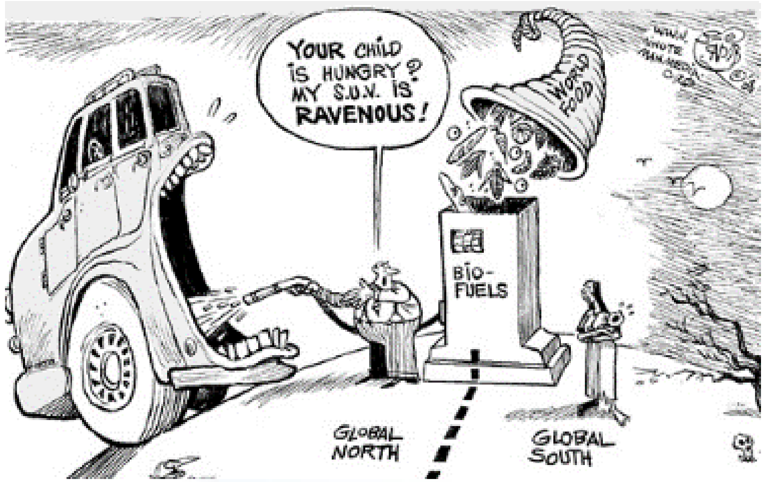


Source: GLOBIOM simulations

Let’s not forget unintended consequences…

Food vs. fuel debate

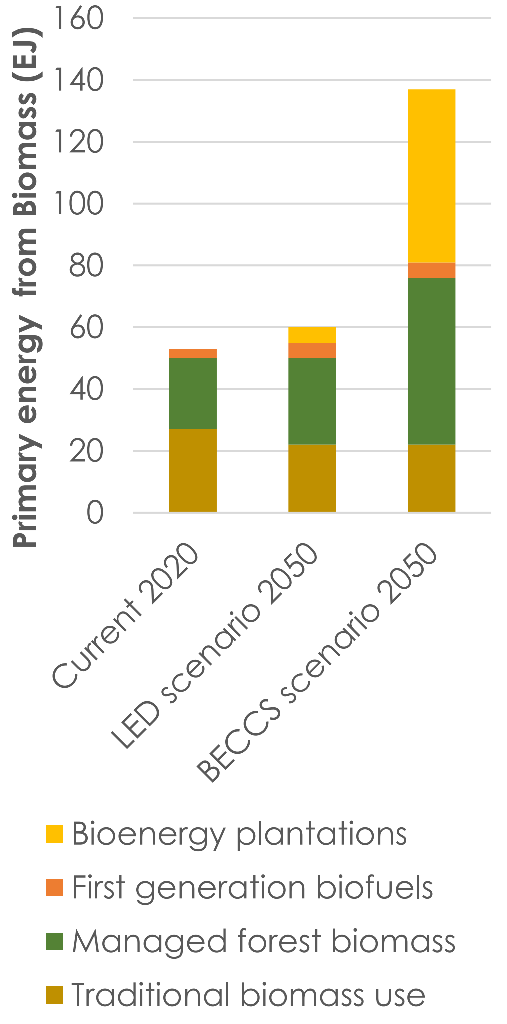
Land grabbing debate



Bioenergy considered in the FOLU-GLOBIOM Better Futures Scenario, but not a primary driver

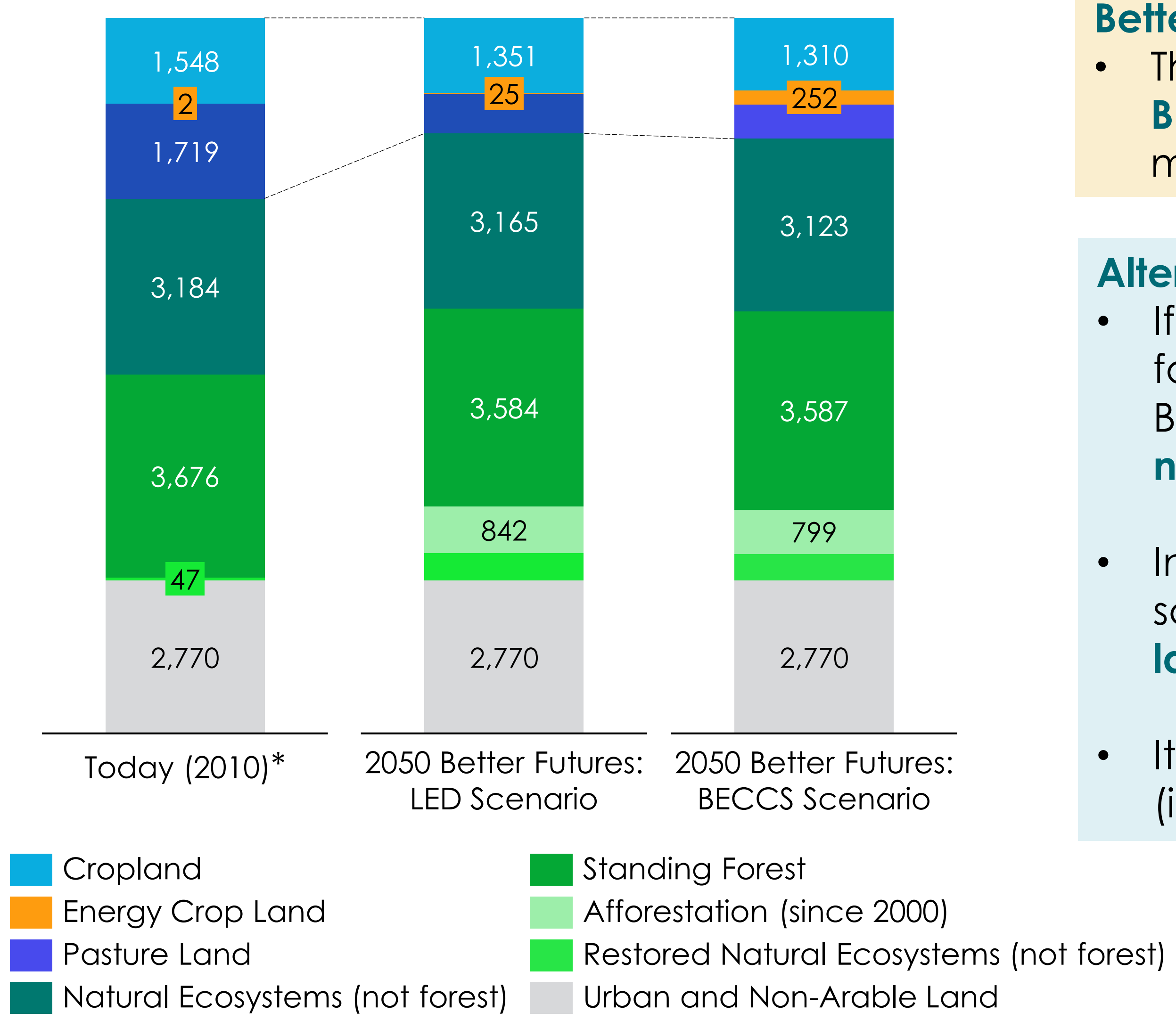
How is bioenergy captured in GLOBIOM?

- Bioenergy demand in GLOBIOM is computed through **iterations with the IIASA energy model** (MESSAGE) to determined the energy mix for reaching the climate target.
- GLOBIOM bioenergy production covers **all primary bioenergy use:**
  - **Modern biomass** demand increases in the baseline under the current policies
  - Raw **traditional biomass** for cooking at home and forest foraged firewood slowly decreases in developing countries (-20% on 2020-2050).
- **Under climate policies:**
  - **New biomass/biofuels can be produced from dedicated crop plantations** (such as short rotation coppice) and **fast growing wood plantations**.
  - **Increased bioenergy wood extraction** from forest can be sourced from **residues** (logging residues, secondary residues from sawmills and tertiary residues from recycled wood), and for larger demand levels, from roundwood.
  - The contribution of **first generation biofuels**, produced by crops that could also produce food (i.e., sugar, corn, oil palm) remains **close to the current policy levels**.
  - Currently, no explicit representation of bioenergy **municipal waste sources**.



We must return 1.2 billion ha of agricultural land to nature to achieve climate and biodiversity objectives - BECCs further increases pressure on land for dedicated bioenergy production.

Total Surface Land Use: million hectares



Better Futures LED Scenario

- The FOLU *Better Futures* scenario **does not require use of BECCs**, due to the use of the Low Energy Demand mitigation pathway.

Alternative: Better Futures BECCs Scenario

- If the necessary decarbonisation & energy efficiency gains for a LED pathway are not realised, we could move to a BECCS scenario as a **"back-up option" to generate negative emissions.**
- In comparison, relying on an alternative BECCs mitigation scenario sees **a X10 increase in dedicated Energy Crop land by 2050, to an area the size of the UK.**
- It would also see a notable increase in managed forest land (included in "afforestation and/or standing forest").

Source: IIASA GLOBIOM 2019 * Baseline data forecast from 2000

The Food and Land Use Coalition

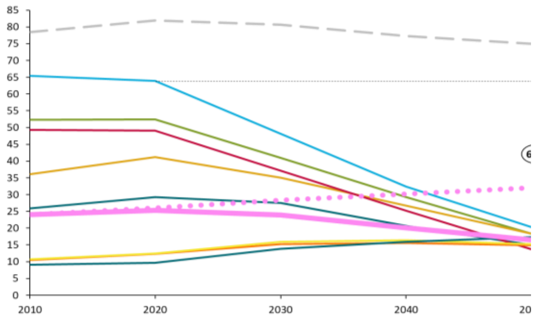
Land use shift in Better Futures is primarily driven by 1) dietary shift, 2) payment for ecosystem services, 3) productivity gains and 4) reduced FLW

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



Payment for Ecosystem Services

A **carbon price** of $129/tonne by 2050, driving protection & restoration of forests for carbon sequestration.

A **biodiversity subsidy** of $300 per hectare, incentivising protection and restoration of land for ecosystem services.

Productivity Increases

By 2050 **yields are increased an additional 10%** beyond current trajectories due to a combination of **technology and regenerative practices**.

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

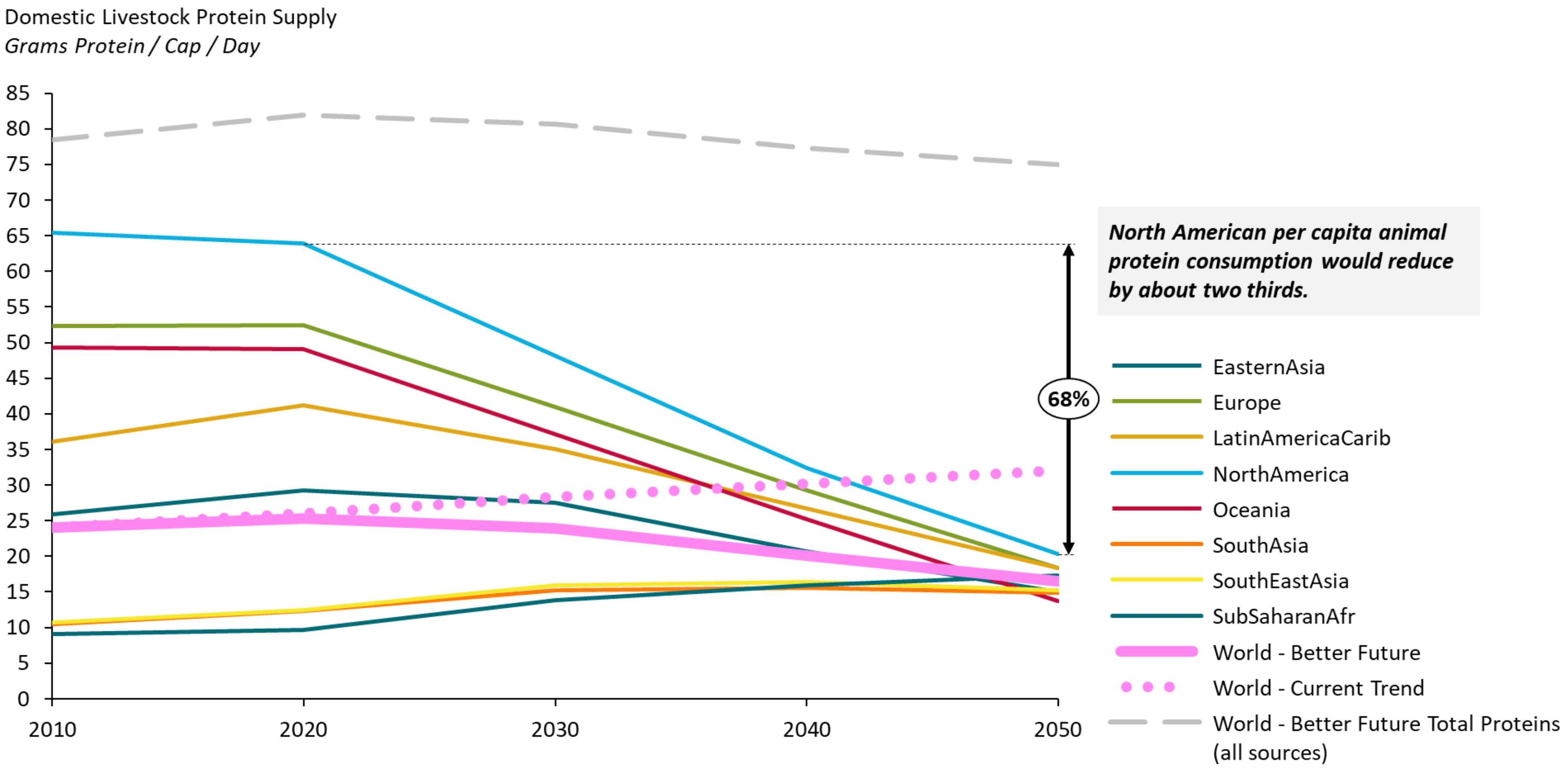
Reducing Food Loss and Waste

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

Source: IIASA GLOBIOM 2019; EAT-Lancet 2019

The Food and Land Use Coalition

Land use shift will, in part, take place due to a global convergence in per capita protein consumption, freeing up space for natural regeneration



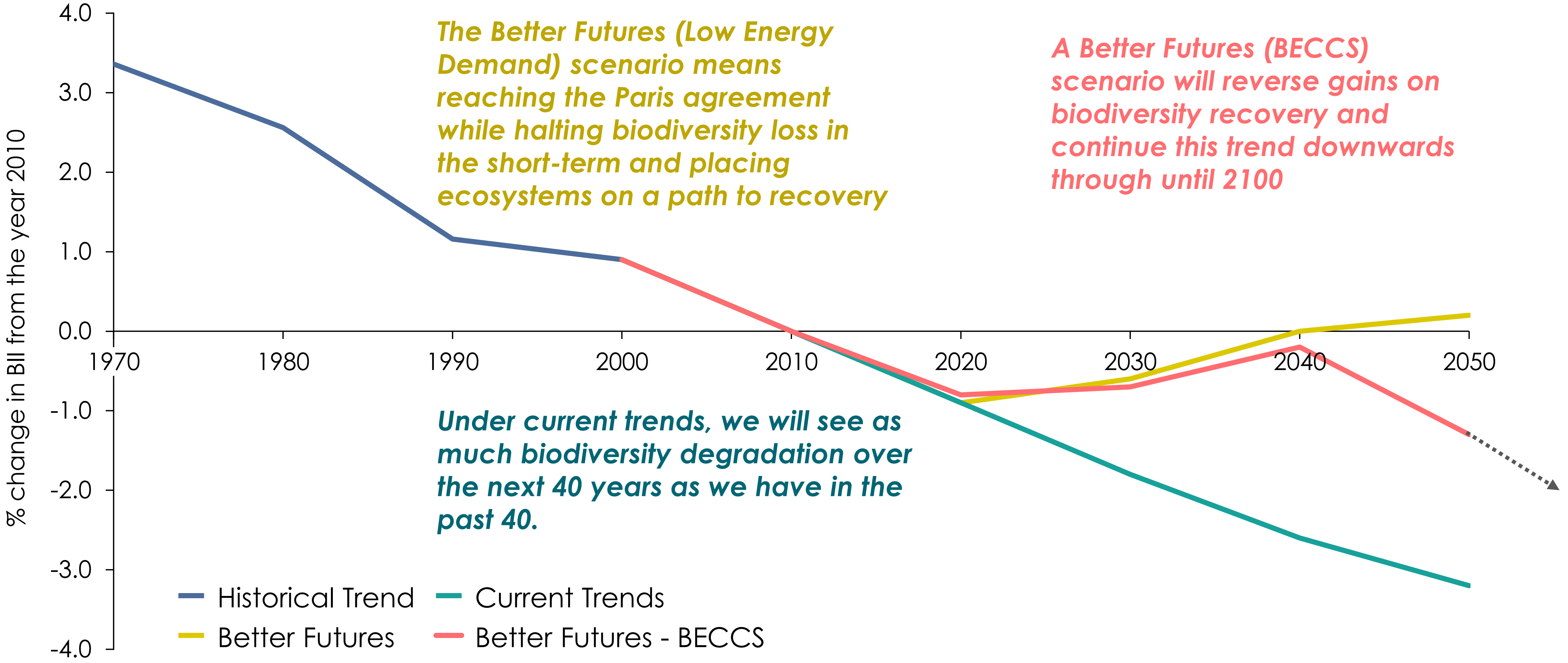
Other primary drivers of land use shift include:

- Climate mitigation policies and carbon tax.
- Biodiversity policies driving land preservation.
- Increased Productivity due to Technical Progress.
- Reduced food loss and waste.

Source: IIASA GLOBIOM 2019; EAT-Lancet 2019

The Food and Land Use Coalition

A BECCS scenario could potentially contribute to both carbon sequestration and the bioeconomy, but would have a major impact on biodiversity



Source: *IIASA GLOBIOM 2019*; Leclère et al 2018 for historical reconstruction

The Food and Land Use Coalition

Rising demand for "nature-based solutions" and forest offsets may strengthen the case for protection and restoration of natural ecosystems over land use for BECCS

Calls for guidelines to be put in place on nature-based solutions ahead of COP 26 in Glasgow to ensure rigorous application.

1. Ensuring it does not delay urgent action to decarbonise the economy
2. Focus on protecting &/or restoring a range of ecosystems (land and marine).
3. Focus on remaining intact ecosystems and biomes.
4. Requiring full engagement and consent of Indigenous Peoples and local communities.
5. Focus on biodiversity, favouring mixed-species natural forests over large-scale tree-planting with single, non-native species or low diversity plantations.
6. Inclusion of nature-based principles in sustainable land and fisheries management e.g. regenerative agriculture and agroforestry.

120+ countries & 750+ companies committed to the UNFCCC's Climate Ambition Alliance: Net Zero 2050, with more initiatives and commitment emerging:

GUCCI CEO scope 1,2 & 3 offset challenge

Commitment to carbon-neutral portfolios

EasyJet fuel offsets for all flights

Shell's carbon-neutral fuel at the pump

Source: https://nbsguidelines.info/; https://climateaction.unfccc.int/

The Food and Land Use Coalition

Bioenergy

Tim Searchinger, Princeton University (tsearchi@princeton.edu)
(202) 465-2074

Benefit bioenergy: Use land to produce plants to displace fossil emissions

But

Cost: Not using land for some other purpose

Benefit v. Cost of Using "Surplus" Land for Ethanol

	Savings from Displacing Petrol No Land Use Change No Production emissions	Savings from Displacing Petrol with Production & Refining Emissions Equal to 50% of Petrol	Carbon Cost of Just Not Allowing Any "Surplus" Land to Regrow Forest
Ethanol at High Yields liters/hectare (~6500 liters/effective hectare: E.g. US Corn Ethanol (after deducting by-products) or Cellulosic ethanol at 17 dry tons/ha/y and 379 liters per ton)	**~3 tons of carbon per hectare = 86 g CO_2/MJ**	**1.5 tons of carbon per hectare = 43.5 g CO_2/MJ**	**~3 tons of carbon per hectare = 86 gCO_2/MJ**

Gasoline = 86 gCO_2/MJ

Solar conversion efficiencies

Iowa corn

Ethanol , 0.013 %

Most optimistic location

future US switchgrass (DOE)

(24 tDM/ha and 100 gallons/tonne)

0.35%

Brazilian sugarcane

ethanol , 0.2%

PV – 20% gross;

~15% net

Credit for Plant Growth Explains Findings of Greenhouse Gas Benefits in LCAs – EU JRC

Source of fuel*	Producing Feedstock (crude oil or crop)	Refining	Tailpipe Emis-sions	Ferment-ation emissions	Total GHGs & % Increase for Biofuel ***Without Plant Credit***	Credit for Plant Growth	Total GHGs & % Savings for Biofuel
Gasoline	**+4.5**	**+8**	**+73.3**	**-**	**85.8**	**-**	**85.8**
EU Ethanol	***+40***	***+21.2***	~~***+71.4***~~	~~***+35.7***~~	***168.3 (+96%)***	~~***107.1***~~	***+61.2 (-29%)***

Greenhouse gas emissions and sinks (CO_2 eqv.) per mega joule of fuel

Credit for Plant Growth Explains Findings of Greenhouse Gas Benefits in LCAs – EU JRC

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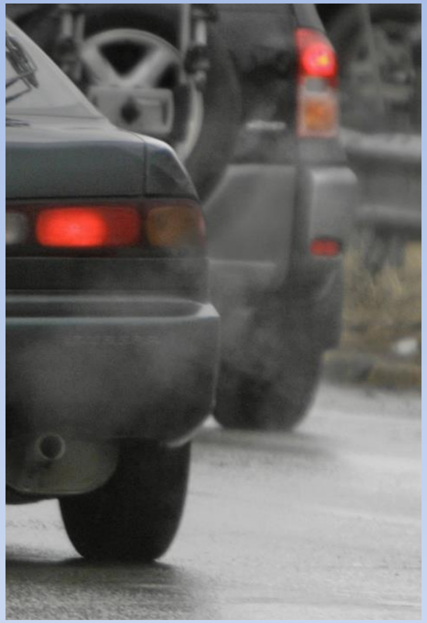
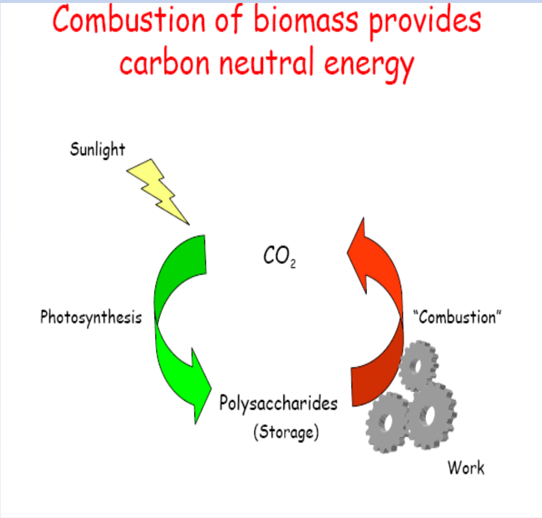
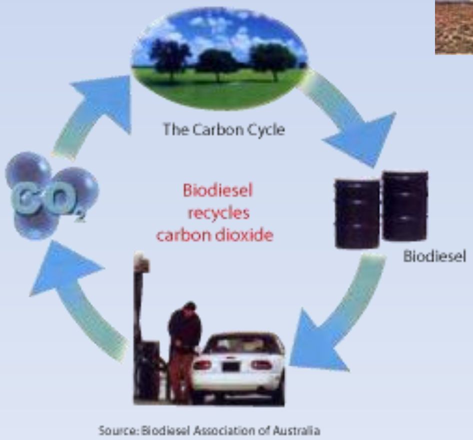
Gasoline	**+4.5**	**+8**	**+73.3**	**-**	**85.8**	**-**	**85.8**
EU Ethanol	***+40***	***+21.2***	***~~+71.4~~***	***~~+35.7~~***	***168.3 (+96%)***	***~~107.1~~***	***+61.2 (-29%)***

Greenhouse gas emissions and sinks (CO_2 eqv.) per mega joule of fuel

Both biomass and fossil fuel combustion emit carbon dioxide, Potential Savings Come from Plant Uptake







BIOENERGY IS A FORM OF LAND-BASED CARBON OFFSET

Land grows plants whether for bioenergy or not:

* forest
* food

Only ADDITIONAL plant growth helps

Effect of switching from gasoline to biofuels grown on otherwise unproductive land – Reduced atmospheric CO_2 through increased plant growth

Unproductive land

CO_2 emission

Car, gasoline

New crop growth

CO_2 uptake

CO_2 emission

Car, ethanol

Gasoline Use

Ethanol Use

Using otherwise burned or decomposed crop residues for biofuels - Reduced emissions through reduced land sources

