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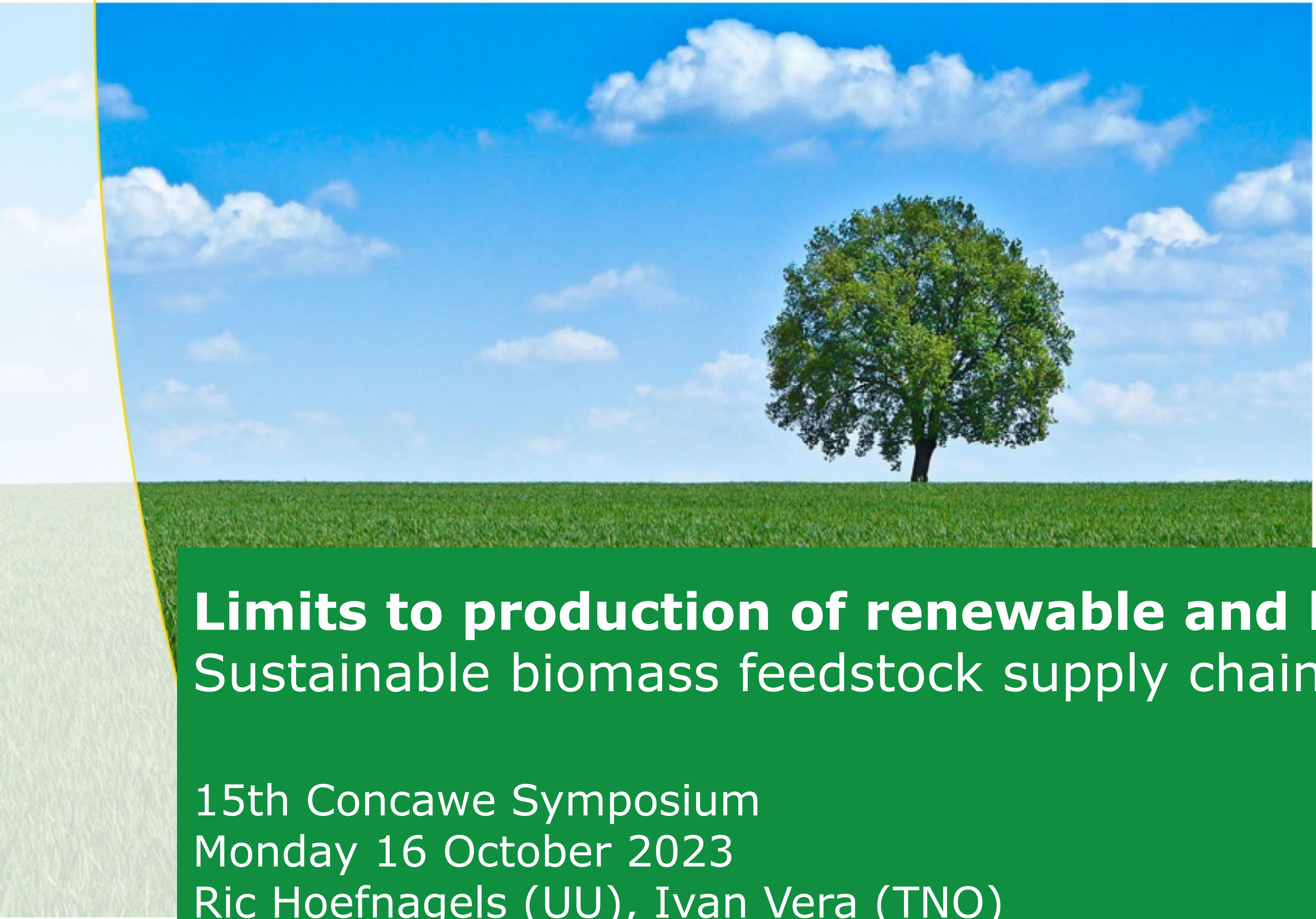