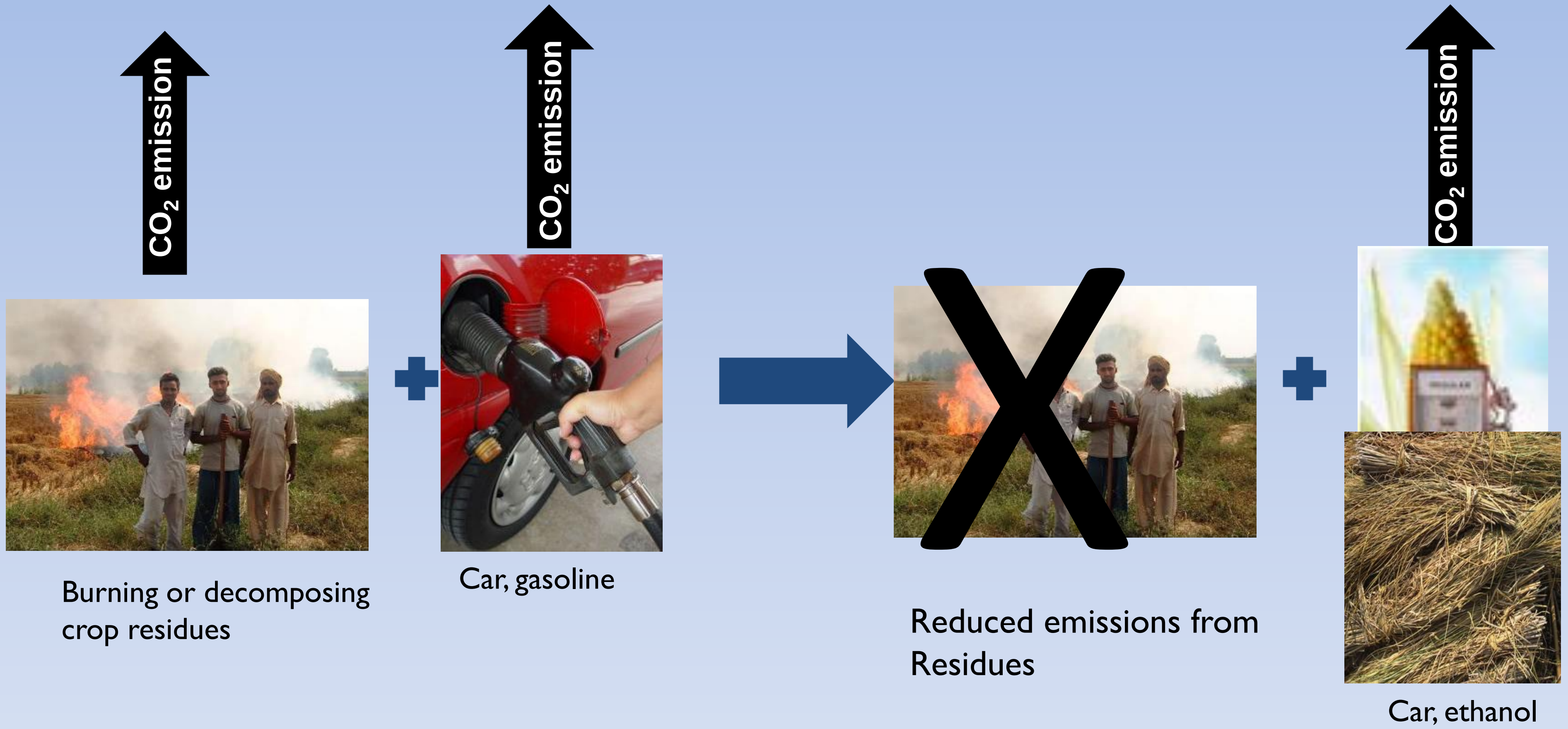
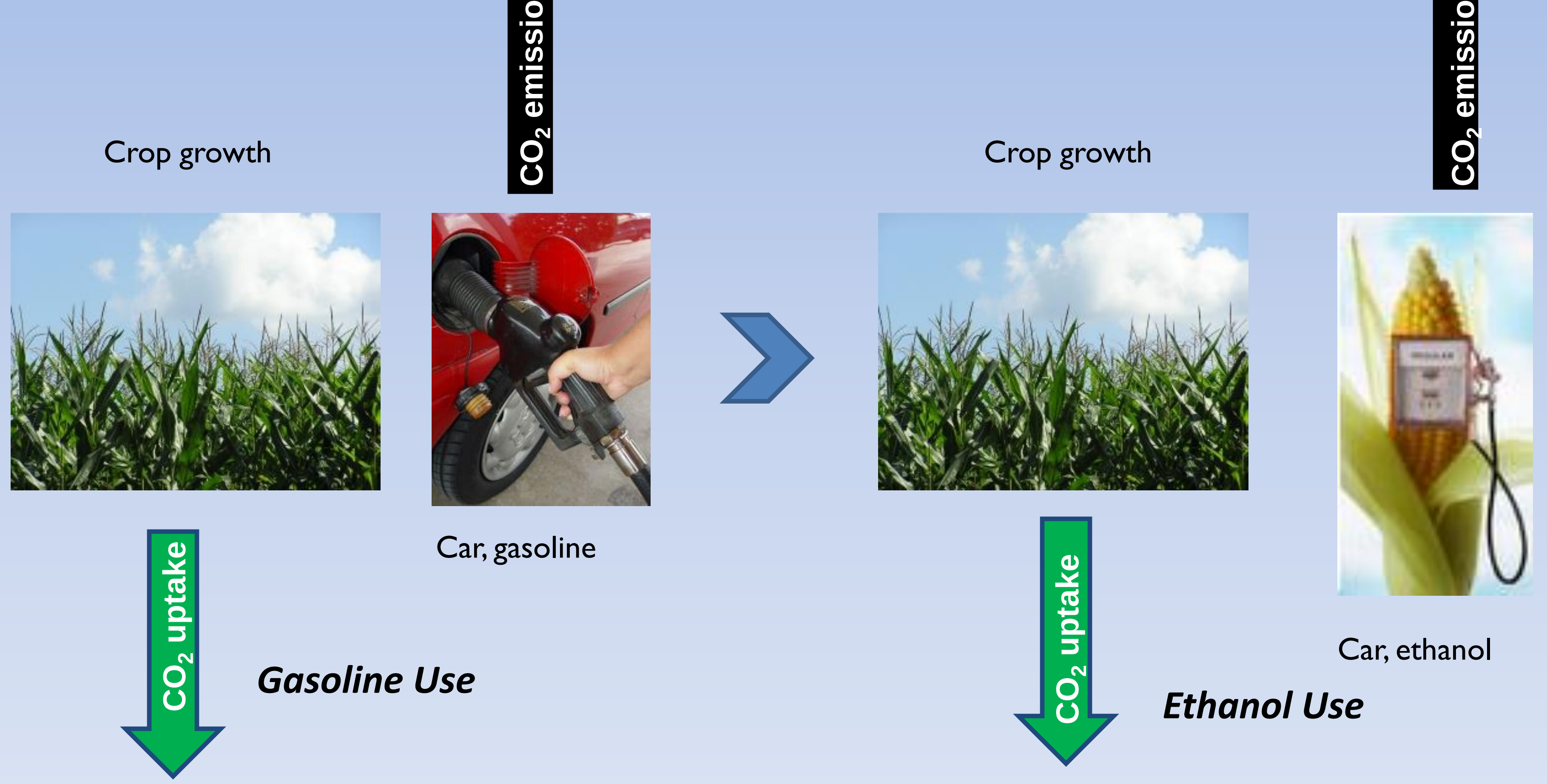
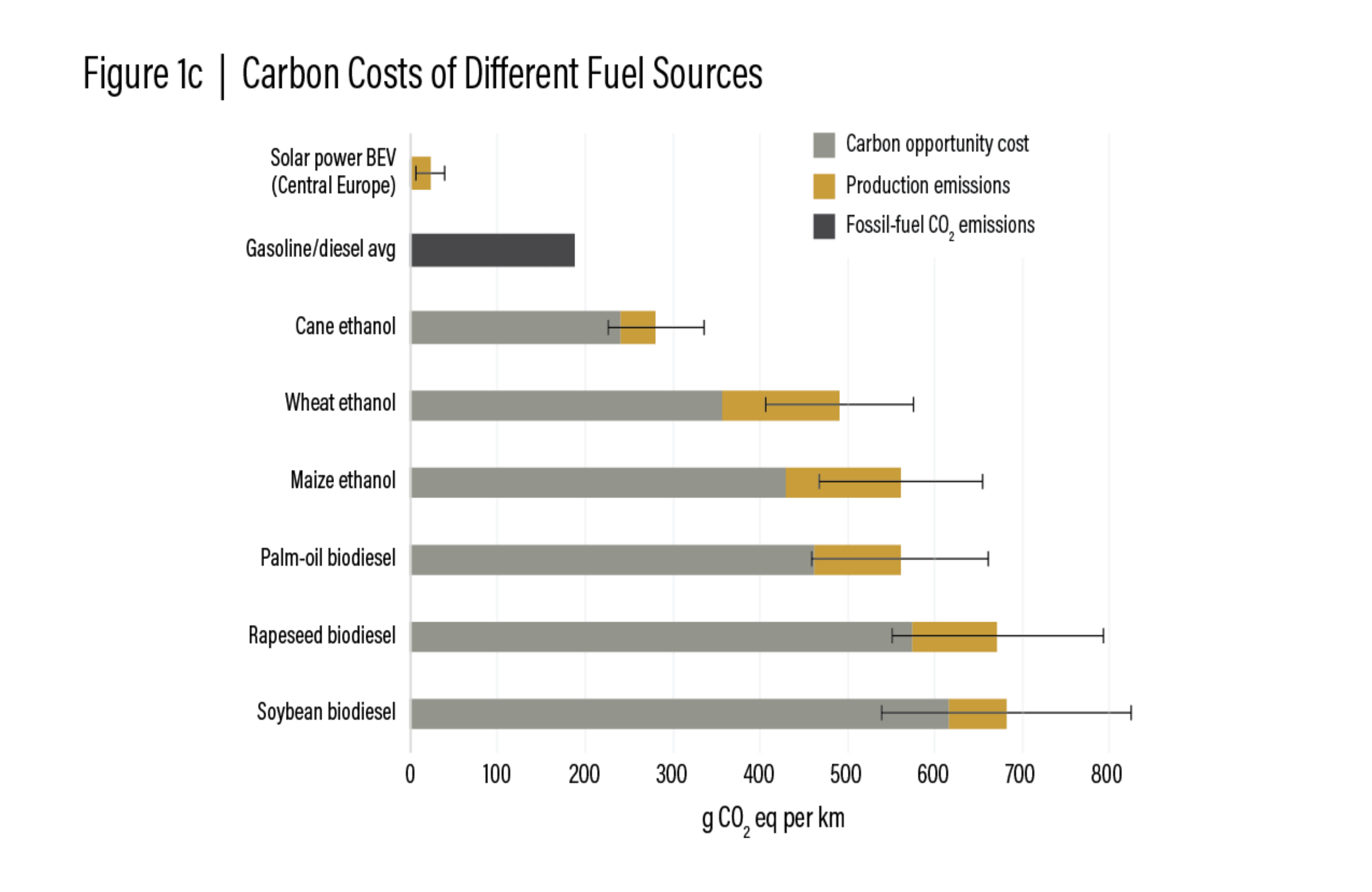


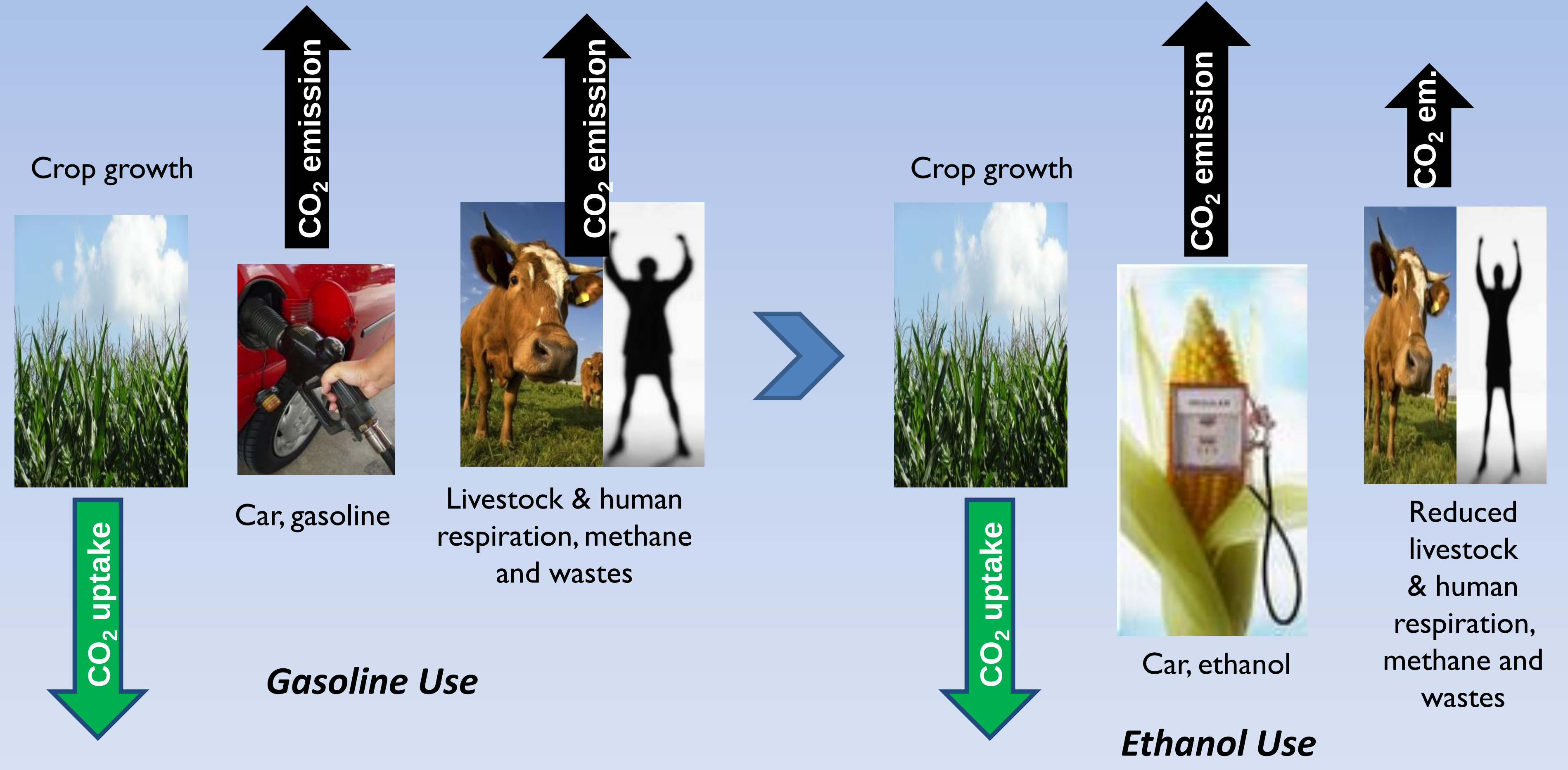
Figure 2 - Direct effect of switching from gasoline to biofuels that use existing crops – No change in emissions





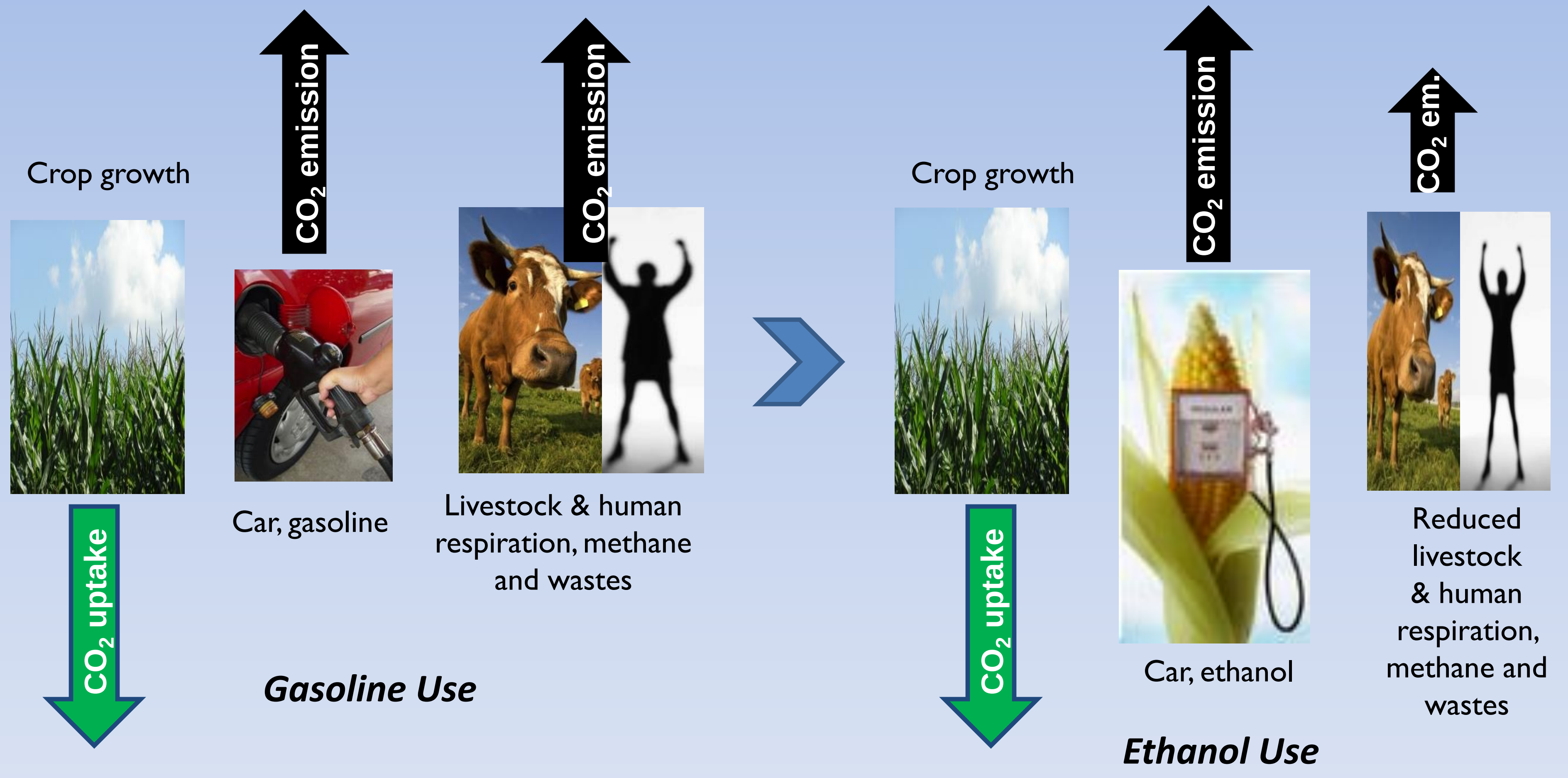
Searchinger et al., Assessing the Carbon Efficiency of Land Use Change (In review)

Figure 3 - Indirect effect I of adopting ethanol – Ethanol leads to less crop consumption for feed and food, which reduces CO_2



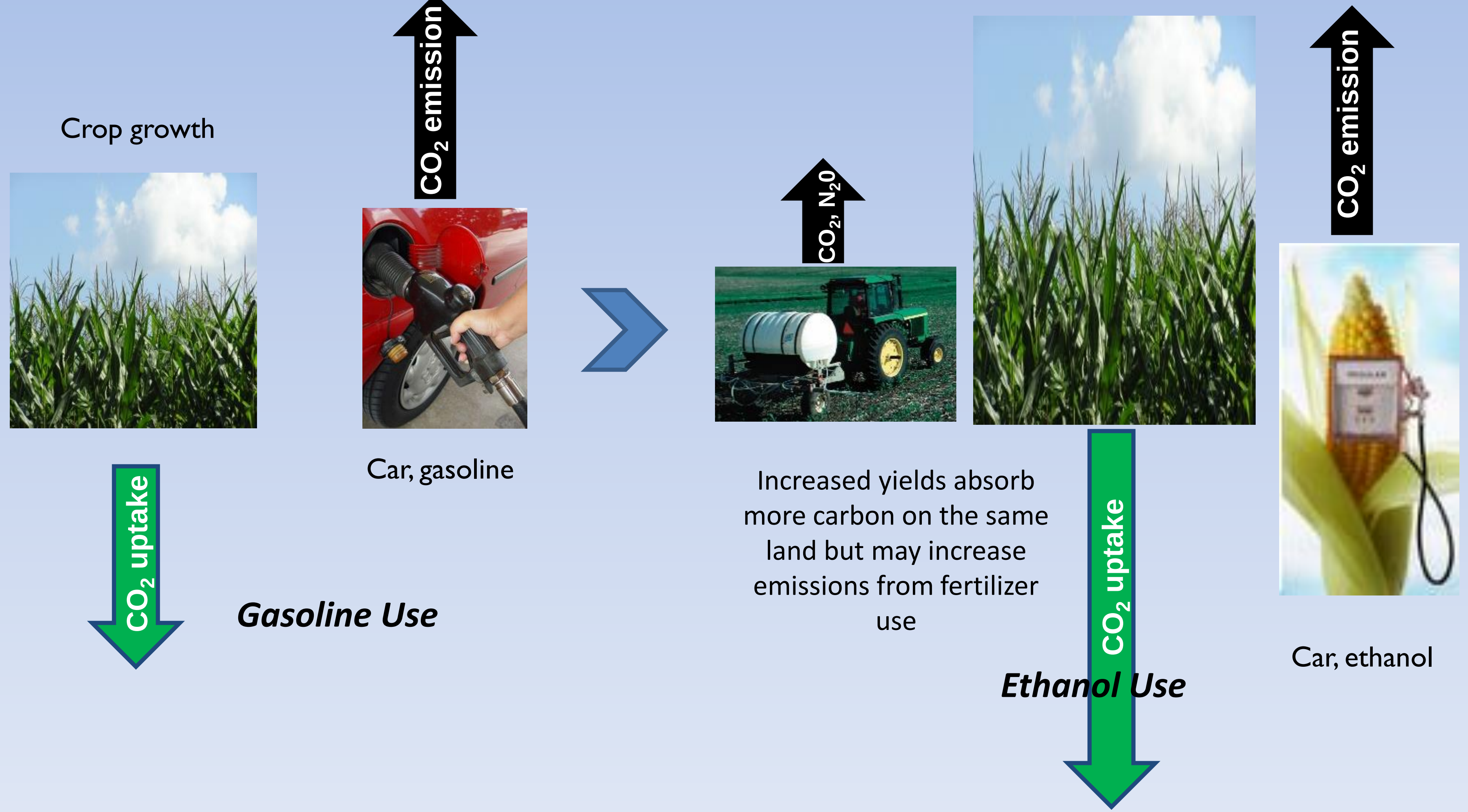
(vertical arrows indicate carbon uptake and emissions)

Figure 3 - Indirect effect I of adopting ethanol – Ethanol leads to less crop consumption for feed and food, which reduces CO_2



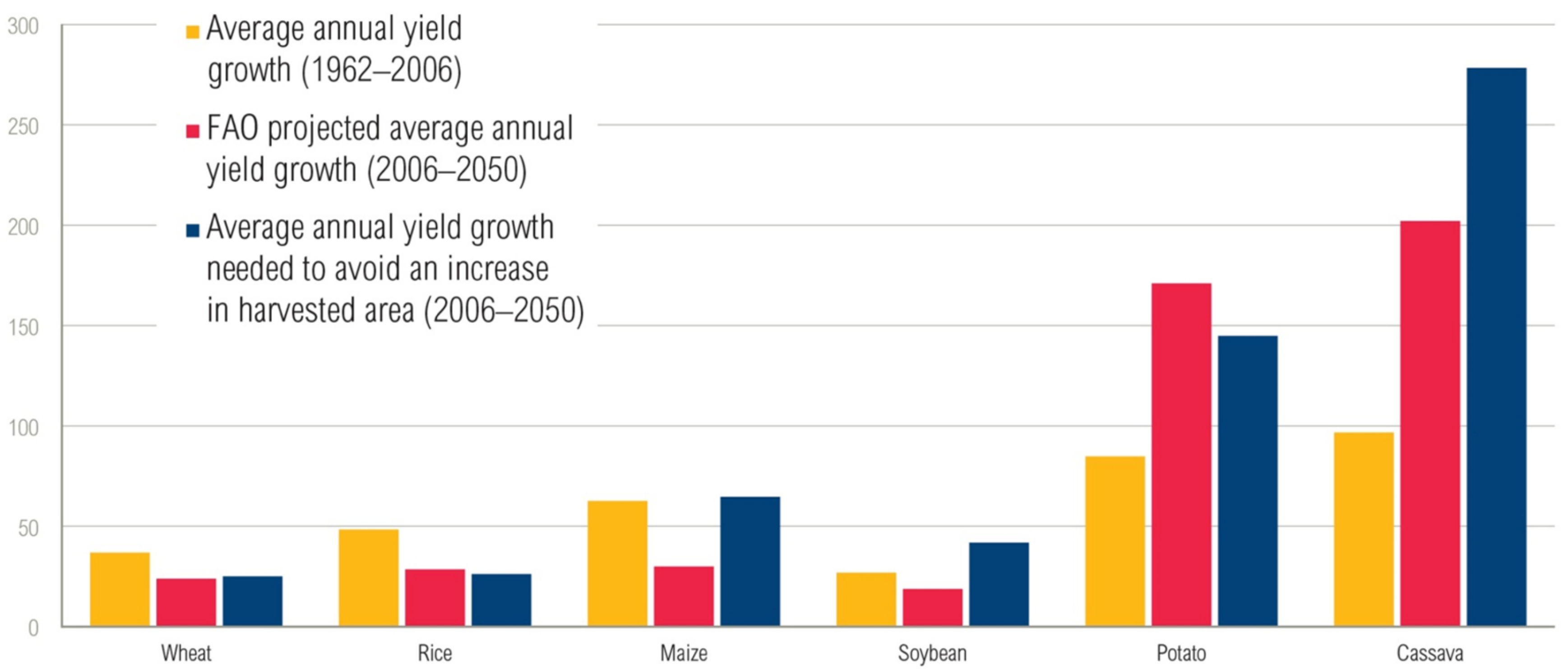
(vertical arrows indicate carbon uptake and emissions)

Figure 4 - Indirect effect 2 of adopting ethanol – Ethanol leads to yield growth on existing farmland to replace diverted crops, absorbing more carbon and probably reducing CO_2



Future yields overall will need to grow faster than historical rates to prevent new land conversion

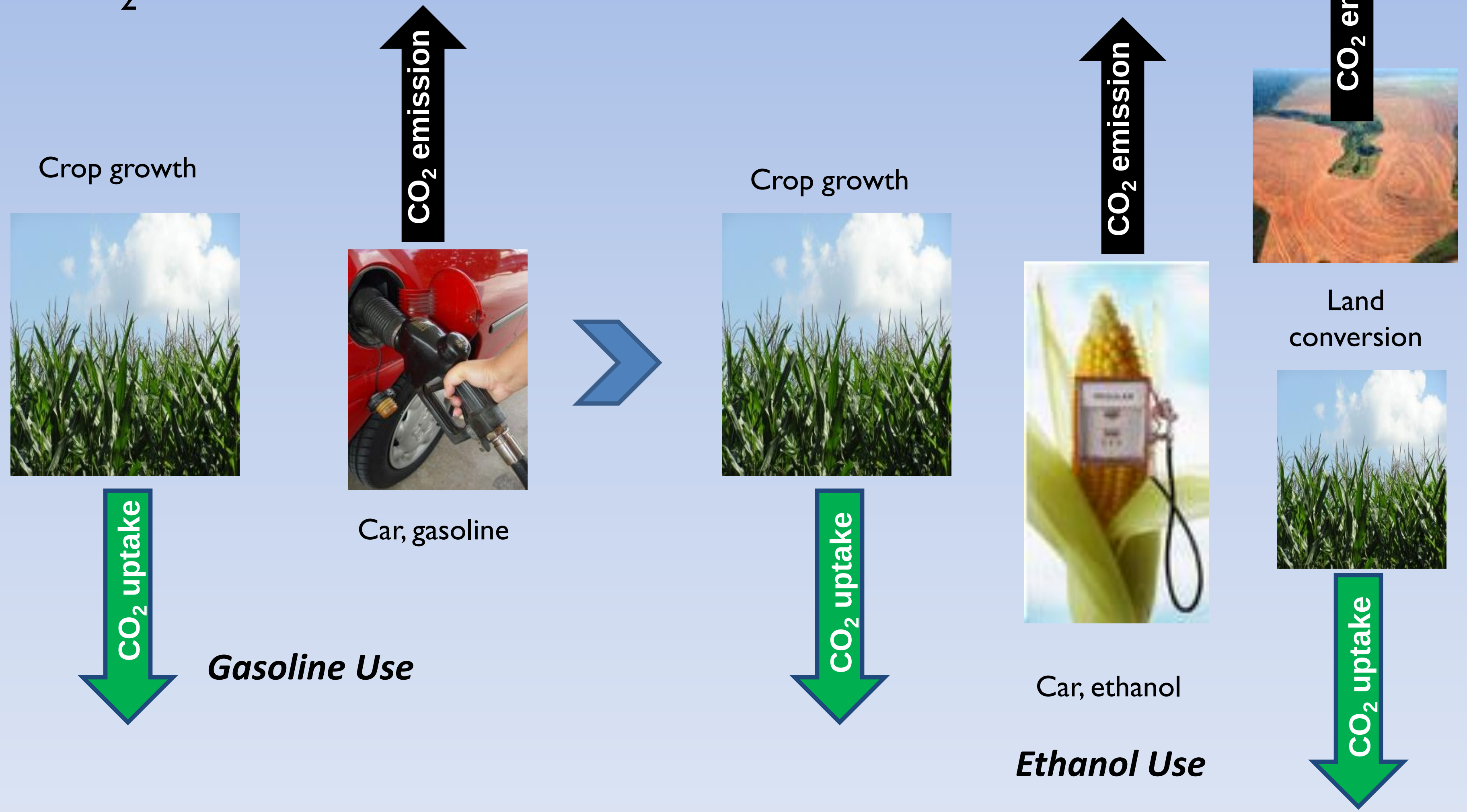
Kg/ha/year



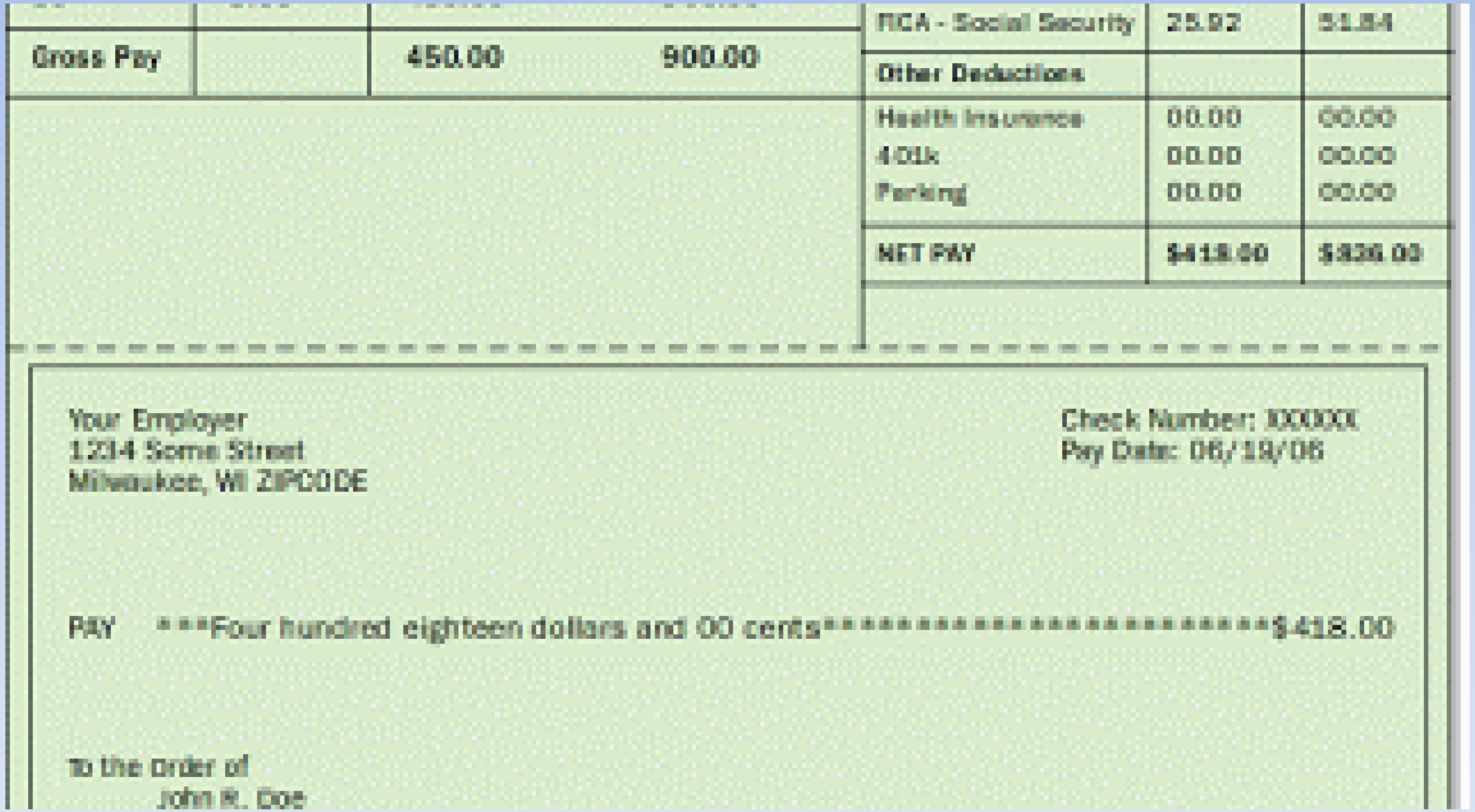
Source: Alexandratos, N., and J. Bruinsma. 2012. *World agriculture towards 2030/2050: The 2012 revision.* Rome: FAO; ACE and WRI analysis.

WORLD RESOURCES INSTITUTE

Figure 5 – Indirect effect 3 of adopting ethanol – Ethanol leads to land use change, which increases crop growth, but sacrifices forest or grassland and probably causes net increase in CO_2



Renewable Does Not Equal Carbon Free



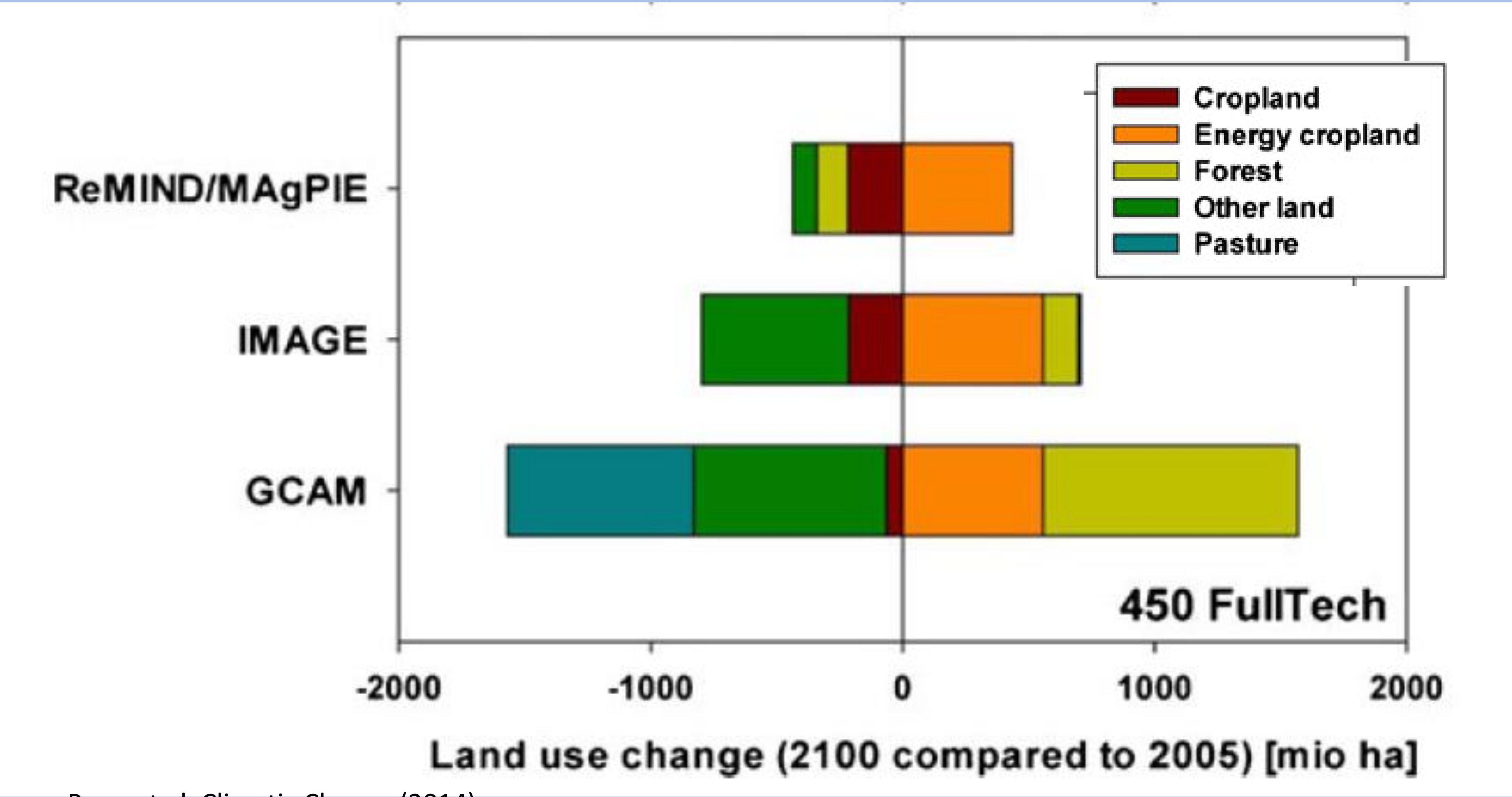
IPCC Guidelines

- IPCC 2000 Land Use Report (p. 355): Because “fossil fuel substitution is already ‘rewarded’” by excluding emissions from the combustion of bioenergy, “to avoid underreporting . . . any changes in biomass stocks on lands . . . resulting from the production of biofuels would need to be included in the accounts.”

NUTS2 regions

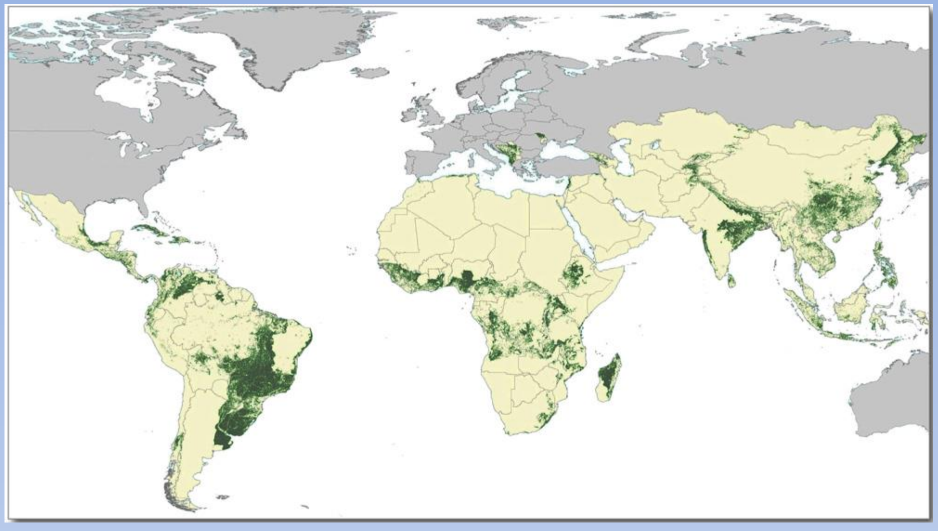
Understanding low ILUC Models – E.G., GLOBIOM - Marginal non-forested, non-agricultural land is source of new cropland because model estimates it has same yields as ag and forest land in cell but lower financial costs.

IAMS THAT PREDICT LARGE QUANTITIES OF BECCS ARE THOUGHT EXPERIMENTS BASED ON ULTRA-LAND EFFICIENT WORLD

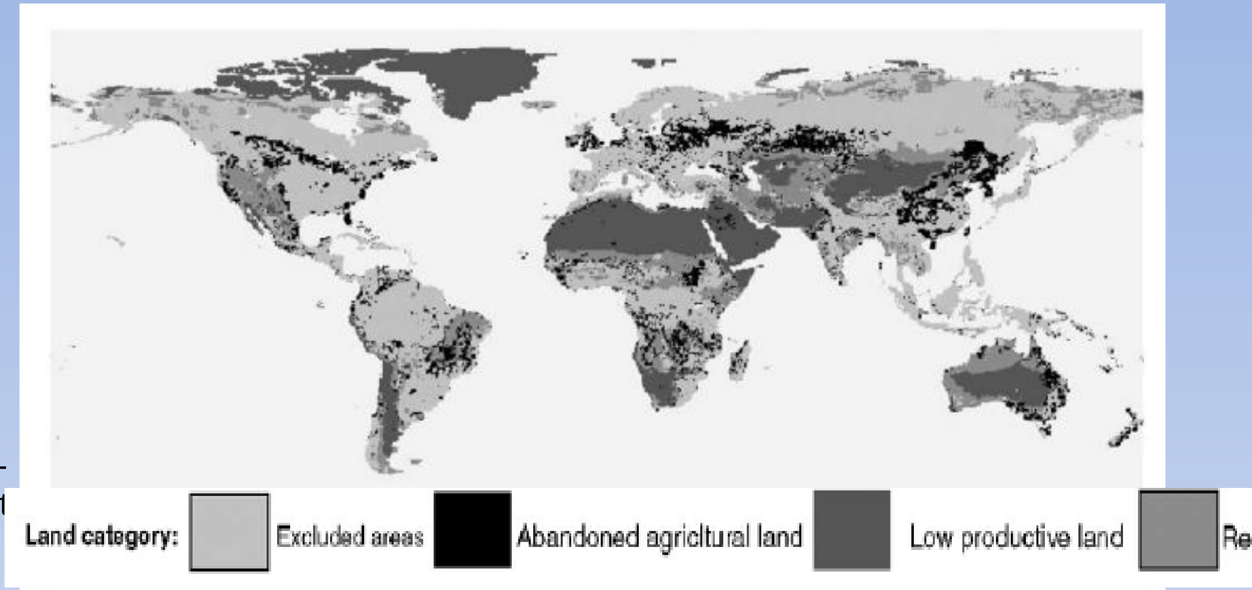


Popp et al. Climatic Change (2014)

Claimed Marginal Land is Misnomer



Zomer et al. Ag Ecosystems (2008): Fig. 2. Global map of CDM-AR suitable land (dark green) within Non-Annex I countries (light yellow), as delineated by the land suitability analysis. A 30% crown cover density threshold was used to define forest, and protected areas are not included.



Hoodgwijk et al. (2005)

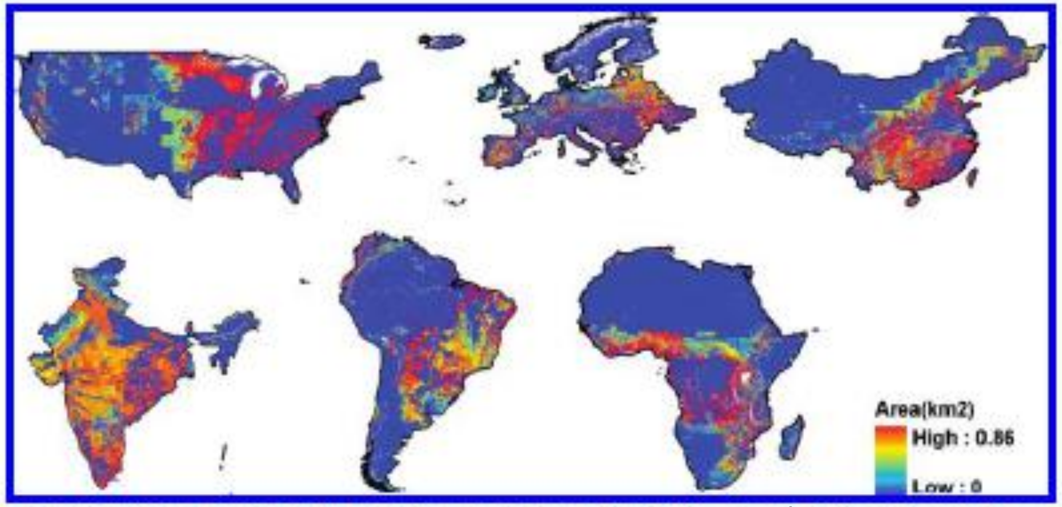


FIGURE 2. Maps of land available for bioenergy production under scenario 4 in U.S., Europe, China, India, South America, and Africa.

Searchinger 2017

Cai et al., Figure 2

Agribusiness Boom Threatens Key African Wildlife Migration
(March 7, 2011)

Converted Miombo Woodland Zambia

Source # 2: Biomass from waste and residual sources
Forest residues

Sources of biomass		Key sustainability questions considered
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		

Biomass from forest residues: sustainability considerations

A) Type of forest used to source wood	Scope of ***types of forests*** included in analysis, whether from managed forests or timber plantations. Native forests typically excluded.
B) Definition of "residues"	Scope of residues from forests considered eligible as a source of biomass, including at different points along the value chain (e.g. logging residues, black liquor, industrial by-products or recycled wood).
C) Exclusion of protected / high biodiversity areas	Exclusion of land areas based on high ***biodiversity value*** or other reasons of ***preservation*** (e.g. natural landscapes, soil carbon levels, ecosystem services).
D) Soil and forest health criteria	Exclusion of areas based on ***soil erosion*** levels and proportion of residue retention assumed necessary for ***soil health, including soil organic carbon.***
E) Exclusion due to competing demand or uneconomic collection	Assumption of the proportion of biomass that can be ***economically collected*** as well as projected demand from ***other sectors*** (e.g. timber, pulp & paper) *Note: market price increases could enable increased uptake of available sustainable biomass*

Biomass from forest residues: Comparison of methods and assumptions (1/2)

Europe

	ECF-ICCT (7) *EU 2030*	ICCT (4) *Global 2050*	ACRE Satellite Model (1) *Global 2050*	FOLU/IIASA – LED & BECCs (3) (2) *Global, 2050*	IIASA – EU RECEBIO (5) *Europe, 2050*
A Type of forest used to source wood	Roundwood production data (FAO) + estimated bark volume (UNECE ratios)	Wood plantations only (FAO)	Global new forest growth (FAO)	Industrial short rotation plantations, managed forests and traditional fuel wood (manually collected)	Forests, short rotation coppice plantations and industrial by-products (e.g. black liquor), firewood, recycled wood and imported wood pellets.
B Exclusion of protected / high biodiversity areas	Exclude protected areas	Excludes all natural forests	Exclude forest landscapes, peatlands, wetlands, areas of high biodiversity	Forest area valued for carbon sequestration and biodiversity protected with carbon tax and biodiversity subsidy in model	*Assumed that native forests excluded from study.*
C Definition of "residues" used in the study	Residue ratios range from 0.17-0.47 (softwood vs. hardwood)	Assume residue ratio of 0.3 Replace nutrient loss with fertiliser application	Primary residues (branches and tops) Low-grade roundwood (incl. thinning, ex barks) Secondary residues from high-grade roundwood	Primary residues (Logging) Secondary residues (bark, black liquor, and sawdust & wood chips) Tertiary residues from wood recycling	Forest residues (e.g. logging residue - tree branches & tree tops, Technical losses from forest harvesting 30-40% Industrial by-products, roundwood for energy, firewood, recycled wood.[1]

Note: FOLU model uses cost accounting (e.g. country level, field level, transportation).

(1) Only forest residues, black liquor and industrial byproducts included in assumption for forest residues for this comparison exercise.

Biomass from forest residues: Comparison of methods and assumptions (2/2)

Europe

	ECF-ICCT (7) EU 2030	ICCT (4) Global 2050	ACRE Satellite Model (1) Global 2050	FOLU/IIASA – LED & BECCs (3) (2) Global, 2050	IIASA – EU RECEBIO (5) Europe, 2050
D Soil and forest health criteria applied	Minimum 50% residue retention on ground, average 68% (country specific) Exclude riparian buffer zones	Natural forest logging residues excluded (removal causes nutrient losses & reduced forest growth)	Leave 16%-31% of residues on the ground for pixels that were not excluded from land model (1000 t/km3); primary residue retention of 70% when accounting for all forests, globally Exclude areas with gradient >25%	As for RECEBIO Study	Soil erosion: For steep sites extraction limited.[1] Soil Health: Soils with low levels of SOC or shallow soil depth excluded. Primary logging residues: min. 30cm soil depth, min. 0.6% topsoil soil organic carbon
E Economic collection and competing uses	Excludes residues used for heat and power, based on current usage by country. No other uses considered.	*Na*	Exclude ~25-30% of residues available for uneconomic collection or competing uses, including fuelwood.	GLOBIOM is a market price model that food and carbon prices to adjust demand for land and bioenergy.	Sustainable residue capacity accounted separately from economy capacity based on affordability due to market prices.

Note: FOLU model uses cost accounting (e.g. country level, field level, transportation).

(1) For soil erosion, residue extraction in forest areas that have slopes with an inclination >50% was not allowed for broadleaved forests and limited to 33% of conifer sites. On slopes with inclination between >30 and ≤50%, the extraction was limited to 33% of broadleaved and 66% of conifer stands. *Fluvio et al.*,

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Biomass from forest residues: Comparison of biomass estimates

Inferred from information provided

Europe

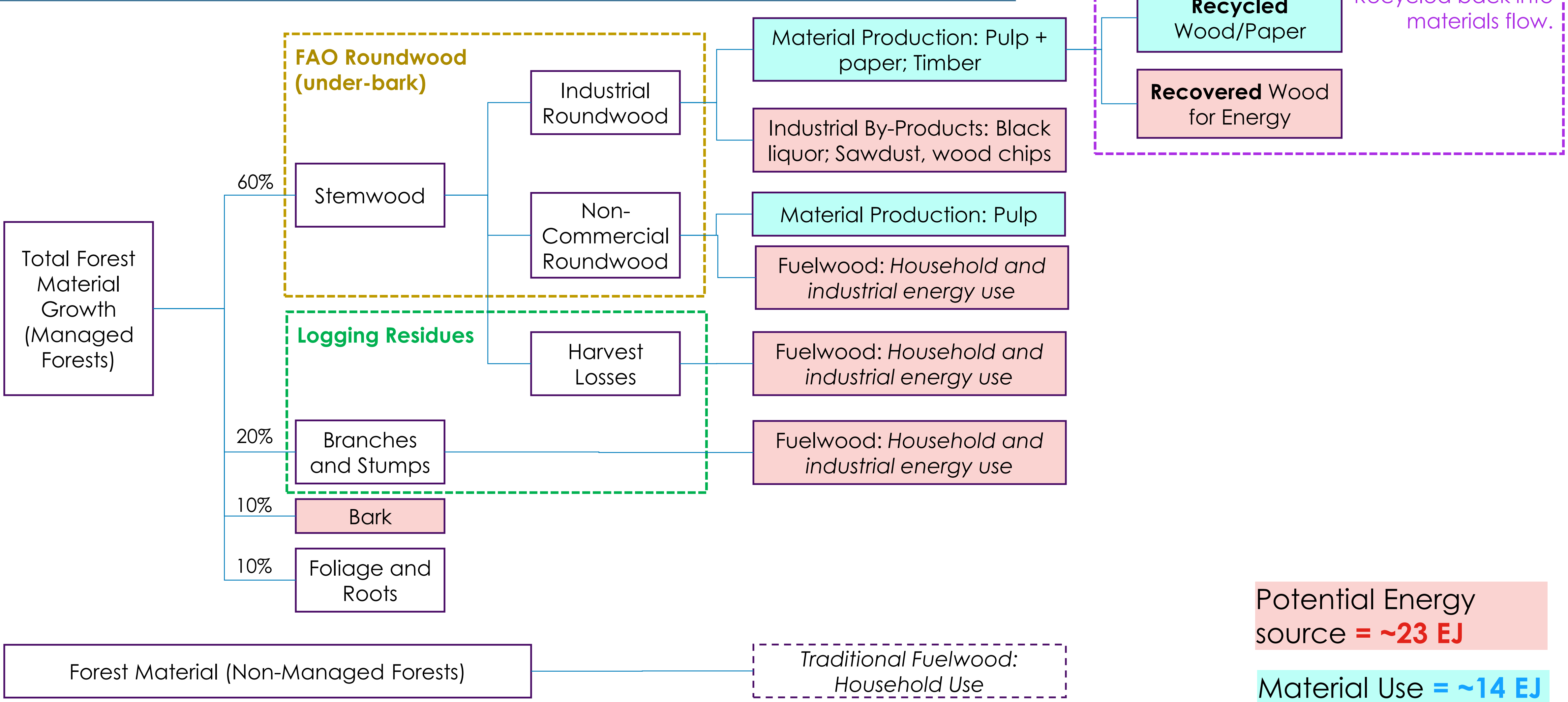
		ECF-ICCT *EU 20230* (7)	ACRE Model *Global 2050* (1)	ICCT *Global 2050* (4)	FOLU/IIASA – LED *Global 2050*[1] (2)	FOLU/IIASA – BECCS *Global 2050* (3)	IIASA – RECEBIO *Europe 2050* (5)
Total Forest Area	Mha.	n.a	n.a	n.a	4426 (all forest)	4386 (all forest)	n.a
Total Available Biomass from Forests	Mt/yr.	266	3579-8053[1]	855	n.a.	n.a.	317 (domestic harvest)
Forest Residues Only	Mt/yr.	80	632-1368	256	1,375	3,380	125[2]
Excluded Areas			*Areas excluded before residues estimated*				
Biodiversity Protection	Mt/yr.	n.a.	1685-4053	n.a.	n.a.	n.a.	n.a.
Soil Health	Mt/yr.	46	174-189	n.a.	n.a.	n.a.	n.a.
Uneconomic Collection	Mt/yr.	n.a.	842-1579	56	n.a.	n.a.	n.a.
Socio-Political Risks	Mt/yr.		11-26	50	n.a.	n.a.	n.a.
Total Sustainable Biomass from Residues	Mt/yr.	34	263-837	150	1,375	3,380	125
Total Energy from Forest residues	EJ/yr.	0.7	6-15	3	22	54	2

- (1) ACRE model and IIASA use conversion factor of 19 and 16 GT/ton for woody biomass, resp..; Forest residues include roundwood and timber wastes. Traditional fuel wood not included. (2) RECEBIO Forest residues number includes Forest Residues, Black Liquor, and Industrial By-products

How does forest biomass break down into useable parts?

2 Biomass from waste and residues
A Forest residues

Uses of Forest Biomass – *IIASA / FAO Model*



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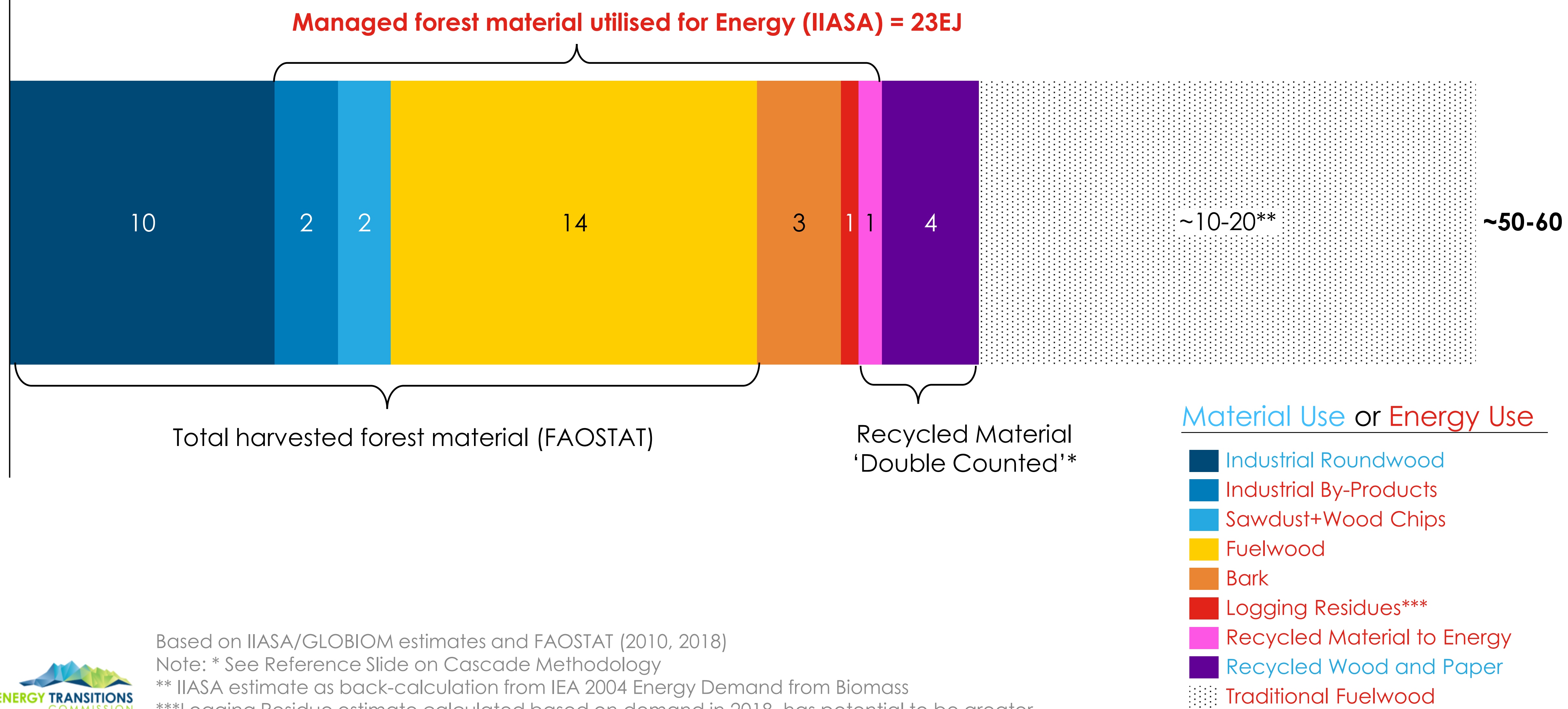
Note: We've noted uses cases, but this doesn't mean that 100% of the source is used

~ 60% of forest residues collected today already used for energy as fuelwood

Total Use of Forest Biomass 2018 (EJ/year)



Based on IIASA/GLOBIOM estimates and FAOSTAT (2010, 2018)
Note: * See Reference Slide on Cascade Methodology
** IIASA estimate as back-calculation from IEA 2004 Energy Demand from Biomass
***Logging Residue estimate calculated based on demand in 2018, has potential to be greater

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Biomass from forest residues:
Key assumptions from the IIASA EU RECEBIO Study

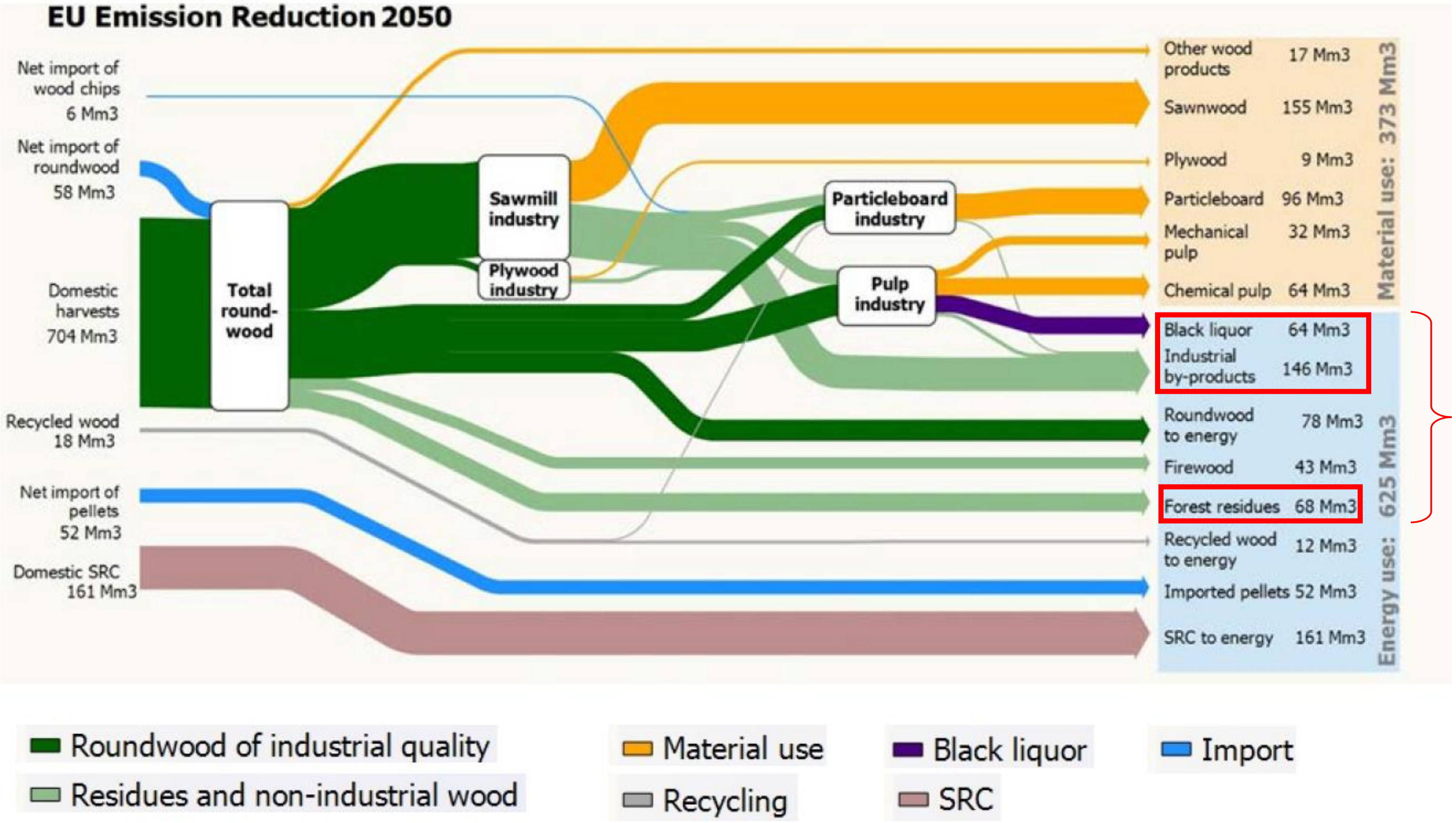


Figure 2. *The wood flows in the EU28 in 2050 in the EU Emission Reduction scenario, in Mm3 solid wood equivalent.*

For the purposes of like-for-like comparison, **Forest residues** accounted for in this comparative exercise included black liquor, industrial by-products and Forest Residues.