# Limits to production of renewable and low-carbon fuels

## Sustainable biomass feedstock supply chains for advanced biofuels

15th Concawe Symposium

Monday 16 October 2023

Ric Hoefnagels (UU), Ivan Vera (TNO)

# Agenda

1. Introduction
2. Overview of the project
3. Key findings (focus on biomass from agriculture)
4. Conclusion and next steps

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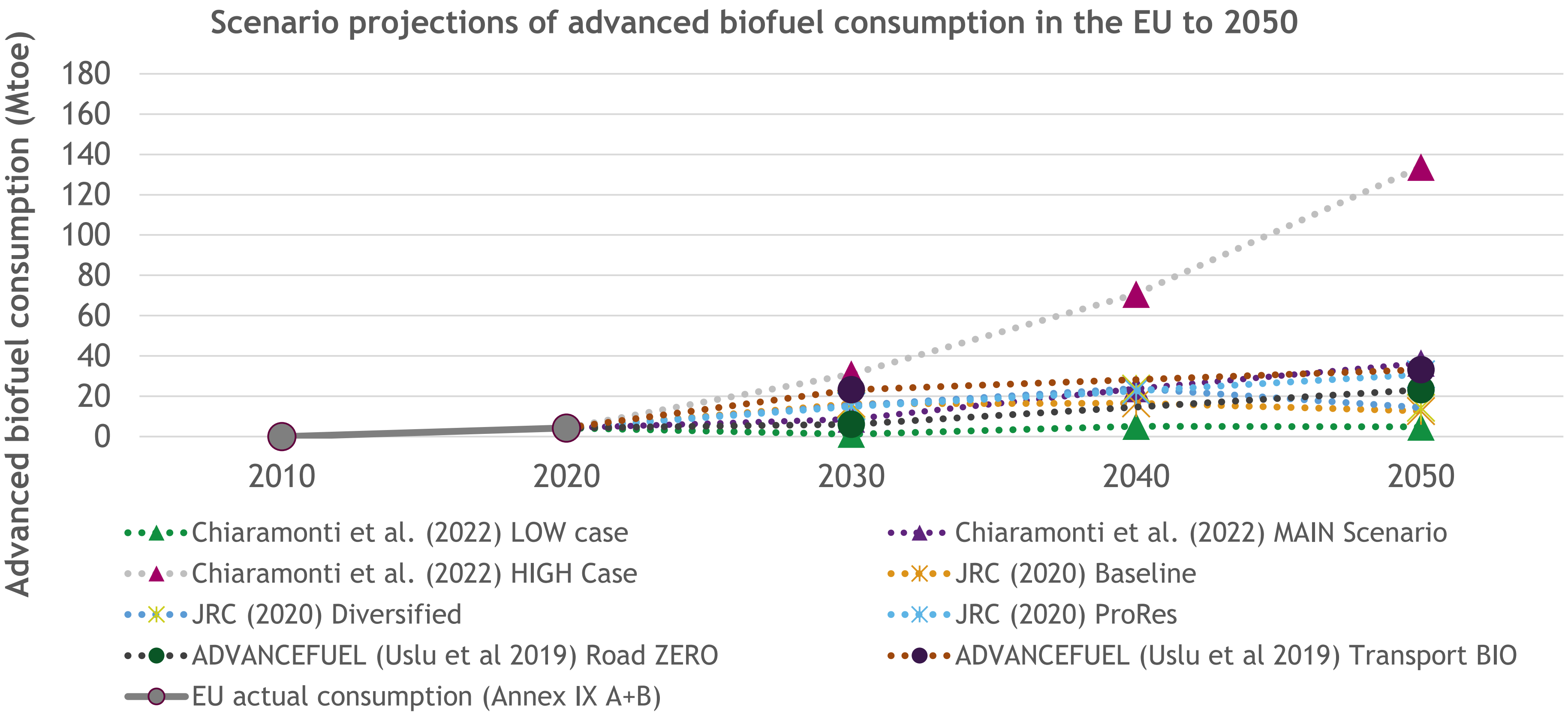
# The research team