Source: Forsell, N. et al. 2016: Study on impacts on resource efficiency of future EU demand for bioenergy (ReceBio). Final report. Project: ENV.F.1/ETU/2013/0033. Luxembourg: Publications Office of the European Union, 2016. 43 p.

Forestry Residues

European Climate Foundation

icct THE INTERNATIONAL COUNCIL ON Clean Transportation

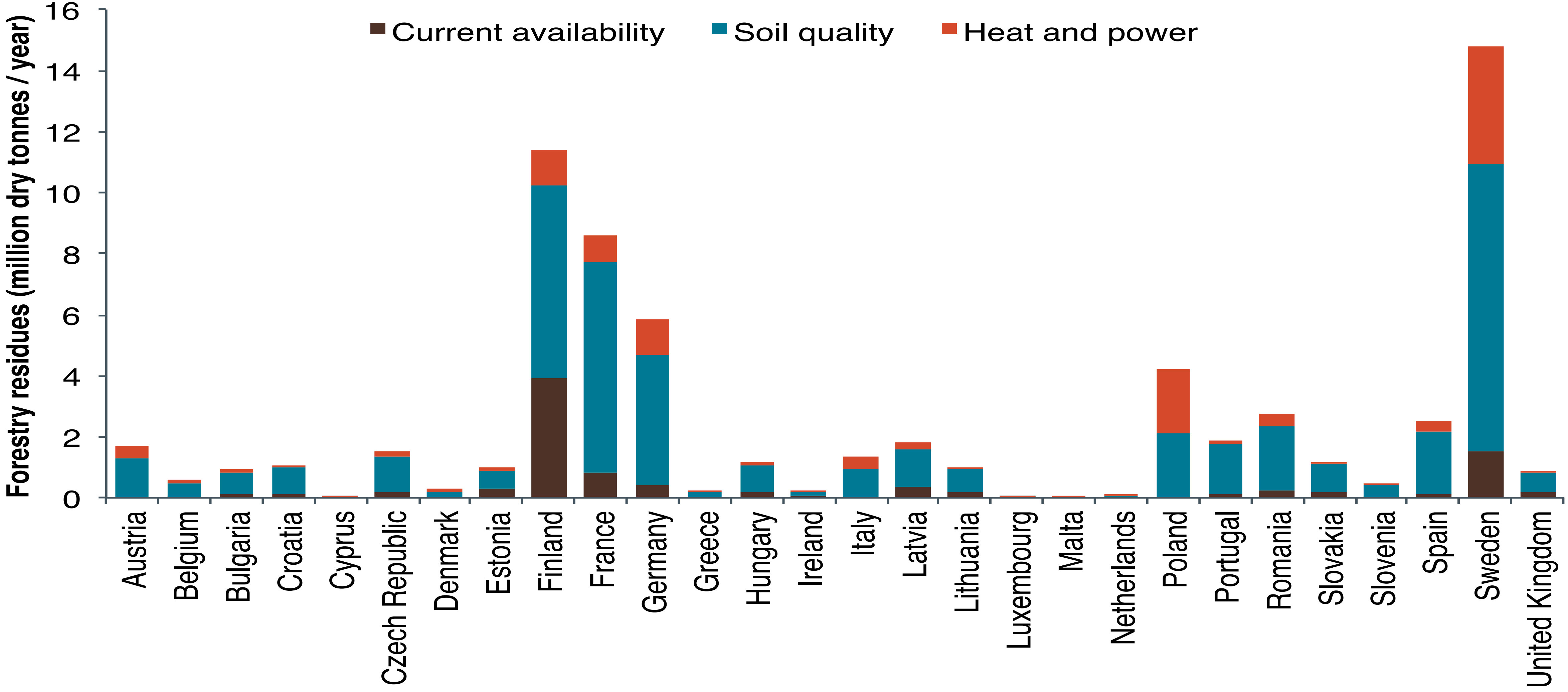
Forestry residues: Methods

- Roundwood production data from FAOSTAT
- Estimate bark volume (from UNECE)
- Residue ratio based on region and hardwood/softwood composition (not including stumps)

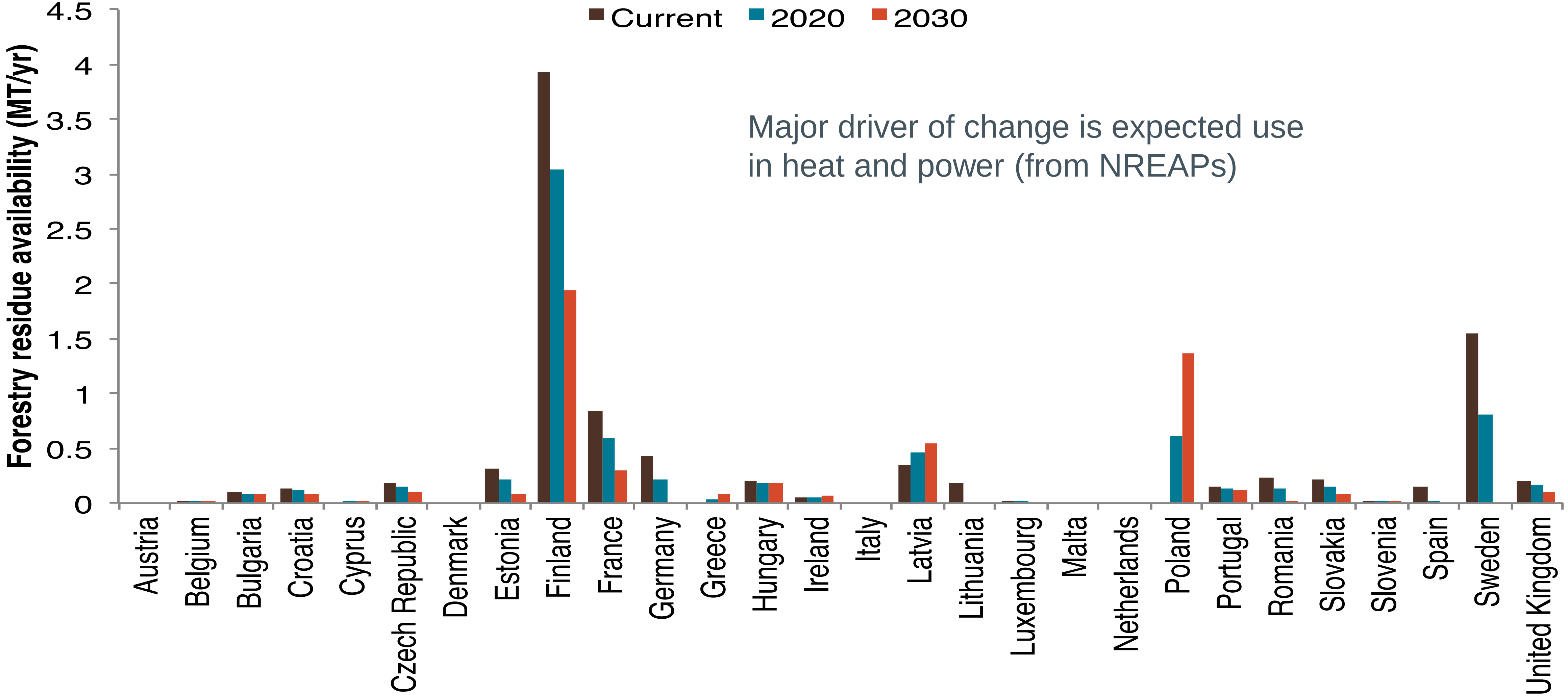
	NORDIC	OTHER
Softwood residue to roundwood ratio	0.47	0.17
Hardwood residue to roundwood ratio	0.31	0.34

- Subtract estimated amount necessary to protect soil quality (similar to agricultural residues calculation)
- Subtract amount used for heat and power (use national data where available, otherwise estimated from EUROSTAT data)

Sustainable availability of forestry residues

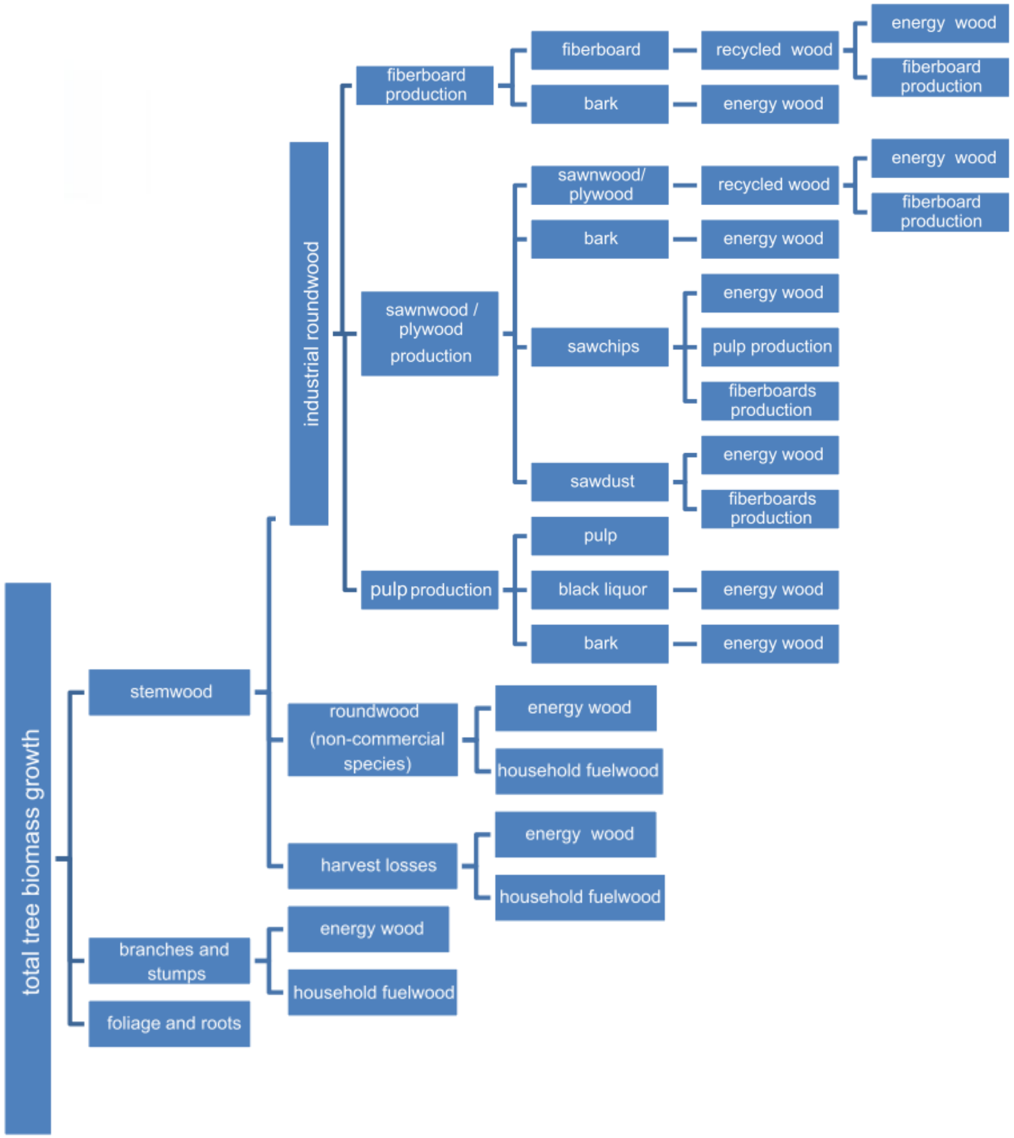


Sustainable availability of forestry residues

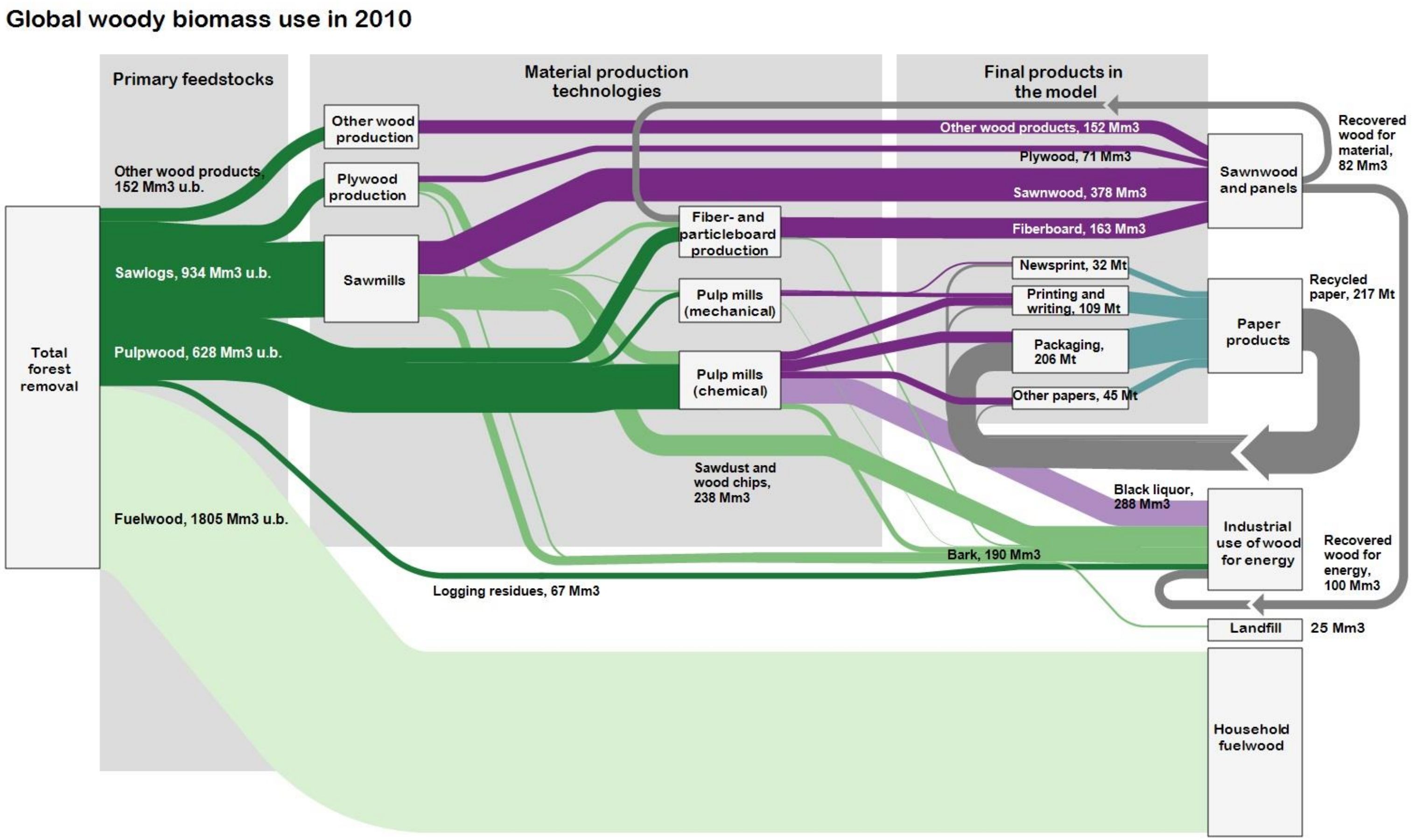


Forestry products and residues in GLOBIOM

- Three main bioenergy sources in the model:
  - Industrial short rotation plantations
  - Managed forest
  - Unsustainable use of biomass (fuel wood)
- GLOBIOM currently incorporates a detailed representation of forestry industries
- Different type of residues available for bioenergy
  - Primary residues (logging)
  - Secondary residues (bark, black lickor, and sawdust & wood chips that can be pelletized)
  - Tertiary residues from wood recycling



Representation of wood flows in GLOBIOM



Lauri P, Havlík P, Kindermann G, **Forsell N**, Böttcher H, Obersteiner M (2014). Woody biomass energy potential in 2050. Energy Policy, 66, 19-31.

Forsell N, Eriksson L.O, Athanassiadis D, Assoumou E (2018). Swedish Forest Harvest Level Considering Demand of Biomass for Energy Purposes. FORMATH Vol. 17.

Lauri P, **Forsell N**, Gusti M, Korosuo A, Havlik P, Obersteiner M (In press). Global woody biomass harvest volumes and forest area use under different SSP-RCP scenarios. Forestry.

Cost accounting module

Country level

Adaptation of unitary costs:
- Capital
- Labor
- Operational

Simulation unit level (field)

Selection of harvesting systems and adaptation of performances:
- Soil
- Slope
- Biomass amount

From roadside to facility

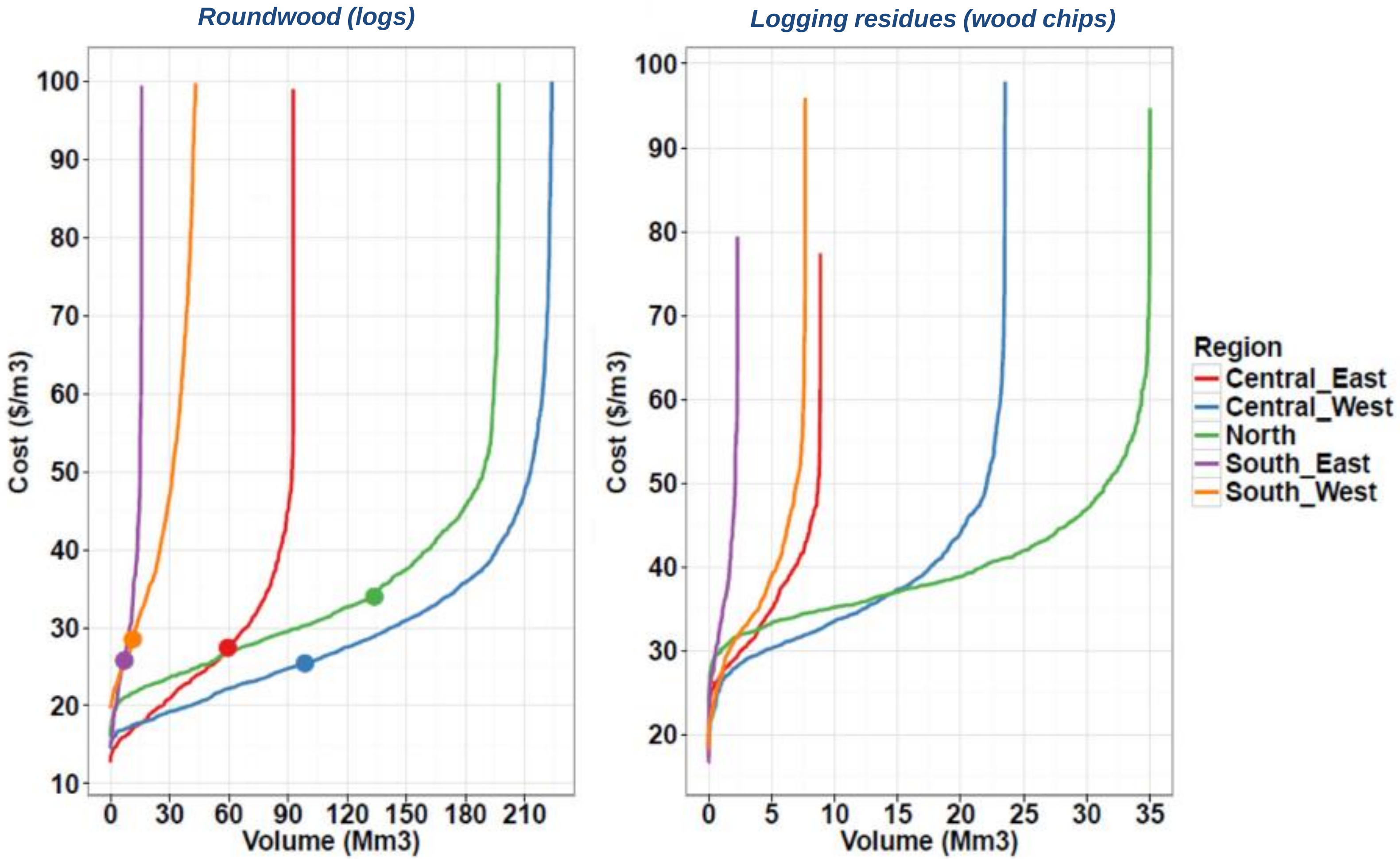
- Selection of transportation systems
- Adaptation of routing and performances

Economic indicators
- PPPs
- Wages
- Fuel prices

COST INDUSTRY GATE

Di Fulvio F, **Forsell N**, Lindroos O, Korosuo A, Gusti M (2016). Spatially explicit assessment of roundwood and logging residues availability and costs for the EU 28. Scandinavian Journal of Forest Research, 31 (7), 691-707.

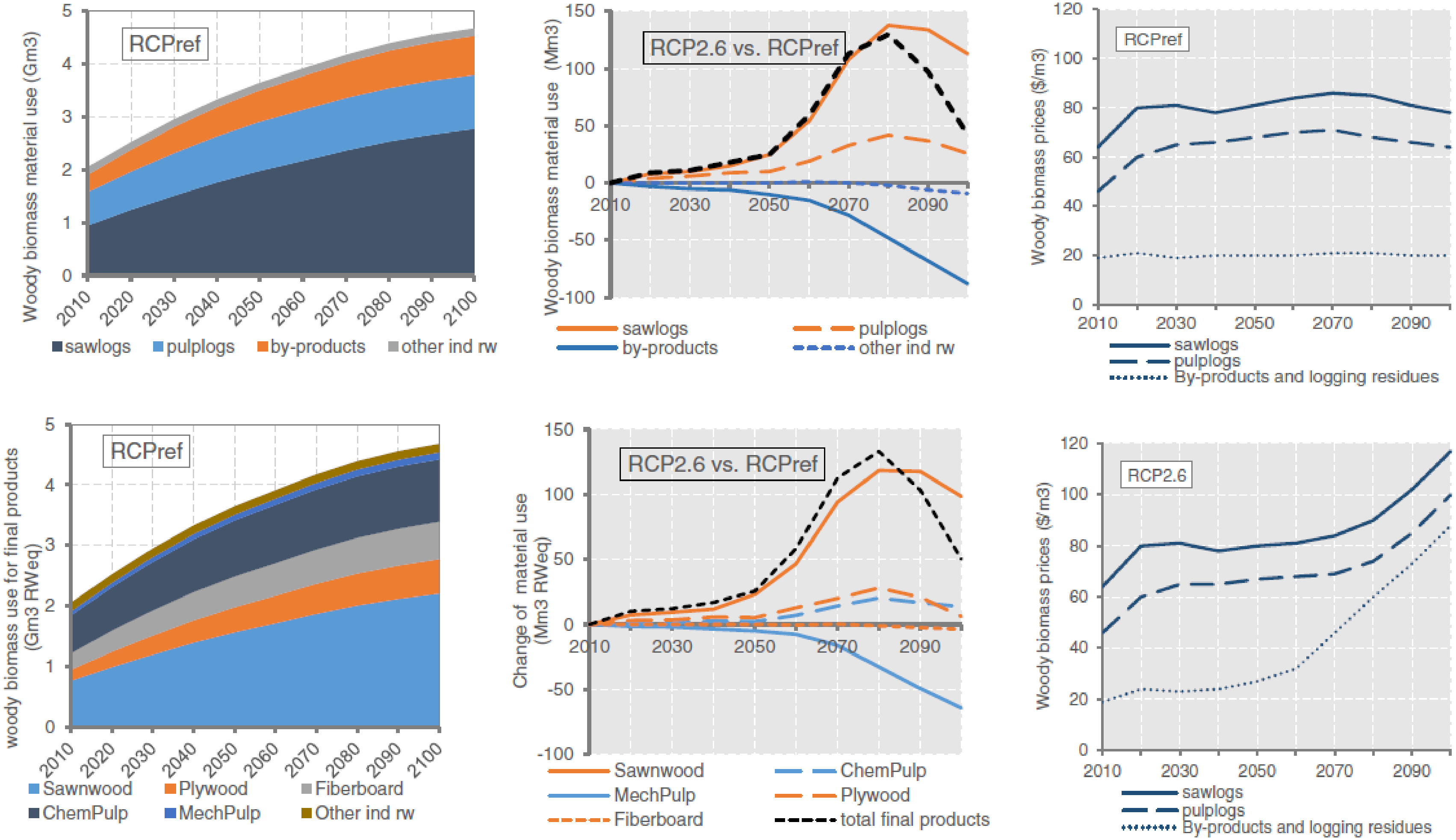
Cost accounting module



The dots on the roundwood curves are current amounts mobilized according to FAOSTAT 2013

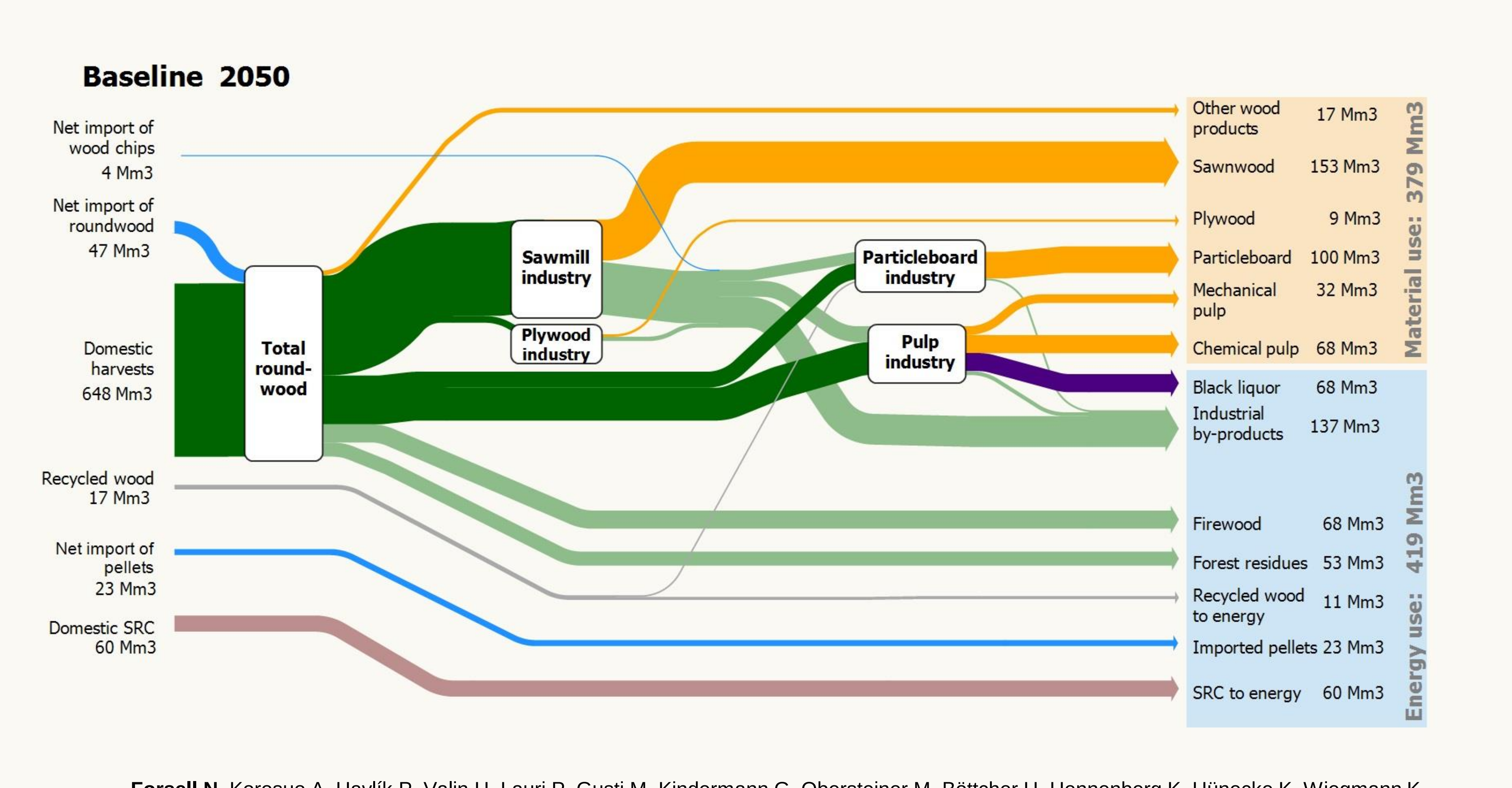
Di Fulvio F, **Forsell N**, Lindroos O, Korosuo A, Gusti M (2016). Spatially explicit assessment of roundwood and logging residues availability and costs for the EU 28. Scandinavian Journal of Forest Research, 31 (7), 691-707.