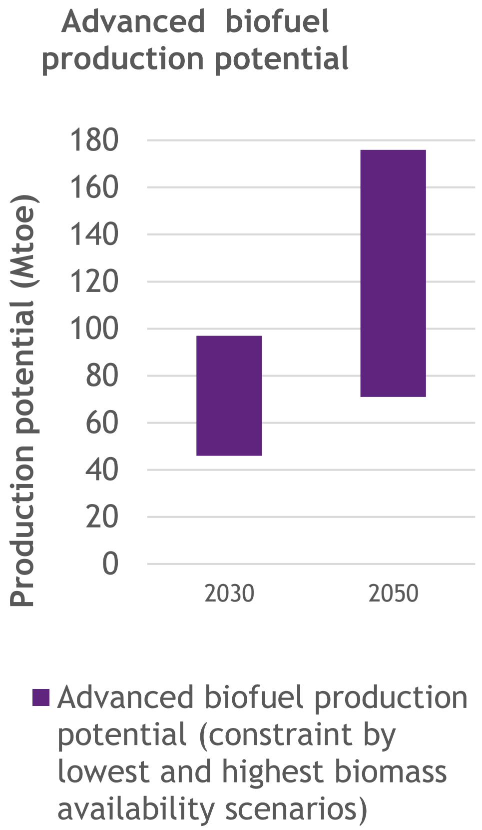
- Dr. Ric Hoefnagels (UU)
- Dr. Ivan Vera (TNO)
- Stender Kwakernaak, Msc (UU)
- Kai Rothenburger, master student
- Dr. Floor van der Hilst (UU)
- Prof. dr. Martin Junginger (UU)






# Sufficient biomass is potentially available to meet the demand for advanced biofuel production in the EU27+UK to 2050





- Chiaramonti, D., Talluri, G., Scarlat, N., & Prussi, M. (2021). The challenge of forecasting the role of biofuel in EU transport decarbonisation at 2050: A meta-analysis review of published scenarios. Renewable and Sustainable Energy Reviews, 139, 110715.
- Uslu, A., van Stralen, J., & Pupo-Nogueira, L. (2020). Role of renewable fuels in transport up to 2050 – a scenario based analysis to contribute to Paris Agreement goals D6.2 RESfuels in transport sector.
- Tsiropoulos, I., Nijs, W., Tarvydas, D., Ruiz, P., & others. (2020). Towards net-zero emissions in the EU energy system by 2050 – Insights from scenarios in line with the 2030 and 2050 ambitions of the European Green Deal, EUR 29981 EN. In Insights from Scenarios in Line with the (Vol. 2030).
- Panoutsou, C., & Maniatis, K. (2021). Sustainable Biomass Availability in the EU, to 2050. Concawe: Brussels, Belgium

# But potentially available does not mean that biomass is readily available to produce advanced biofuels at commercial scale

(Inter)national, regional and local location factors should be considered in supply chain configurations that deliver year-round reliable, sustainable and cost-effective feedstock supply.

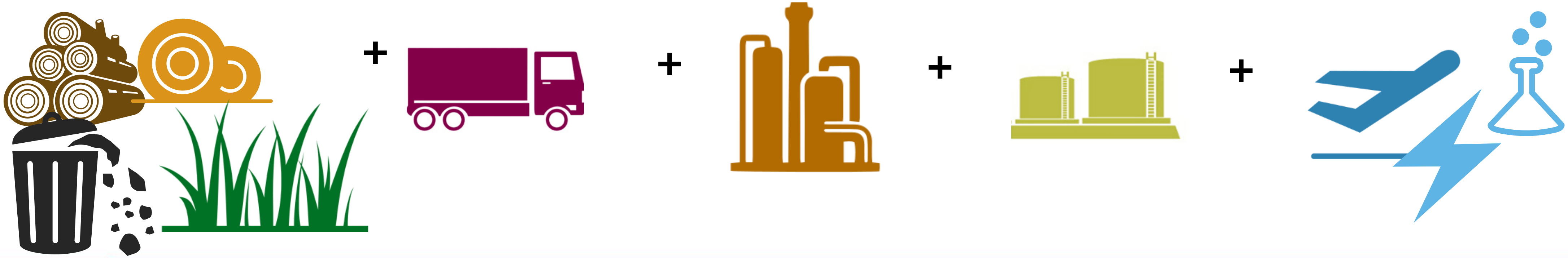
**Feedstock production**
- Development of energy crops
- Mobilization of low-value, underutilized biomass sources

**Feedstock logistics**
- Advanced preprocessing
- Improved storability and flexibility
- Efficient transportation
- Distributed supply chain

**Conversion**
- Multi-output biorefineries
- Smart integration
- Centralized or decentralized production

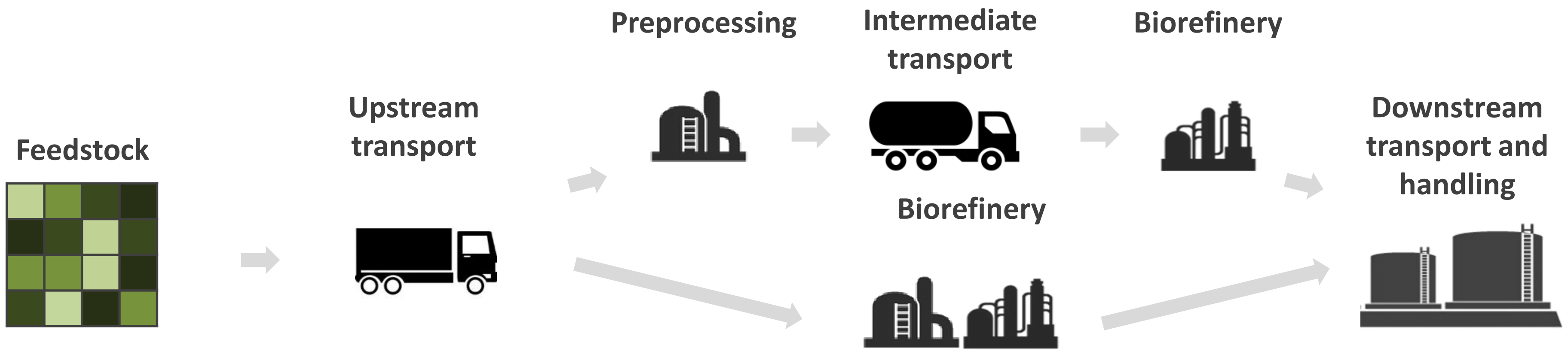
**Distribution**
- Transportation
- Blending
- Storage
- Dispensing

**End-use**
- Steer towards high(er) value applications
- Flexible power
- Biofuels
  - Marine
  - Aviation
- Other (e.g. chemicals)



**Aim: to provide a geospatial explicit assessment of the cost and GHG emissions of biomass feedstock supply chains for advanced biofuels in the EU27+UK between 2030 and 2050.**

**Biofuel supply chain options – distributed (top) and centralized (bottom)**




**Study design**

### Task 1: Biomass supply mapping
- Current and future feedstock cost-supply at roadside*
- GHG emissions from direct land use change*
- GHG emissions from cultivation

### Task 3: Feedstock supply chains
- (Intermodal) transport network analysis*
- Preprocessing options/supply chain configurations
- Integrated supply chain evaluation*

### Task 2: Biorefinery mapping
- Current biorefinery locations*
- Future biorefinery location areas/hot spots

### Task 4: Analysis and reporting
- Opportunities and limitations of cost reductions in feedstock supply chains
- Current and future cost-supply curves
- GHG emissions of advanced biofuel supply chains (wtw)

* Spatially explicit



Based on de Jong, Sierk, et al. "Cost optimization of biofuel production–The impact of scale, integration, transport and supply chain configurations." Applied energy 195 (2017): 1055-1070.