Forest sector contribution



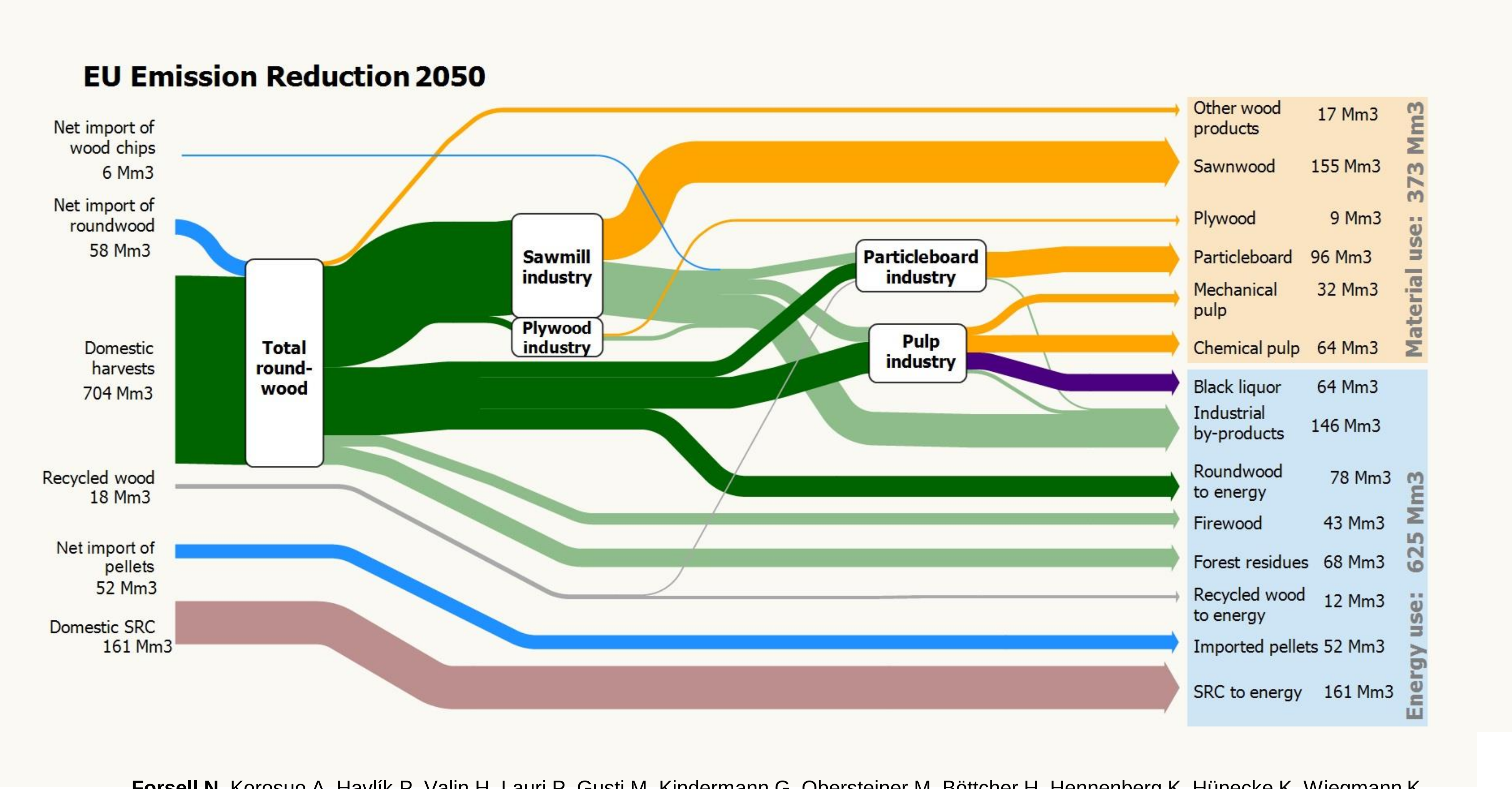
Lauri P, **Forsell N**, Korosou A, Havlík P, Obersteiner M, Nordin A (2017). Impact of the 2 °C target on the global woody biomass use. Forest Policy and Economics, 83, 121-130.

EU Bioenergy assessment



Forsell N, Korosuo A, Havlík P, Valin H, Lauri P, Gusti M, Kindermann G, Obersteiner M, Böttcher H, Hennenberg K, Hünecke K, Wiegmann K, Pekkanen M, Nuolivirta P, Bowyer C, Nanni S, Allen B, Poláková J, Fitzgerald J, Lindner M (2016): Study on impacts on resource efficiency of future EU demand for bioenergy (ReceBio). Final report.

EU Bioenergy assessment

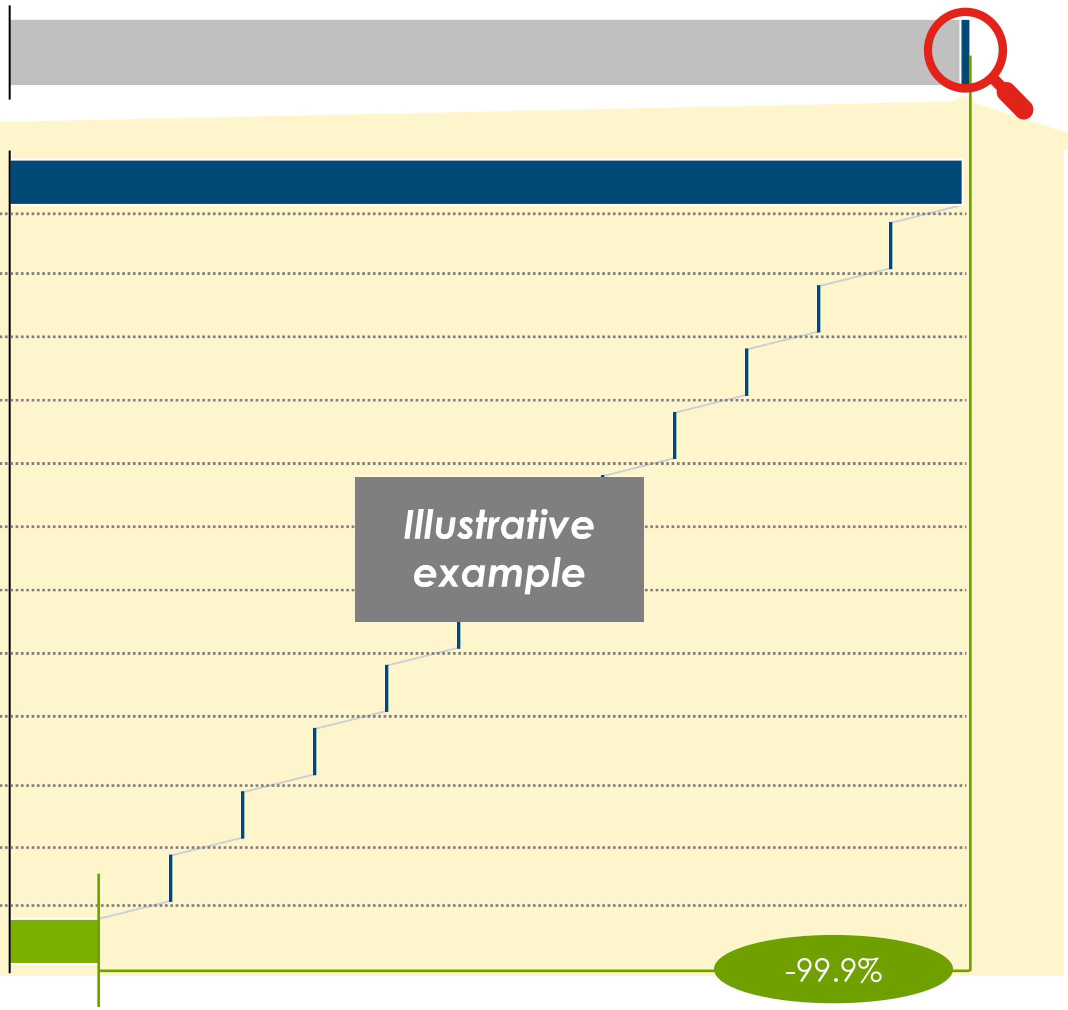


Forsell N, Korosuo A, Havlík P, Valin H, Lauri P, Gusti M, Kindermann G, Obersteiner M, Böttcher H, Hennenberg K, Hünecke K, Wiegmann K, Pekkanen M, Nuolivirta P, Bowyer C, Nanni S, Allen B, Poláková J, Fitzgerald J, Lindner M (2016): Study on impacts on resource efficiency of future EU demand for bioenergy (ReceBio). Final report.

Sustainability filters can rule out as much as 99.9% of certain types of biomass supply

Steps to achieve an estimate of sustainable woody biomass available

Biomass energy at each step[1], EJ



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

a

Take this **new growth** and…

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

b

…**exclude** areas designated as **intact forest** landscapes

...exclude **peatlands**

…exclude areas of **high relative biodiversity**[2]

…exclude **wetlands**

…exclude **protected lands**

…exclude world database of **key biodiversity areas**

…leave 1000t per km^2 of primary residues on the ground to maintain **soil health**

c

…exclude areas with a **gradient** higher than 25%

…of this, remove portions that are **uneconomic** to take or have competing uses[3]

…exclude certain countries for reasons of **corruption or slavery**

…and you arrive at the sustainable woody biomass potential

1 Where filters overlap, energy values have been divided equally 2 Areas of biodiversity equal to, or higher than, that of the Amazon rainforest 3 Including changes to account for uses of fuelwood. SOURCE: FAO 2015 FRA; ESA CCI Land Cover; O'Brien (2016); IPCC; Diaglou et al. (2016); Smeets and Faaij (2007); FAO Forest Products statistics; Global Soil Erosion; JRC; Intact Forests.org; Newbold et al. (2016); Wu et al. (2017); Tootchi et al. (2018); Digital Observatory for Protected Areas v4; Deng et al (2015); Thomson Reuters Country Check, Transparency International Corruption Index

Source # 2: Biomass from waste and residual sources
Agricultural residues

Sources of biomass		Key sustainability questions considered
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		

Biomass from agricultural residues: sustainability considerations

A) Amount of crop land	Assessment of ***agricultural land area*** available as a source of residue collection for bio-energy purposes
B + C) Crops & residues considered	Range of ***crop types*** covered in analysis and decision to include ***primary vs. secondary/processing*** residues, and assumptions on ***residue ratios***
D) Soil health criteria	Proportion of residue retention assumed necessary for ***soil health***, i.e. nutrient loss and soil erosion.
E) Economic collection and (traditional) competing uses	Assumption on proportion of biomass that can be ***economically collected*** and projected demand from ***other traditional sectors*** (e.g. animal feed and bedding, horticulture, cultivation.) *Note: market price increases could enable increased uptake of available sustainable biomass*

Biomass from agricultural residues: Comparison of method and assumptions

Inferred from information provided

Europe

	ECF-ICCT *Europe 2030* (7)	ICCT *Global 2050* (4)	ACRE Satellite Model *Global 2050* (1)	FOLU/IIASA – LED & BECCS *Global 2050* (2) (3)	IIASA –ILUC Study *Europe 2030* (5)
A) Amount of crop land				LED: Agri pasture/crop land decreases 1.2bn ha vs. today to 2.1bn ha, of which 1.375bn crop land	~100 m Ha total cultivated areas in 2020
B) Crops considered	Top 12 crops in EU	Top 12 crops globally	Top 5 crops globally	Exogenously included in the model and incorporated into the category of traditional fuel from biomass	Country specific to the 28 EU States
C) Amount of crop biomass left as 'residue'	Crop-specific residue ratios for i) primary (i.e. production on field), ii) processing	Crop-specific residue ratios for primary residues Excludes processing residues	Primary residues only for cereals & maize Secondary residues included for rice & sugar cane	The amount gathered from agricultural residues is kept base year level (2000) in model and not explicitly reported on.	The representation of agricultural residues focusses on wheat and other cereals straw
D) Soil health criteria	Leave 3.7t/ha residues on average Country specific based on that erosion rates, tillage practices (EUROSTAT) and soil carbon concentration	Assume only 90% of residue produced can be physically harvested Leave 70% on field (prevent soil erosion, carbon & nutrient loss)	Exclude areas with low soil organic carbon Exclude areas with soil loss >10 t/ha/yr. (Deng et al. 2015) Leave 250t/km3 of primary residues	Not major consideration in FOLU study.	Sustainable removal (~33-50%), around 40% on average.
E) Economic collection and (traditional) competing uses	Cap on feasible collection of 65% of total residues Ex. competing demand for livestock, mushrooms, horticulture	10% residues used for animal bedding and horticulture	Remove competing demand and uneconomic collection Exclude 41 countries based on corruption and slavery risk	Soil health and agricultural productivity assumed as priorities, but not a focus of the study.	Collection and transport costs Animal feed and bedding, fixed demand for mushrooms and other industrial uses

Biomass from agricultural residues: Comparison of biomass estimates

Inferred from information provided (green)

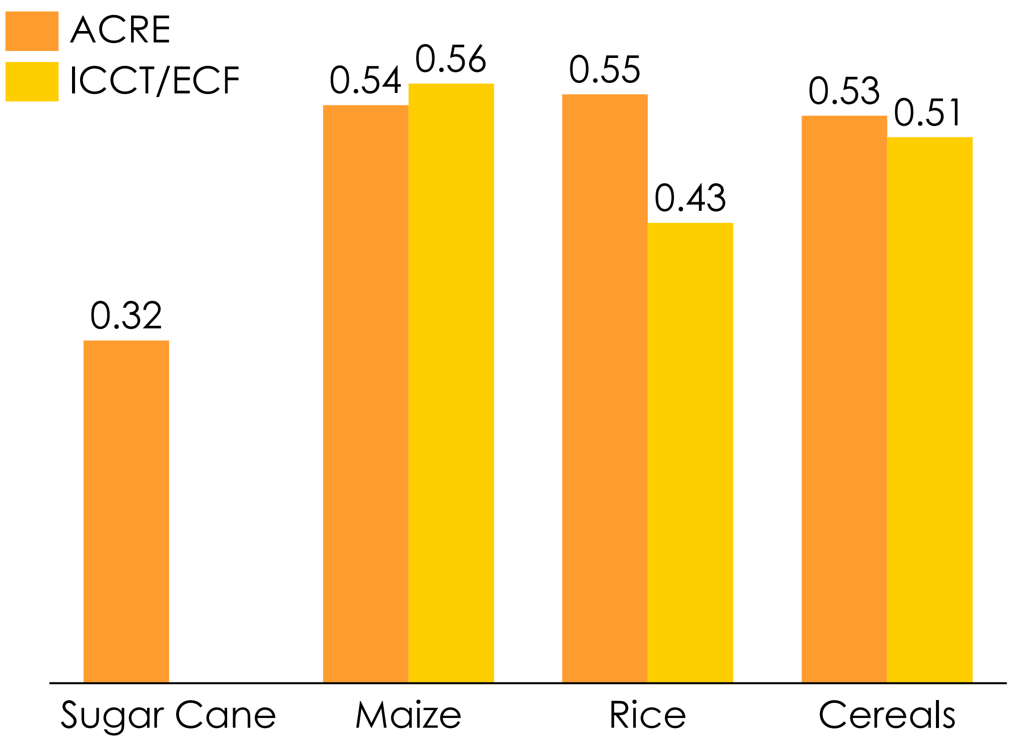
Europe (light blue)

		ECF-ICCT (7) *EU 2030*	ACRE Satellite Model (1) *Global 2050*	ICCT (4) *Global 2050*	FOLU/IIASA – (2) (3) *Global 2050*	IIASA –ILUC [2] (5) *EU 2030*
Total Potential Available Biomass	Mt/yr.		4666	10,075	n.a.	n.a.
Residues Only	Mt/yr.	501	1955-2662	4614	n.a.	214[1]
Excluded Biomass						
Protected Land	Mt/yr.				n.a.	n.a.
Soil Health	Mt/yr.	196	1111-1183	3691	n.a.	128.4
Uneconomic Collection	Mt/yr.	175	622-690		n.a.	n.a.
Socio-Political Risks	Mt/yr.		9-66	461	n.a.	n.a.
Total Sustainable & Accessible Biomass	Mt/yr.		265-1287	288	n.a.	85.6
Total Energy from Agri. Residues	EJ/yr.	1.5	4-22	5	n.a.	1.71

Note: ACRE model breakdown inferred using average HHV, not crop-specific. (2) Note: For GLOBIOM only cereal straw included here – total crop biomass difficult to extract from upstream models.

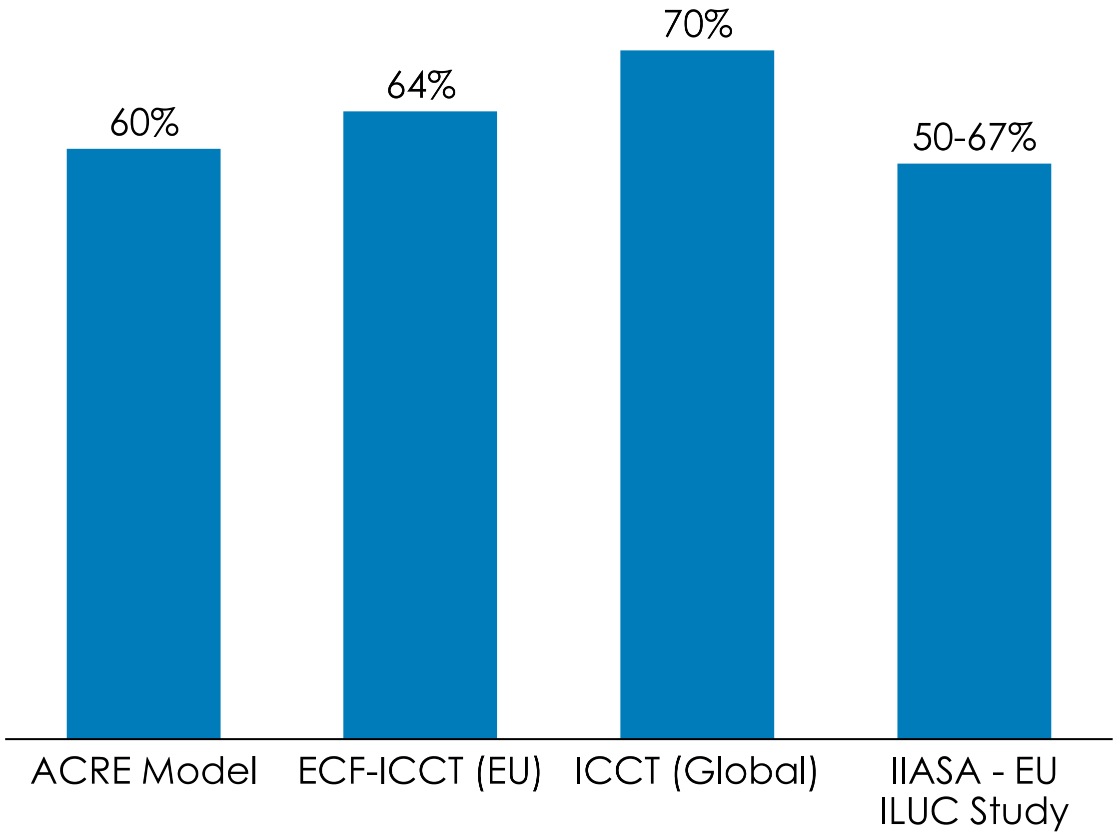
Biomass from agricultural residues: Key assumptions

Crop Residue Ratios
% Total Biomass



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

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

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Crop Residues

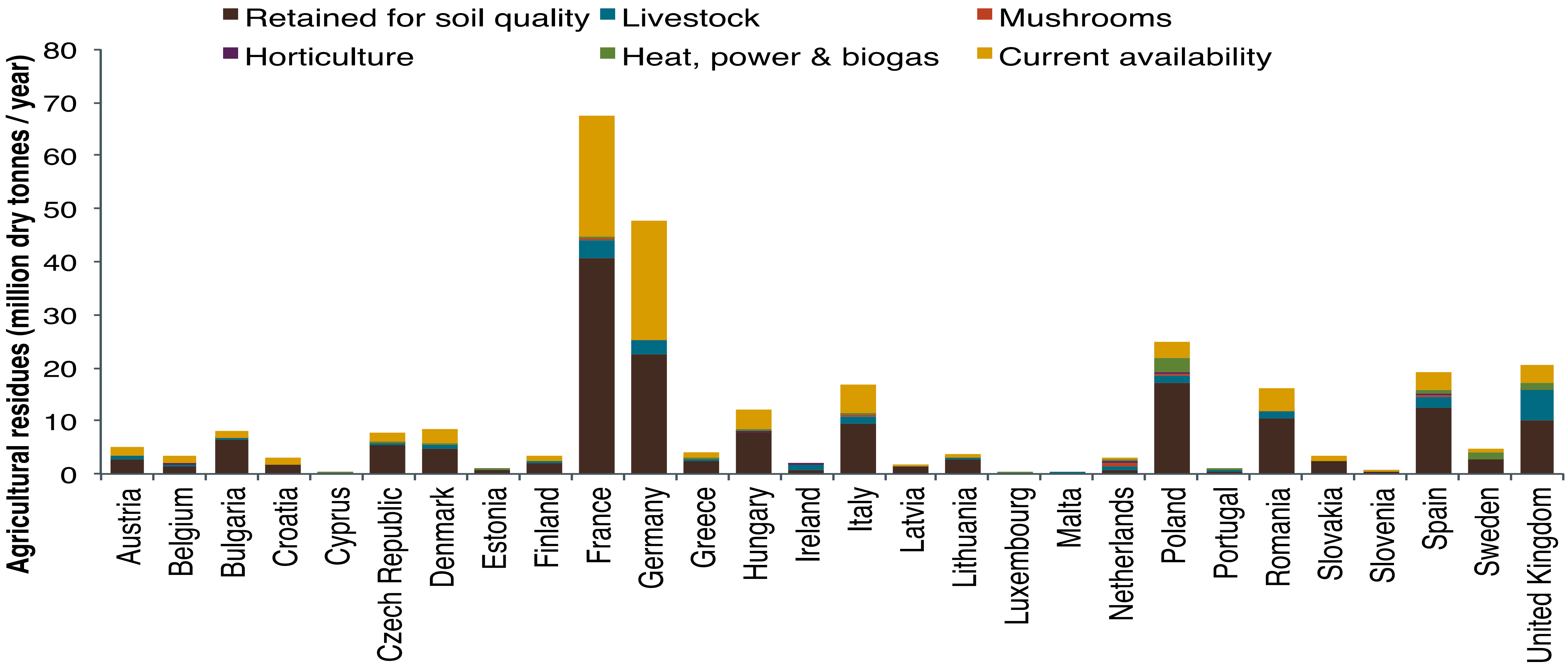
Agricultural residues: Methods

- Top 12 crops in EU

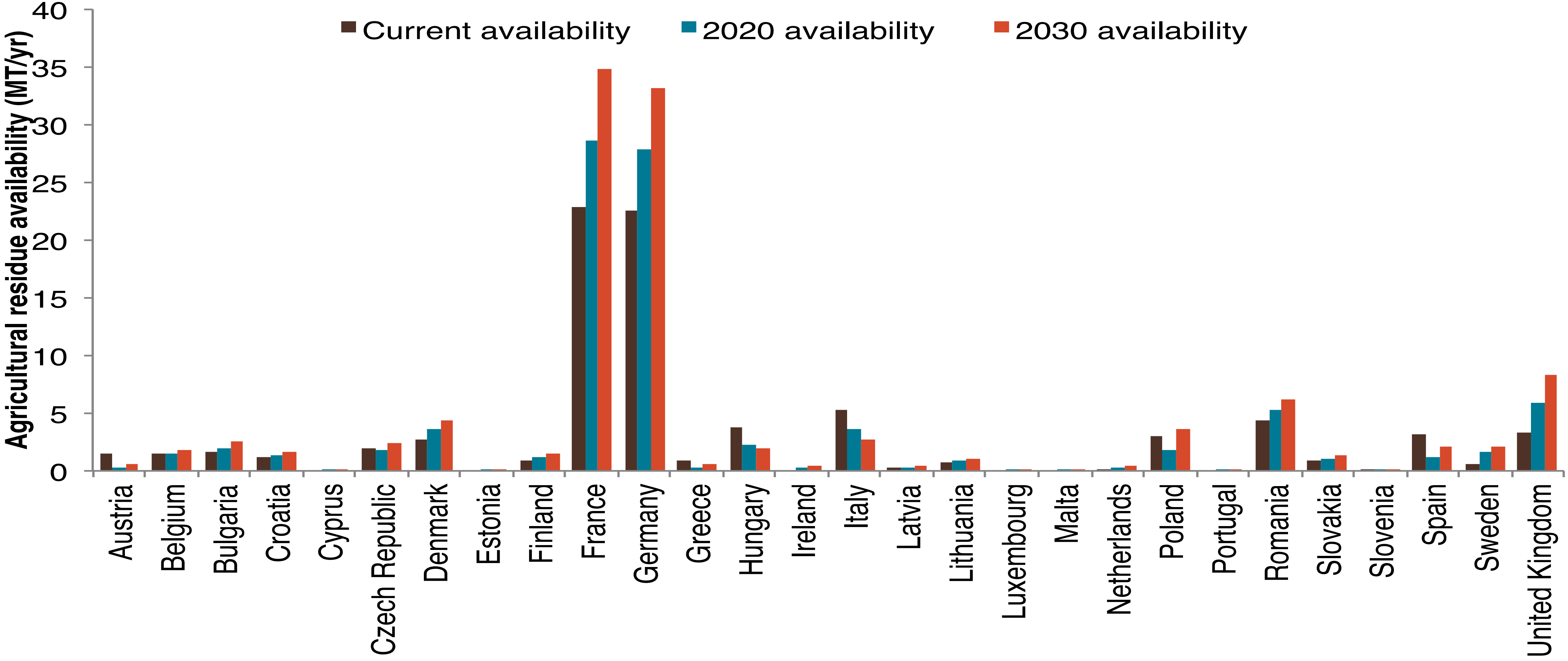
Barley	Rapeseed	Sugarbeet
Maize	Rice	Sunflower seed
Oats	Rye	Triticale
Olives	Soybeans	Wheat