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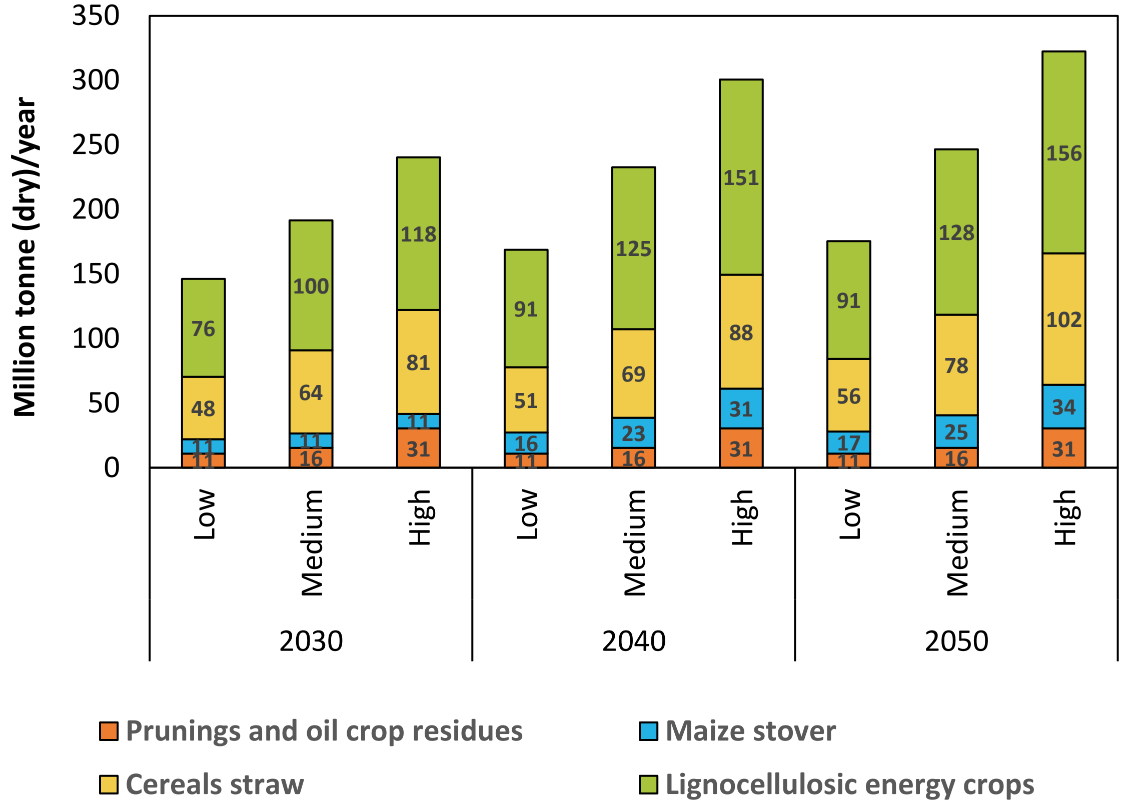
# Key finding 1: Biomass supply potentials from agriculture




- Difference in biomass supply potentials over time is driven by:
  1. Yield increases
  2. Spatially explicit biophysical characteristics
  3. Adaptability of crops to such conditions.
  4. Management practices

**Agriculture biomass potentials in the EU27 + UK for the low, medium and high scenario**
Lignocellulosic energy crops, cereal straw, maize stover: **dedicated mapping 1km x 1km (TNO)**
Agricultural prunings and oil crop residues: NUTS3, assumed constant 2030-2050 (EU S2Biom)