- Crop production data from FAOSTAT
- Apply residue ratio to estimate production of field (e.g. straw) and processing (e.g. olive pits) residues
- Subtract estimated amount of field residues necessary to protect against soil erosion, SOC and nutrient loss based on each MS’s erosion rates, avg SOC, management practices
- All processing residues may be harvested
- Subtract estimated amount used for livestock (estimated using data from EUROSTAT), mushrooms (data from USDA), horticulture, heat, power, and biogas (data from EUROSTAT)

Sustainable agricultural residue availability



Sustainable agricultural residue availability



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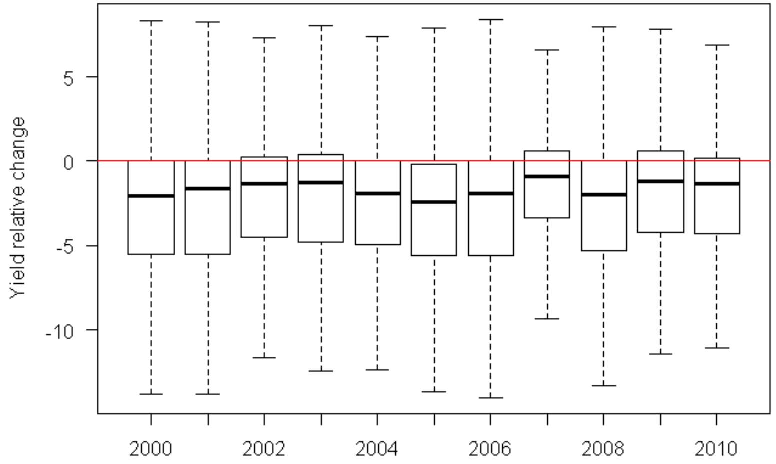
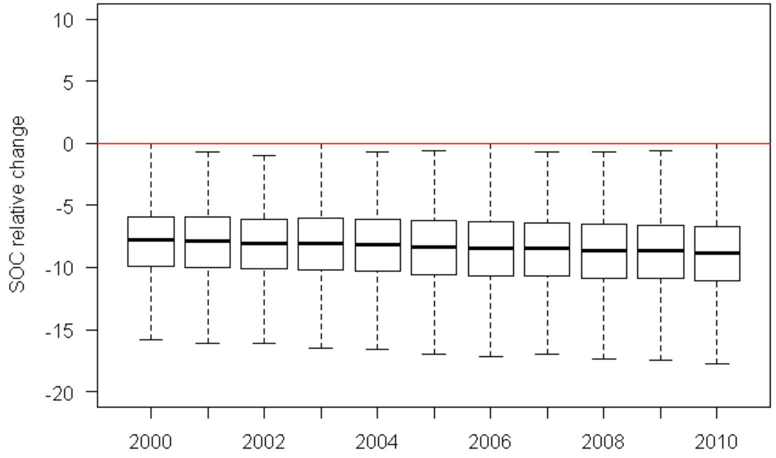
Using ag residues as bioenergy

- Specific analysis for the modelling of impacts of biofuel policy in the EU (2015)
- Estimates at NUTS2 level of supply and demand of cereals straw estimated based on JRC methodology
- Data and expert knowledge from specific countries in partnership with Ecofys
  - France, UK, Hungary as case studies
- Modelling in GLOBIOM of 3 production systems:
  - No straw removal
  - Sustainable removal (~40%)
  - Full removal (90%)
- Cost of collection and transport based on Austrian statistics
- Demand side:
  - Animal feed and bedding substitute
  - Fixed demand for mushrooms and other industrial uses
- Modelling in EPIC of the impact of full residues removal

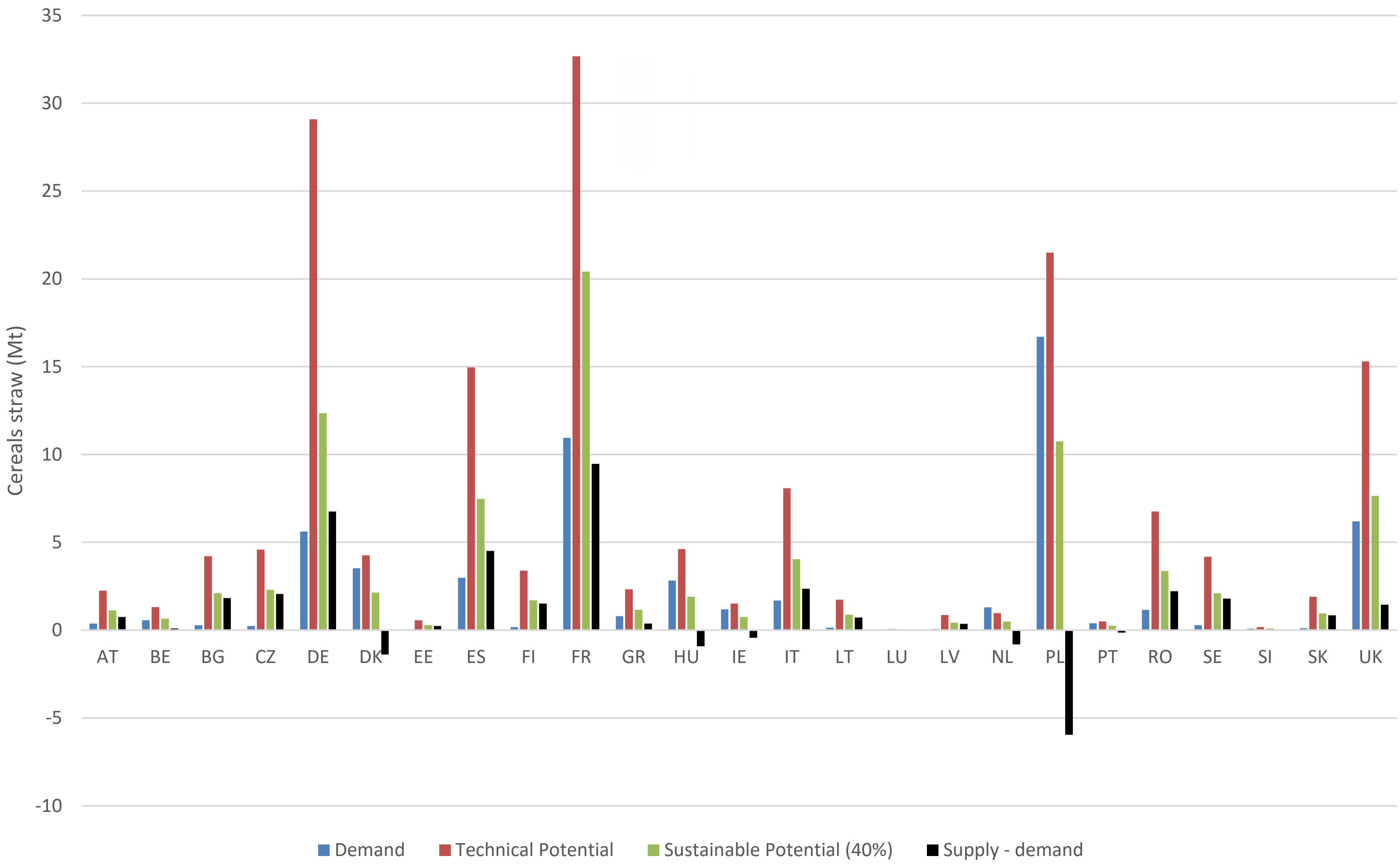
Yield effect



SOC effect



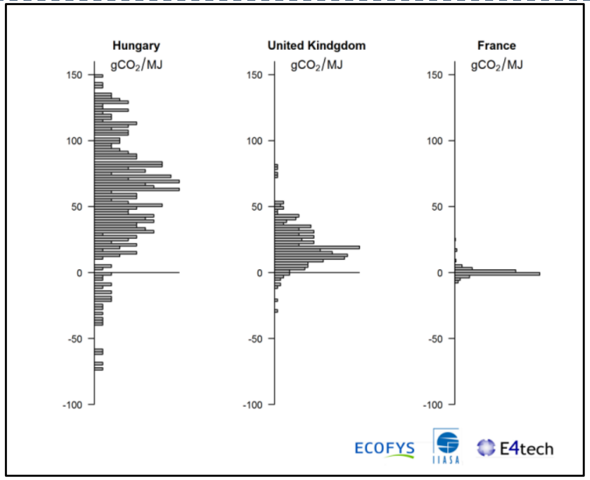
Estimates for the EU (2015 GLOBIOM ILUC study)

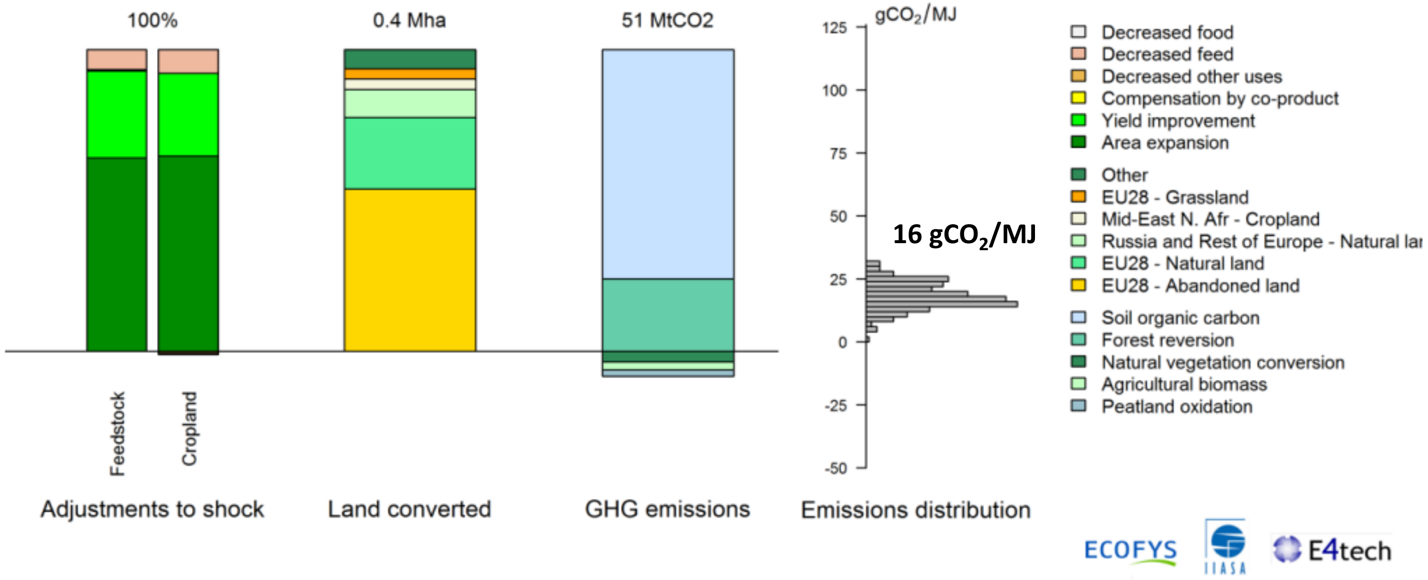


Indirect impacts to be expected…

- Demand policies for straw likely to generate
  - land use changes (through yield decrease)
  - GHG emissions (through LUC and SOC)

- Local markets: impacts depend on the region





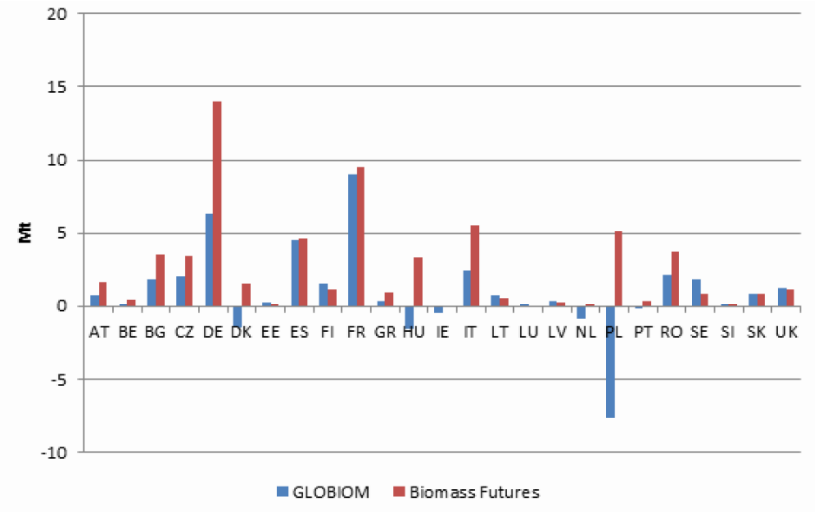
Source: Valin et al., 2015

Several sources of uncertainties

- Demand and competitive uses are not well documented
  - Requires country level checks – statistics difficult to find
- Rate of removal without significant impacts is debated
  - Yield and SOC impacts
- Availability, price and impacts of using substitution material (e.g. bedding needs)

- Beyond EU…
  - Problems above become larger when looking globally
  - Use of corn stover in the US most documented other bioenergy source in literature

Cereal straw availability – GLOBIOM vs Biomass Future



Source # 2: Biomass from waste and residual sources Municipal and industrial residues

Sources of biomass		Key sustainability questions considered
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		

Biomass from municipal & industrial solid waste: sustainability considerations

Incentivising Waste Creation	**Use of MSIW** for energy purposes may incentivise the production of extra waste material and **disincentivise circular economy efforts** to increase recycling and material re-use
Alternative Uses	**Resource recovery should be maximised**. Where residuals remain, the embedded carbon **should not be incinerated** and released into the atmosphere; **landfill biogas should be captured**.
Recycled Carbon	Bio-energy from MISW should focus on the biogenic proportion of waste streams and avoid using recycled carbon components, i.e. plastics. As **MSW residual waste streams** typically contain a substantial proportion of plastic waste that is economically infeasible to separate, this resource **cannot be considered sustainable**.

Biomass from municipal and industrial waste: Comparison of method, key assumptions and estimates

Inferred from information provided

Europe

		ECF-ICCT *Europe 2030* (7)	ICCT *Global 2050* (4)	FOLU/IIASA – LED & BECCs *Global 2050* (2)(3)
Waste source		• Household and MSW (assume 63% biogenic share) • Sorting residues (assume 50% biogenic share) • Cardboard wastes • Wood wastes • Animal and mixed food waste • Vegetal wastes • Animal faeces, urine and manure • Common sludges	• Only consider biogenic share of MSW and animal manure	• Exogenously included in the model and incorporated into the category of traditional fuel from biomass. The amount gathered from biogenic residues is therefore kept at the level of the base year (2000) in the model.
Key Assumptions		• Exclude waste used for other useful purpose (recycling, composting, backfilling, incineration with energy recovery)	• Waste biomass-to-cellulosic ethanol conversion efficiencies of 15-24% • Exclude ~32% for socio-political/governance quality risks	n.a.
Total Sustainable & Accessible Biomass	*Mt/yr.*	63	486	n.a.
Total Energy from MISW	*EJ/yr.*	0.4	3.4	n.a.

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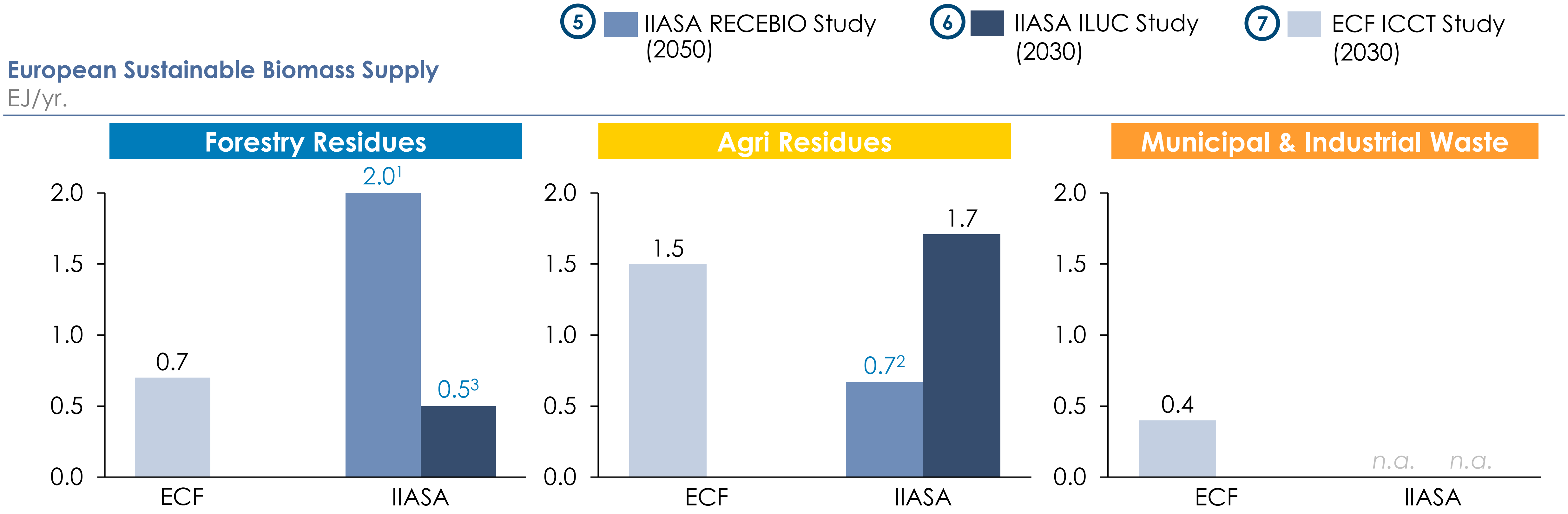
Note: Shi et al. (2009). Assume conversion factor of 7 GJ/ton for biogenic waste.
Note: Not relevant for IIASA EU Studies

European studies focused on waste & residues sources in detail, and in some areas suggest higher availability than equivalent ICCT and IIASA global studies

2 Biomass from waste and residues



Illustrative scaling of EU waste and residue estimates to a global level

	Forestry Residues			Agri Residues			Municipal & Industrial Waste		
EU as % of global	*29%*			*14%*			*14%*		
EU scaled to global (EJ)	2.3	6.9	1.7	11.3	5.1	12.4	3.1	*n.a*	*n.a*

Note: Assuming conversion factors of 17 and 20 GJ/ton for agricultural and forest residues, respectively. EU ILUC study only considers wheat straw for agri residues. ((1)Forestry residues in RECEBIO Study assumed to include Black Liquor, industrial by-products and forest residues; conversion factor applied for woody biomass (16 GJ/t); 2)Assuming 1 Mtoe = 5.8 Mm3; Ag residues for RECEBIO for 2030 drawn from 2014 EU Commission Impact Assessment Report, pg 62 ; (3) The sustainable potential estimated to be 73Mm3 (note, not considered therefore to be economic potential based on residue prices, which would be lower).

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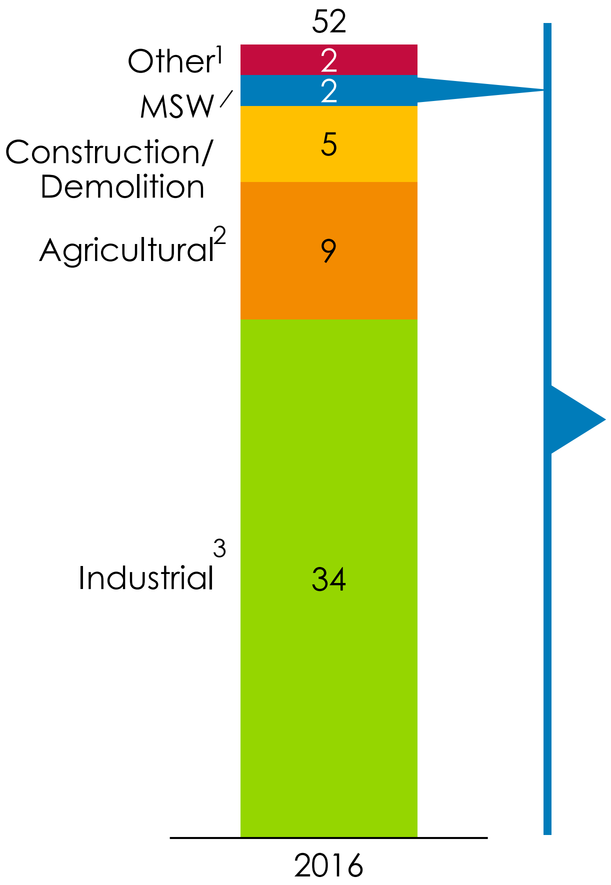
Almost 50% of municipal solid waste is organic, with the largest volumes and lowest recycling rates in Asia

2 Biomass from waste and residues

C Municipal & Industrial waste

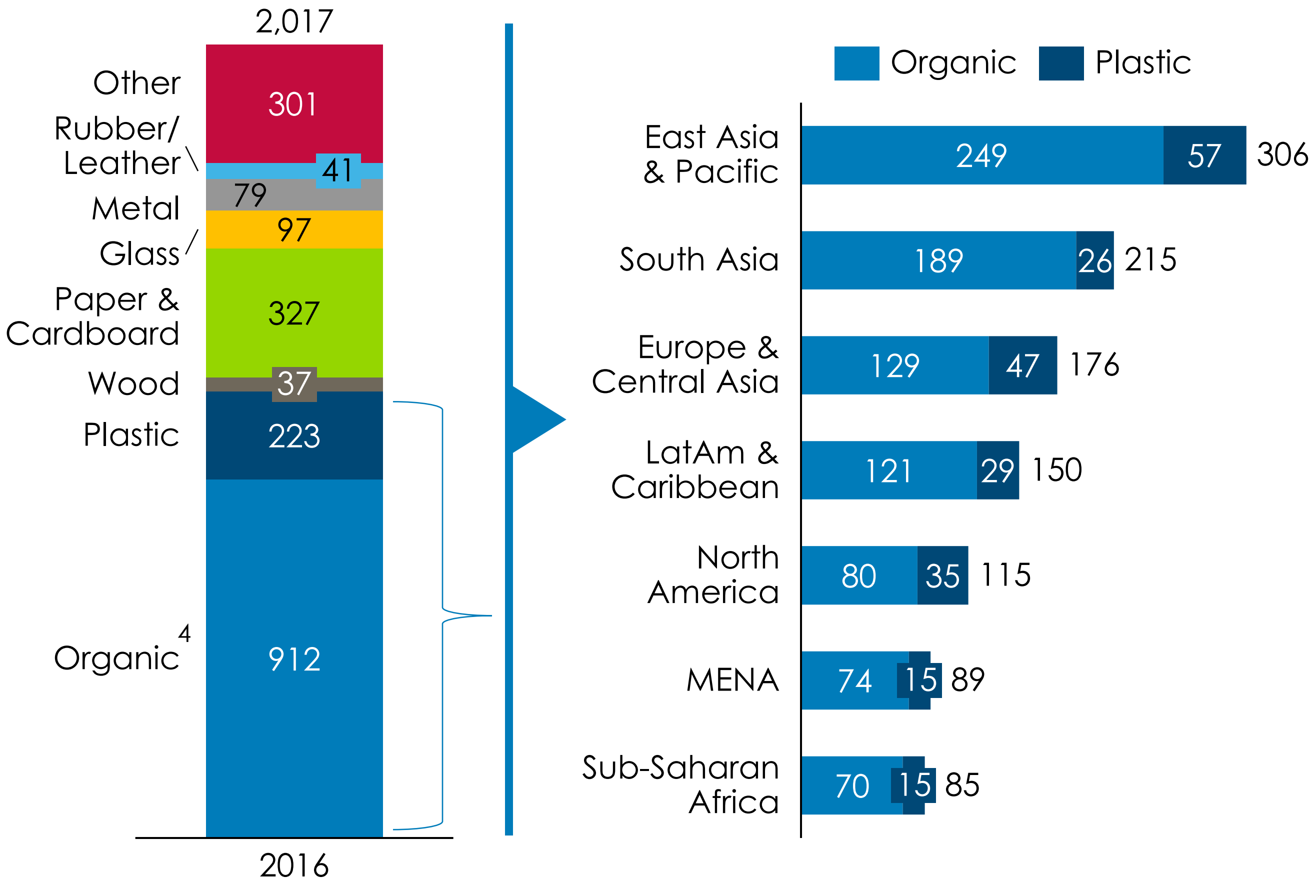
Total Waste

Billion Tonnes



Municipal Solid Waste (MSW)

Million Tonnes



Recycling Method

%

	Incinerated	Recycled/ Composted
East Asia & Pacific	24	11
South Asia	0	21
Europe & Central Asia	18	30
LatAm & Caribbean	0	4
North America	12	34
MENA	0	13
Sub-Saharan Africa	0	7

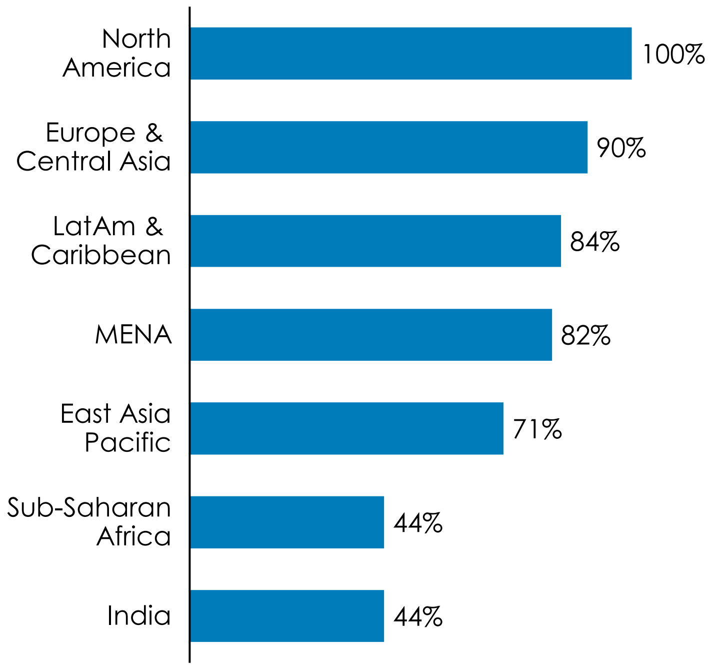
Note: [1]Hazardous, Medical, Electronic. [2]Including dung, straw etc. [3]Including waste rock etc. [4]Food and Green Waste.
Source: World Bank (2018) – What A Waste.

There are challenges across the waste processing supply chain, but major opportunities for improvement

Collection

- Collection rates significantly lower in developing regions

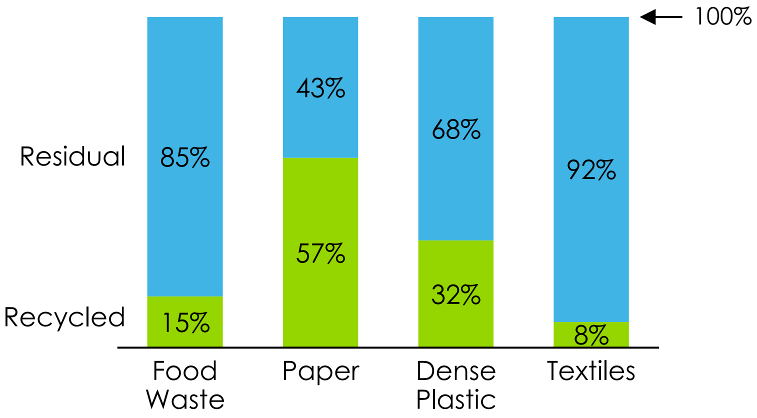
MSW Collection by Region, % Total



Sorting

- Upstream separation and logistics infrastructure reduces downstream sorting costs
- Materials with higher bulk density incur lower sorting costs per tonne
- Major issue is the high cost of separating organic & plastic streams in residual waste (i.e. post-recycling)

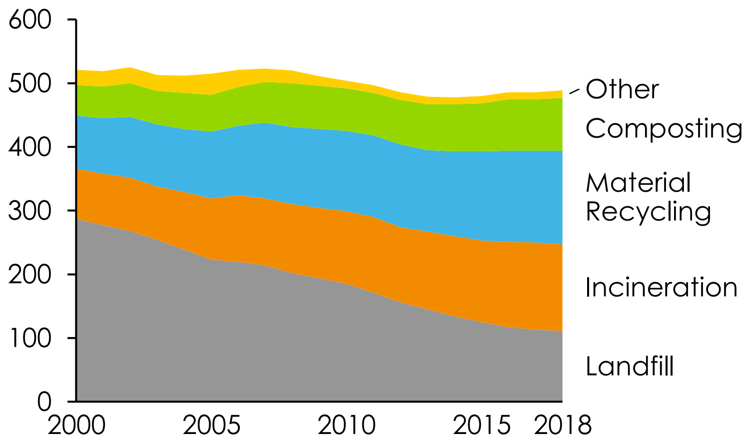
Recycling Capture Rates, UK 2017



Disposal

- 3 main options for waste disposal: recycling/composting, energy generation, landfilling
- Significant decrease in landfilling over recent years driven by policy; offset by increase in energy from waste and recycling rates

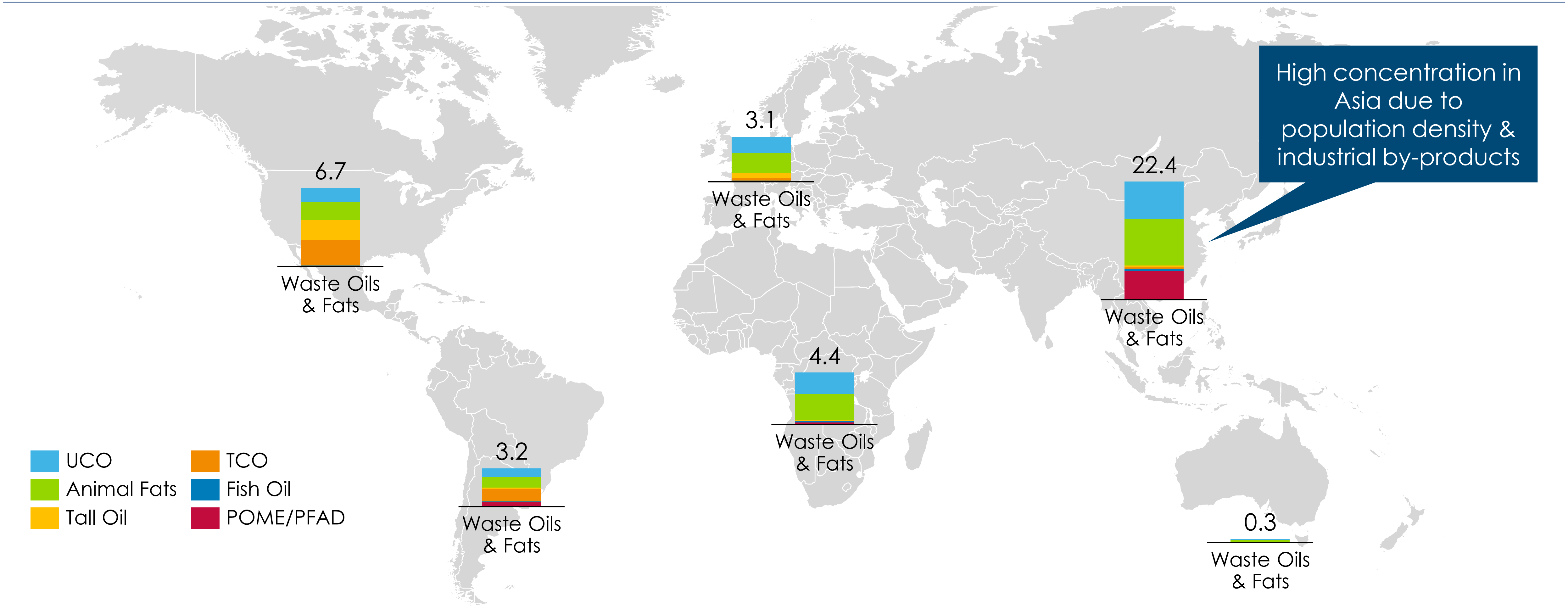
MSW Treatment, EU-28 (kg/capita)



Note: UK recycling capture rates refer to sum of kerbside and household waste.
Source: World Bank (2018) "What a Waste 2.0"; Eunomia (2017) UK WRAP Waste Composition Estimates; European Commission (2020), Municipal Waste Statistics.

Waste oils and fats are distributed unevenly around the world, but are highly transportable

Potential Biofuel Capacity by Feedstock
Mt/yr.



Note: UCO = used cooking oils; TCO = technical corn oil; POME = palm oil mill effluent; PFAD = Palm Fatty Acid Distillate.
Source: CST Analysis (2020)

Biogas provides a local source of power and heat for rural communities & can be upgraded to bio-methane and blended in existing gas pipelines

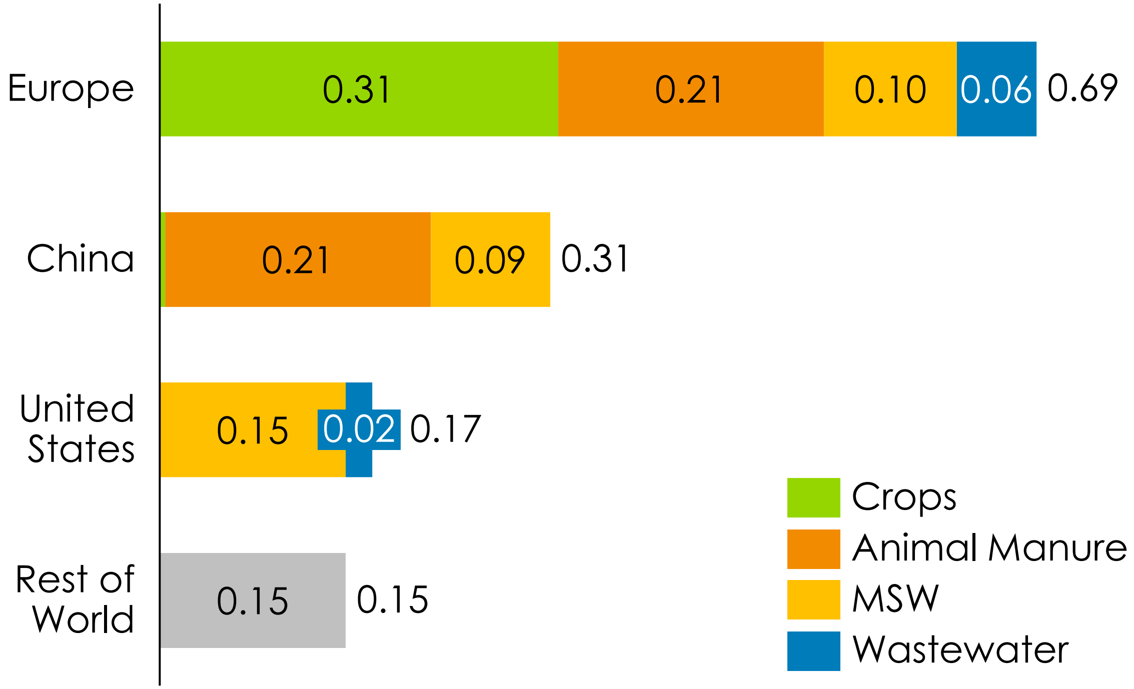
Key Points

- Biogas Production:
  1. In Europe, biodigesters processing **agricultural and municipal wastes**, most notably in Germany, have provided most of the growth in biogas production over the last 10 years
  2. In China, policies have supported the installation of **household-scale digesters in rural areas** as part of a drive to increase access to modern energy and clean cooking fuels
  3. In the United States, policies and regulations have traditionally focused on **landfill gas collection**, which today accounts for nearly 90% of total biogas production

- Biogas can also be **upgraded to bio-methane** and **blended into existing gas pipelines** for distribution across the network

Biogas Production by Region & Feedstock 2017

GJ/yr.



Source: IEA WEO (2019).

Biogenic Wastes

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European Climate Foundation

Biogenic wastes: methods

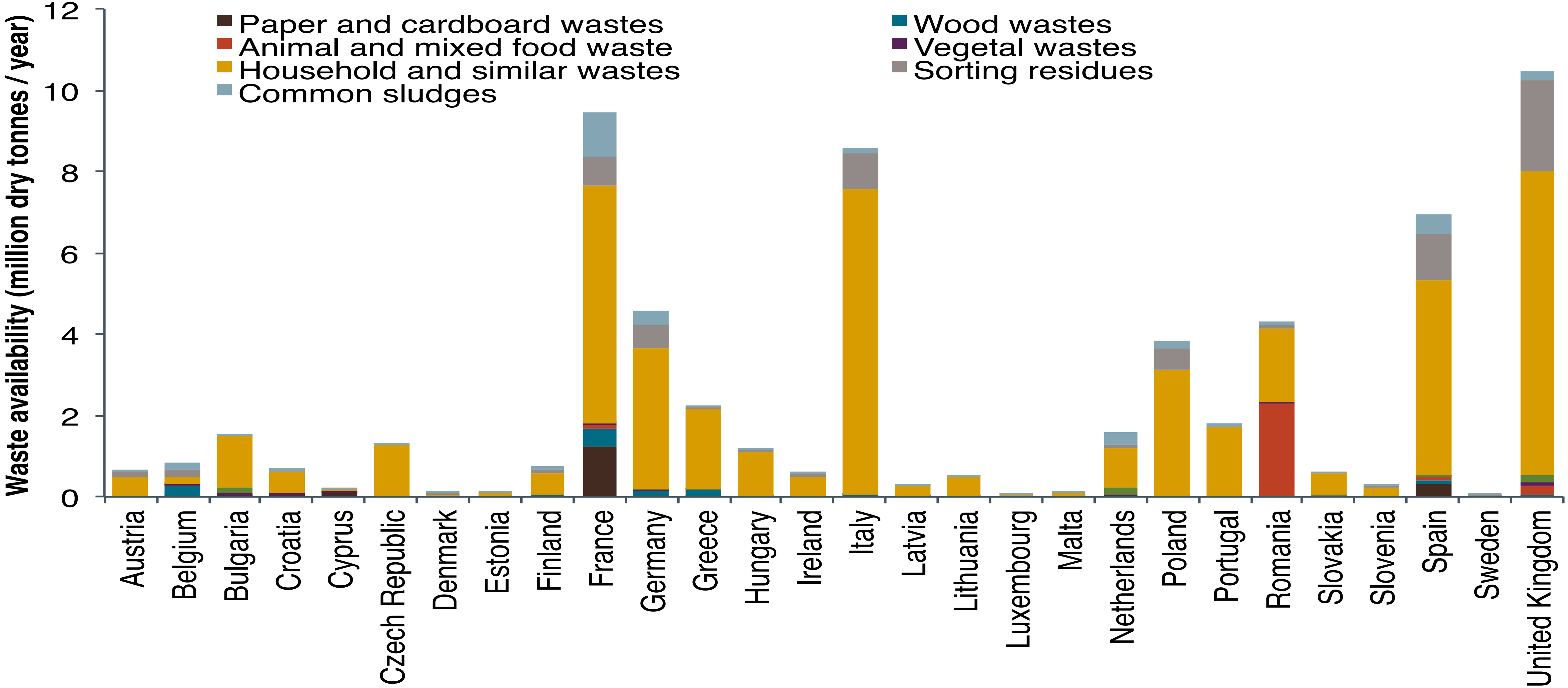
- Data from EUROSTAT

  Paper and cardboard wastes
  Wood wastes
  Animal & mixed food wastes
  Vegetal wastes

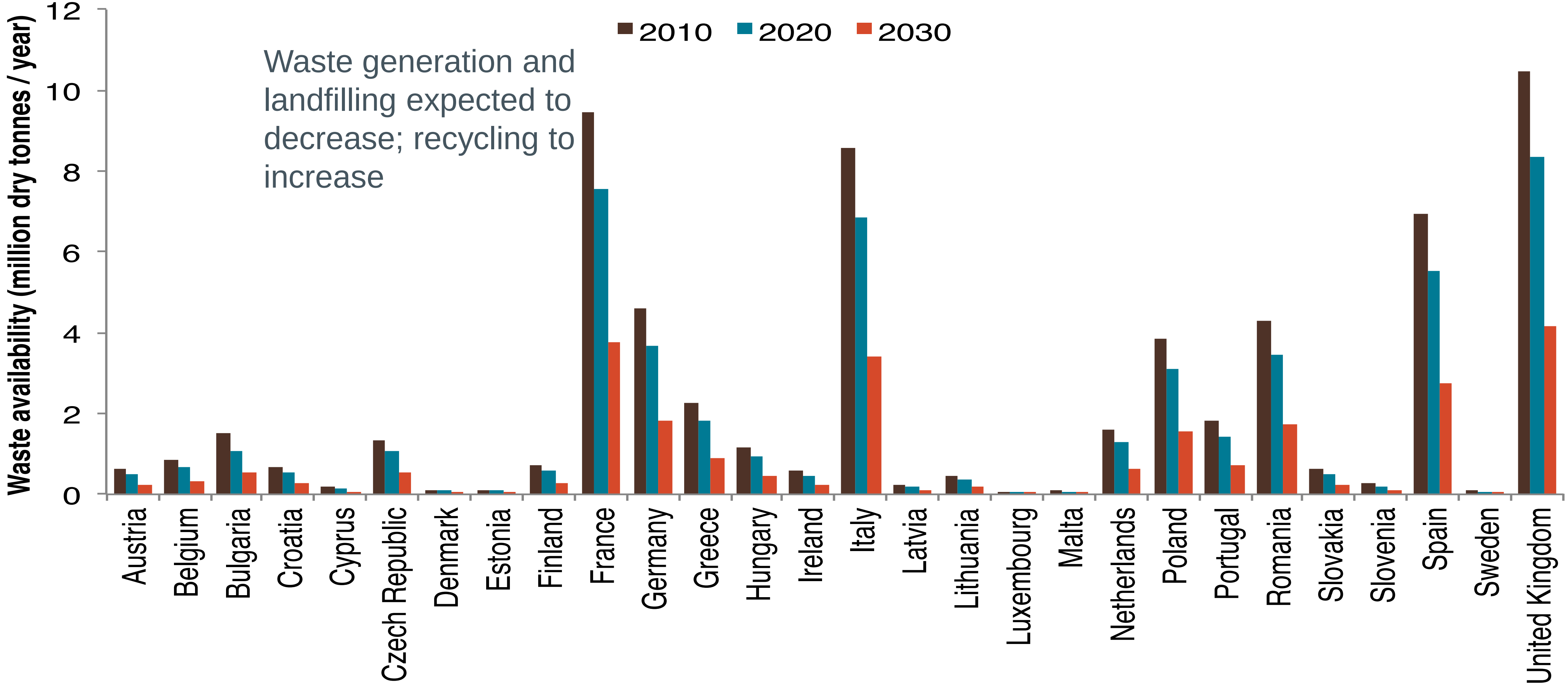
  Household & similar wastes
  Sorting residues
  Common sludges

- Estimate biogenic fraction of household, sorting residues, dry matter content
- Waste that is recycled, composted, or incinerated with energy recovery is not considered available
- Waste that is landfilled, incinerated without energy recovery, or otherwise disposed of is considered available for biofuel

Sustainable availability of biogenic wastes



Sustainable availability of biogenic wastes



Source # 3: Biomass from aquatic sources

Sources of biomass		Key sustainability questions considered
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 open ponds or photobioreactors **on land**
- 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*

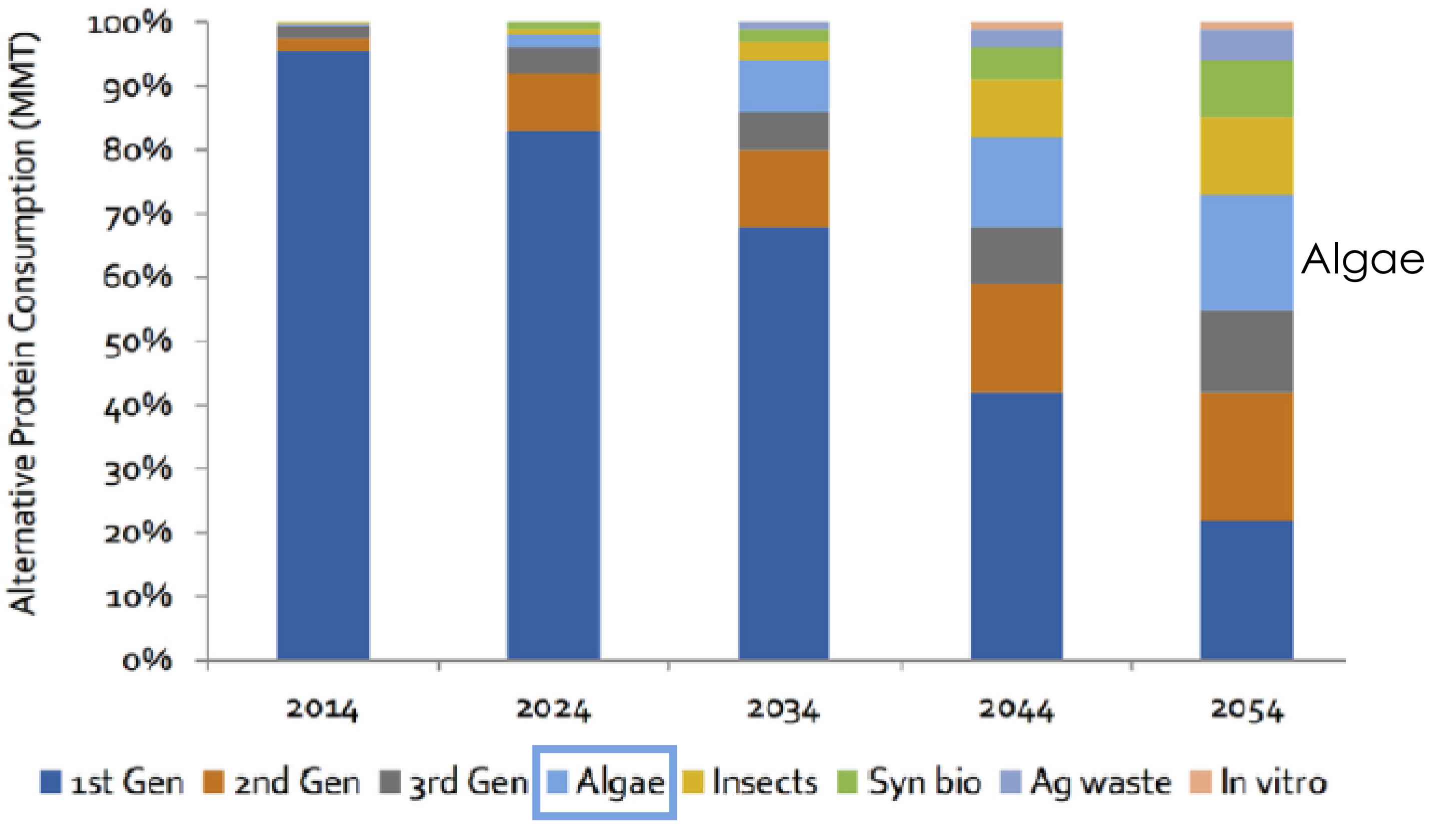
Energy and industrial demands for sustainable aquatic biomass will likely compete with those of the food sector

- **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/

Biomass from macroalgae: sustainability considerations

A) Climate impacts on farming	Although full potential unknown, macroalgal **production assumed to be carbon negative or carbon neutral** through sequestration capacity of seaweed.
B) Exclusion of Marine Protected Areas	**Exclusion of protected ocean areas** based on high biodiversity value or other reasons of preservation (e.g. ecosystem services, fisheries health).
C) Environmental impacts of Farming	Large-scale macroalgae farming must **not risk local introduction of invasive species**, or spread marine disease.
D) Energy consumption	**Energy for transportation and processing** must be embedded in the energy value of the final product.
E) Economic collection and (traditional) competing uses	Assumption of the proportion of biomass that can be **economically collected** as well as projected demand from other sectors (e.g. hydrocolloids, food, cosmetics). Use of algae production for energy **must not impact food security**. *Note: market price increases would enable increased uptake of available sustainable biomass*
F) Types of macroalgae farmed	Where possible, **species diversity** of macroalgal aquaculture must be encouraged.

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Sustainable macroalgae farming has many environmental and social benefits

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

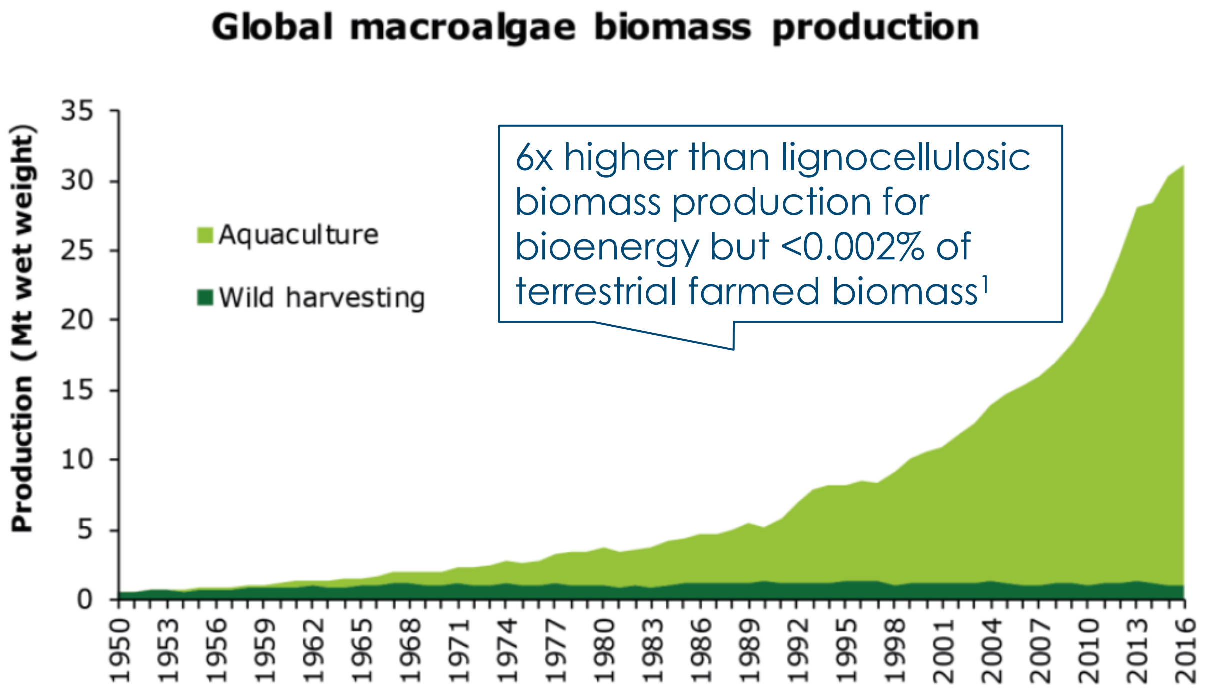
Social benefits

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

Source: SYSTEMIQ Oceans Team

Offshore farmed macroalgae production is growing quickly, but has not reached scale 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
- There is increasing policy support for research to achieve cost reductions, including in China, Norway, EU, USA.

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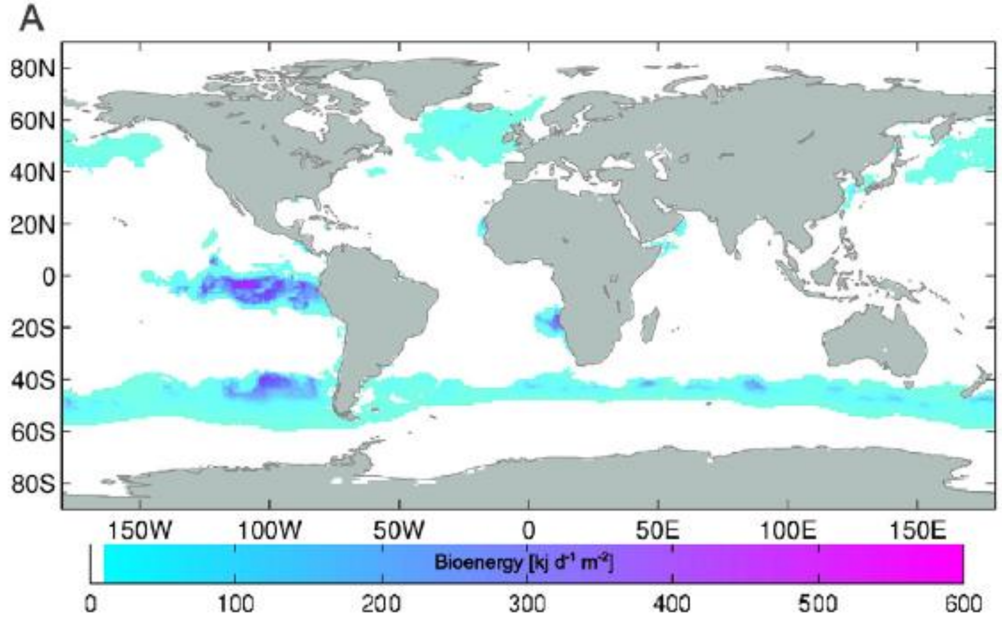
Note: (1) Seaweed farmed fresh weight
Source: I.S. Tan et al. 2020 *Chemical Journal of Engineering;* Buschmann et al, 2017; Lehahn et al., 2016; EU Commission *Brief on Algae Biomass Production* 2019 (Figure)

There is significant untapped global potential for macroalgae production

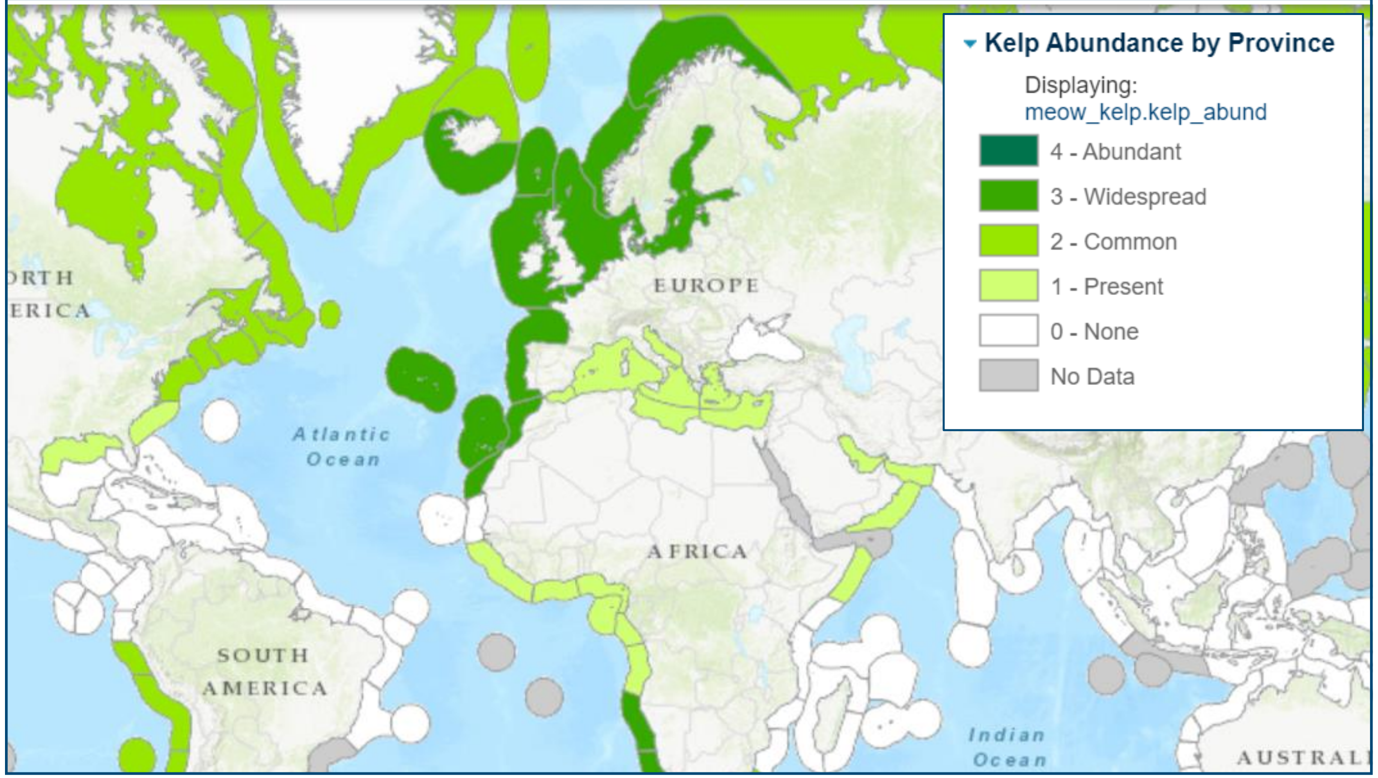
3 Biomass from aquatic sources
A Macroalgae

Global potential for offshore biorefinery is estimated to be **62,500x the area farmed today**



Global potential for offshore biorefinery of seaweed species Ulva

Certain regions are well-suited: Cold and nutrient rich European waters are idea for kelp growth



Source: https://databasin.org/datasets/1d702bf642cd4075aa7a5436a83ad936, data from Hoekstra, J. M., J. L. Molnar, M. Jennings, C. Revenga, M. D. Spalding, T. M. Boucher, J. C. Robertson, T. J. Heibel, with K. Ellison. 2010. The Atlas of Global Conservation: Changes, Challenges, and Opportunities to Make a Difference. Ed. J. L. Molnar. Berkeley: University of California Press.

Production and processing cost of macroalgae needs to be lowered to be viable for biorefinery production

Technical Challenge	Cost reductions needed	Solutions
• Dewatering, processing is energy intensive. • Transportation costs for offshore production significant.	**Develop economics of scale**	• Creating of large scale, offshore farms • Optimizing drying and conversion
• Use of biomass for biofuel would general small revenues/ton despite large demand.	**Optimize value creation**	• Creating novel seaweed based biomaterials (plastics) • Optimizing refining processes to ensure that all compounds of seaweed gets used
• Bioenergy from macroalgae is primarily from carbohydrates and insufficiently high for economy in many species.	**Selective breeding/gene editing**	• Breeding selectively for desired traits for biomass production • Development of carbohydrate rich species of macroalgae

Source: SYSTEMIQ Oceans Team

Macroalgae biomass from aquatic sources:

Few studies have estimated global potential; Lehahn et. al is the best example

Inferred from information provided (green highlight)

Recent studies exploring global macroalgal biomass primary energy potential

Preliminary; in review with experts

	Lehahn et al. 2016	EU Commission 2019	Tan et al. 2020	World Bank 2016	High Level Panel for Oceans (2020)	Seaweed Revolution 2020	*Reasonable Estimate*
Current							
Fresh Weight *MT/year*	17 Mt fresh weight/yr (2011)	32.67 Mt fresh weight/yr (FAO 2016)	29.1 Mt fresh weight/yr (FAO 2018)	~24 Mt fresh weight/yr	NA	33 Mt fresh weight/yr (FAO 2018)	**~30 Mt fresh weight/yr**
Estimated Energy Equivalent *EJ (Primary Energy)*	0.1 EJ[2]	0.2 EJ[2]	0.2 EJ[2]	0.1 EJ[2]	NA	0.2 EJ[2]	**= ~0.2 EJ**
Growth Rate Assumed	NA	NA	10% *Based on current trajectory*	14%	8.3% *Based on current trajectory*	NA	**10% growth rate per annum**
2050 Potential							
Dry Weight *MT/year*	940 Mt dry weight/yr	NA	90 Mt dry weight/yr	500 Mt dry weight/yr	49 - 324 Mt dry weight/yr	60 Mt dry weight/yr	**~ 100 - 500 Mt dry weight/yr**
Estimated Energy Equivalent *EJ(LHV)*[1] *(Primary Energy)*	**~18 EJ**	NA	**~ 1-2 EJ[3]**	**~8-12 EJ[3]**	**~1-7 EJ[3]**	**~ 1 EJ[3]**	**~1- 8 EJ**

Note: Global ocean surface area suitable for macroalgae harvesting is estimated to be >100x larger than the areas assumed in these calculations.

Source, FAO (2016); I.S. Tan et al. 2020 *Chemical Journal of Engineering*
(1) LHV = Lower Heating Value (primary energy); (2) Based on LHV value for *Ulva* species (Lehahn et al)
(3) Assuming current production growth rate of 10% and LHV from expert consultation (16-23 MJ/kg DW); assumed seaweed moisture content ~70%
(4) Final Energy; Assuming production growth rate of 14%; 50% carbohydrate content converted to energy (2007)

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Macroalgae biomass from aquatic sources:

Few studies have estimated global potential; Lehahn et. al is the best example

Key assumptions supporting the Lehahn et. al. Global Potential Model:

Macroalgae aquaculture production would be targeted primarily in EEZs[3], not the High Seas, and **not more than 400km offshore**.

Production is assumed be technologically deployable in shallow coastal waters, **not more than 100m depth**.

Energy cost of transportation must be ~1.8% of energy embedded in the final product; **30% of costs are assumed from transportation**.

Cultivation methods are assumed traditional farming mechanisms (**ropes and cages**); Optimum stocking density: 4kg m^{-2}

Environmental risks mentioned include the introduction of **invasive species and nutrient stripping**

Climate impacts on yield are **not accounted** for

Assumes **current bioethanol conversion rates**. Ulva LHV of 19 MJ kg^{-1} dry weight

Source, FAO (2016); I.S. Tan et al. 2020 *Chemical Journal of Engineering*
(1) LHV = Lower Heating Value; (2) Based on LHV value for *Ulva* species (Lehahn et al)

Biomass from microalgae: sustainability considerations

A) Land use implications	Unlike macroalgae, microalgae is **grown on land** in either open ponds or controlled photo-bioreactors, adding to the many demands for land area. However, microalgae can **utilise land that is unfertile**, such as desert landscapes.
B) Carbon trade-offs	As with non-aquatic biomass, **carbon trade-offs** must be considered with regards to use of agriculturally unproductive land (e.g., could build a solar farm). It is possible to use microalgae to **sequester flue gas carbon** from fossil fuel combustion in the short term before such systems are phased out.
C) Requirements for freshwater	While photo-bioreactors operate as a closed system, open pond systems suffer water losses from evaporation. Depending on the type of microalgae grown (i.e., freshwater or saltwater), this **may put additional pressure on freshwater resources** (especially in arid regions where available, unproductive land is likely to be found).
D) Energy inputs	Microalgae **dewatering and drying are an energy intensive steps** in microalgae biomass production (as are collection and processing, to a lesser degree).
E) Nutrient requirements	Like land plants, microalgae **require nutrients to grow**. If this is not provided by cycling in nutrient-rich seawater, then the nutrients will need to be added separately.
F) Economics	While the economics of natural (minimal input) growing systems are favourable, those of **highly-controlled environments** (e.g., photobioreactors or other closed systems) **suffer from poor economics** and must produce niche products to offset high costs.

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

3 Biomass from aquatic sources
B Microalgae
SuSeWi case study

Promising new developments[1] demonstrate that microalgae:

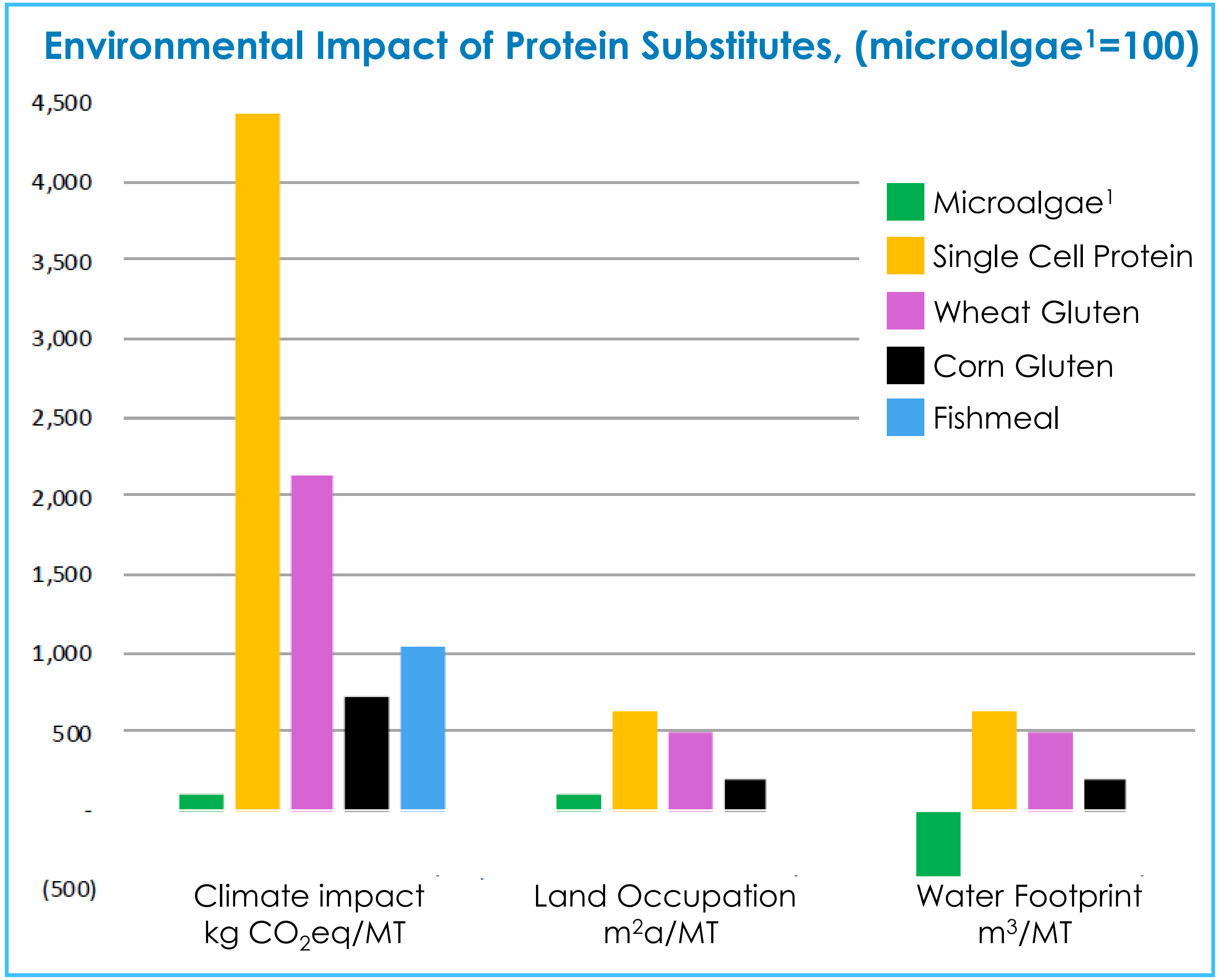
- Can grow faster than terrestrial plants, **using 1/10th of the land** to produce an equivalent amount of biomass
- Can be very **resource efficient** and **low-emissions,** produced **without relying on agricultural land, freshwater, or addition of nutrients** (i.e., by utilising desert lands and providing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

Other features of interest include:

- Microalgae are diverse and **can be used for many purposes**: food, feed, chemicals, fertilisers, pharmaceuticals and nutraceuticals
  - Some strains also have **high oil content**[2]
- Potential for industrial **carbon sequestration**[3]

Limitations include:

- **Land use** requirements
- **Production volume today is limited** and algae is currently being used for **high value food and nutraceutical extracts**
- Grown in a **controlled environment**, adding to **expense**



(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[2]**

Due to its **limited scale**, high costs, and nutrient-rich biomass, **microalgal production is best suited to meet demands for food and high-value products rather than used for energy.**[3] Microalgae's use for food and feed can have **indirect land use benefits** due to its high resource efficiency, potentially freeing up agricultural crop and pasture lands for other uses.

*Global potential 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; (3) Due to high cost and scale limitations, microalgae is not suited to replace oil or clean fuel sources (the lowest cost algal fuels cost >$200/barrel; an area the size of South Africa would be necessary to produce 5 million barrels per day). Microalgal biomass can be used for other industrial needs, including for carbon neutral packaging, alternative plastics, fibres to make shoes and clothes, lighting, ventilation and architecture; nevertheless, scale remains an issue. Sources: SuSeWi; Milledge et al. 2014

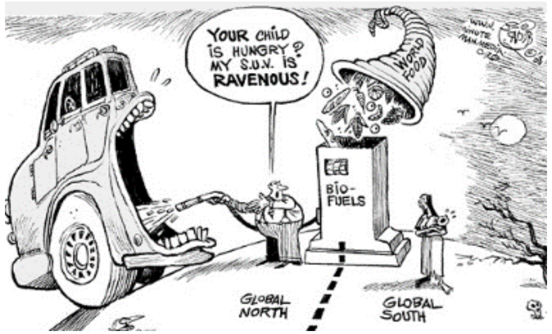
Actions and policy

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-emissions

Policymakers and industry must learn the lessons from previous failures

Food vs. fuel debate

Land grabbing debate



Key Actions

- **Set clear sustainability and low carbon standards** (e.g., target low carbon opportunity cost land for dedicated biomass production, do not source food crops, protect soil health)
- **Maintain high traceability** throughout the bio-resource supply chain
- **Maximise sustainable use of waste and residue sources**, while safeguarding land and soil health; encourage circular economy efforts, including material recovery, waste collection & separation
- **Support critical innovations** (e.g. macroalgae production)

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Source: IIASA presentation from April 2020

Biofuel mandates in road transport have created large demand for energy crops and projections indicate this will continue to grow

Global Biofuel Mandates

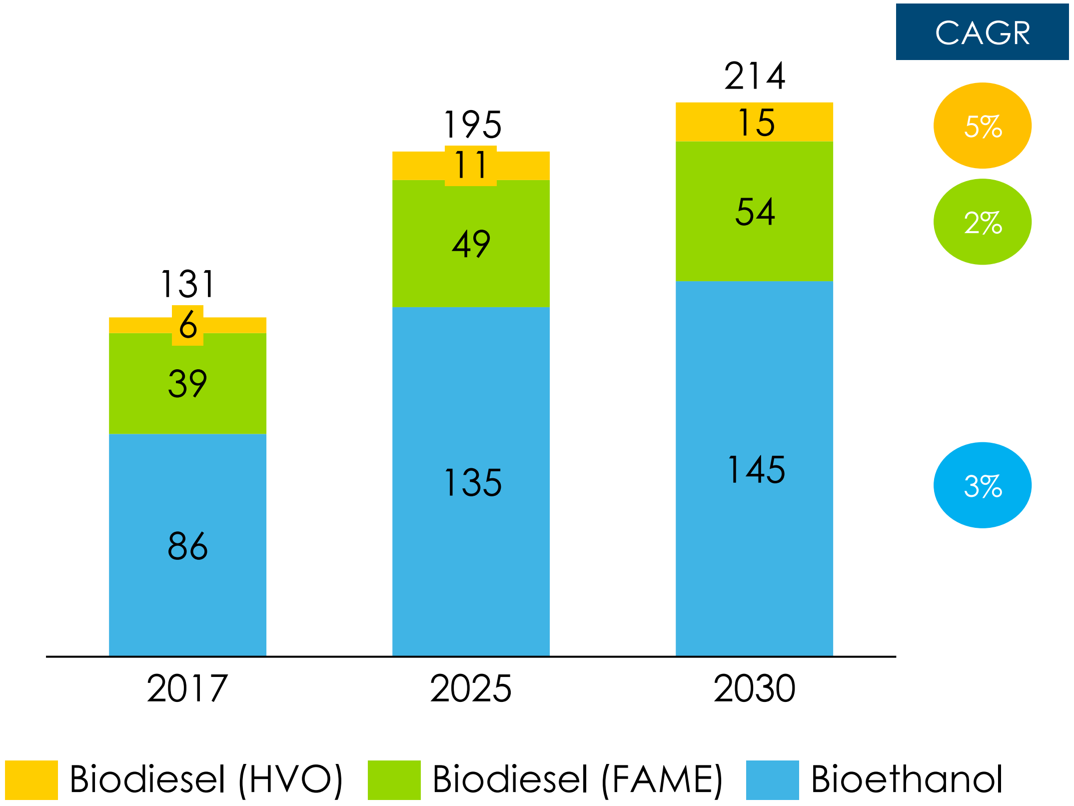
% Total road transport fuels (esimtated)

Country		2020	2025	2030
	EU	7%	7%	7%
	USA	7%	9%	13%
	Brazil	27%	31%	64%
	China	2%	3%	7%
	India	4%	10%	20%[1]

No official national mandate currently in place

Global Biofuel Demand

Million tonnes per year



Note: Biofuel mandates include both ethanol and biodiesel (weighted average). [1] Indicative national target
Source: Energy Insights (Jan 2019), Global Energy Perspective, IEA (2019), USDA.

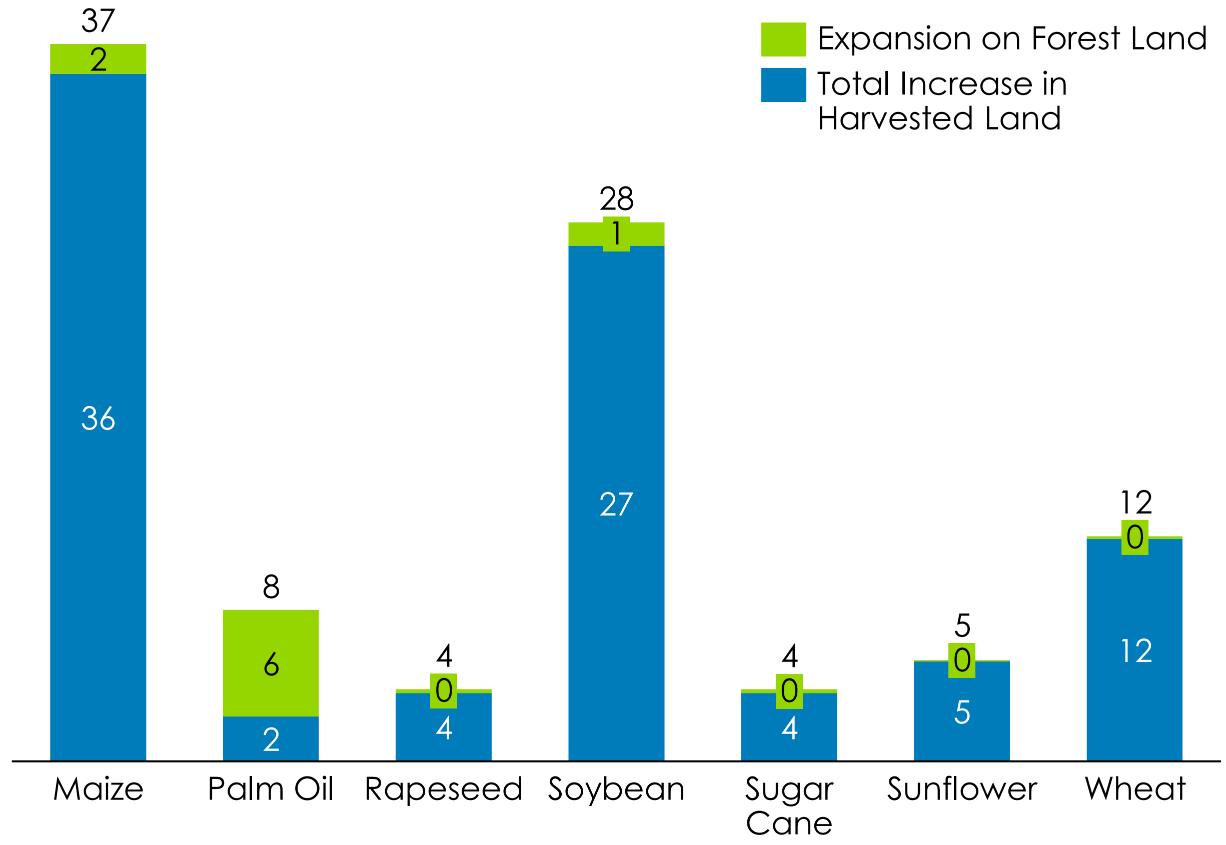
The expansion of harvested land for energy crops has resulted in deforestation and is likely to continue despite efforts to exclude certain crops

Key Points

- 70% of the expansion of harvested land for **palm oil** from 2018-2016 resulted in **deforestation**, of which 18% was on **high carbon stock** peatland forest
- New EU regulation sets criteria to **phase out high-ILUC crops in biofuels by 2030**, which de facto only excludes palm oil – though with major exceptions (e.g. smallholder farmers)
- In the EU, biofuels from **food/feed crops** cannot contribute to more than 7% of total energy consumption in the transport sector from 2020-2030
- The EU biofuel mandate is projected to result in the conversion **8.8 million hectares of land**, approx. the size of Austria[1]
- This includes around **1 million hectares of tropical forest and peatlands**

Deforestation from Expansion of Harvested Land by Crop Type

Million hectares, 2008-2016



(1) Figures refer to land use change modelling undertaken by IIASA (2015) for the European Commission.
Source: European Commission (2019), IIASA (2015), USDA, FAOSTAT.

Overview of RED-II Sustainability Criteria

Background

- EU member states are required to source 10% of transport energy from renewable sources by 2020.
- Following the ILUC reform, only **a maximum of 7%** of this target can be from **land-based biofuels**.
- Feedstocks for biofuels **cannot be sourced from land with high biodiversity or high carbon stock** – i.e. high-ILUC crops – these are to be phased out to zero from 2030 to 2030.
- **Palm oil**, identified as a high emitting biofuels, is being **phased out** and support will end in 2030, with exemptions (e.g. for small holder farmers)
- Member States will still be able to import and use fuels included in the category of high ILUC risk biofuels, the **limit only affects the amount of these fuels that can be counted when calculating the overall national share** of renewables and the share of renewables in transport.

Indirect land use change definitions

High-ILUC Feedstocks

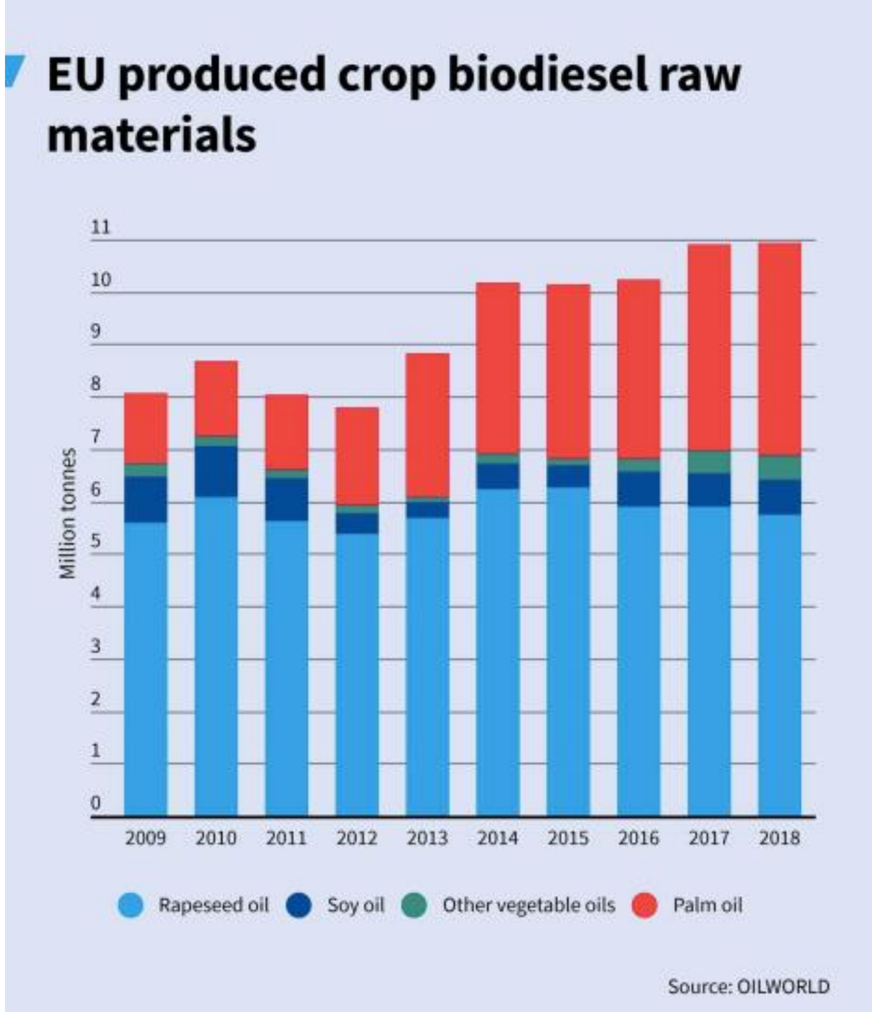
- High ILUC-risk fuels are those produced from feedstock with a significant expansion into land with high carbon stock, such as forests, wetlands and peatlands. Conditions:
  - a) the global production area of the feedstock has increased annually by more than 1% and 100,000 hectares after 2008.
  - b) more than 10% of such expansion has taken place on land with high carbon stock.

Low-ILUC Feedstocks

- Low-ILUC feedstocks can only be grown on unused land that is not rich in carbon stock. Criteria:
  1. Compliance with the sustainability criteria set in Renewable Energy Directive, which entails that feedstock can only be grown on unused land that is not rich in carbon stock;
  2. Use of additional feedstock resulting from measures increasing productivity on the already used land, or from cultivating crops on areas which were previously not used for cultivation of crops (unused lands), provided that a financial barrier has been overcome, or the land was abandoned or severally degraded, or the crop has been cultivated by a small farmer; and,
  3. Robust evidence that the two previous criteria are met.

Source: European Commission (2019), Sustainability criteria for biofuels specified

Will the market deliver sustainability?



RED 1 - Hindsight shows that the EU's 2020 biofuels policy was insufficient to deliver the intended policy outcomes: GHG savings, or revenues for EU farmers. Most of the growth came from palm oil.

RED 2 - Forest Research proposed 15 criteria to ensure sustainability of bioenergy – Only 12 were served by the RED 2

Although not a primary focus, FOLU described in Growing Better the role and parameters of sustainable bioenergy use

For FOLU the essential questions include; (i) whether bioenergy production competes with land for food production or natural ecosystems; and (ii) whether it is a cost-effective climate mitigation approach.

FOLU's Key Perspectives on Bioenergy are:

1. **Land is a fixed and limited resource.** Therefore the focus of bioenergy efforts must be on forms of bioenergy that do not, or only minimally, increase pressure on land.
2. Bioenergy demand should, where possible, **be first met from waste sources,** including residues.
3. The **potential justification for biofuels is greater for hard-to-abate sectors** – in particular long-haul air travel. For these sources, biofuels could help reducing use of fossil fuel and keep more oil in the ground.
4. For both environmental and economic cost effectiveness reasons, **at no point should bioenergy be allowed to drive deforestation** or other conversion of natural ecosystems, or impede degraded land restoration.

- While the science is clear about the comparative carbon benefits from using a hectare of land to regenerate forest versus produce bioenergy, the economic mechanisms to ensure optimal allocation of land still need to be put in place whether for forest protection or bioenergy. Hence, **we must push both to formalise and enforce forest and other natural ecosystem protection and restoration, and to develop high-quality REDD+- and national payments for ecosystem-markets.**

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Source: Food and Land Use Coalition, 2019

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The Energy Transitions Commission is hosted by SYSTEMIQ Ltd.