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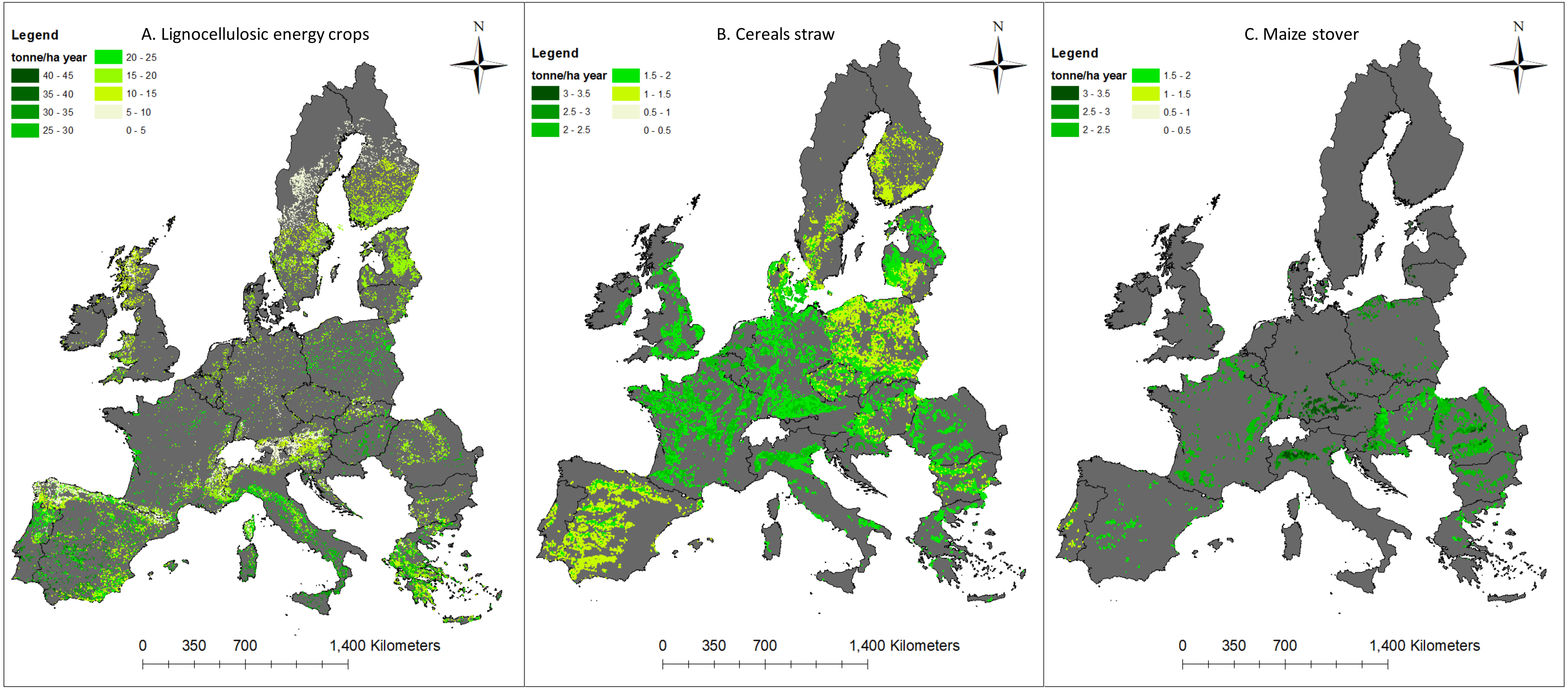
# Key finding 1: Biomass supply potentials




Spatial distribution of (A) lignocellulosic energy crops, (B) cereals straw and (C) maize stover yields for 2050 (tonne/ha year) in the high scenario. The pixel size is enhanced for displaying purposes

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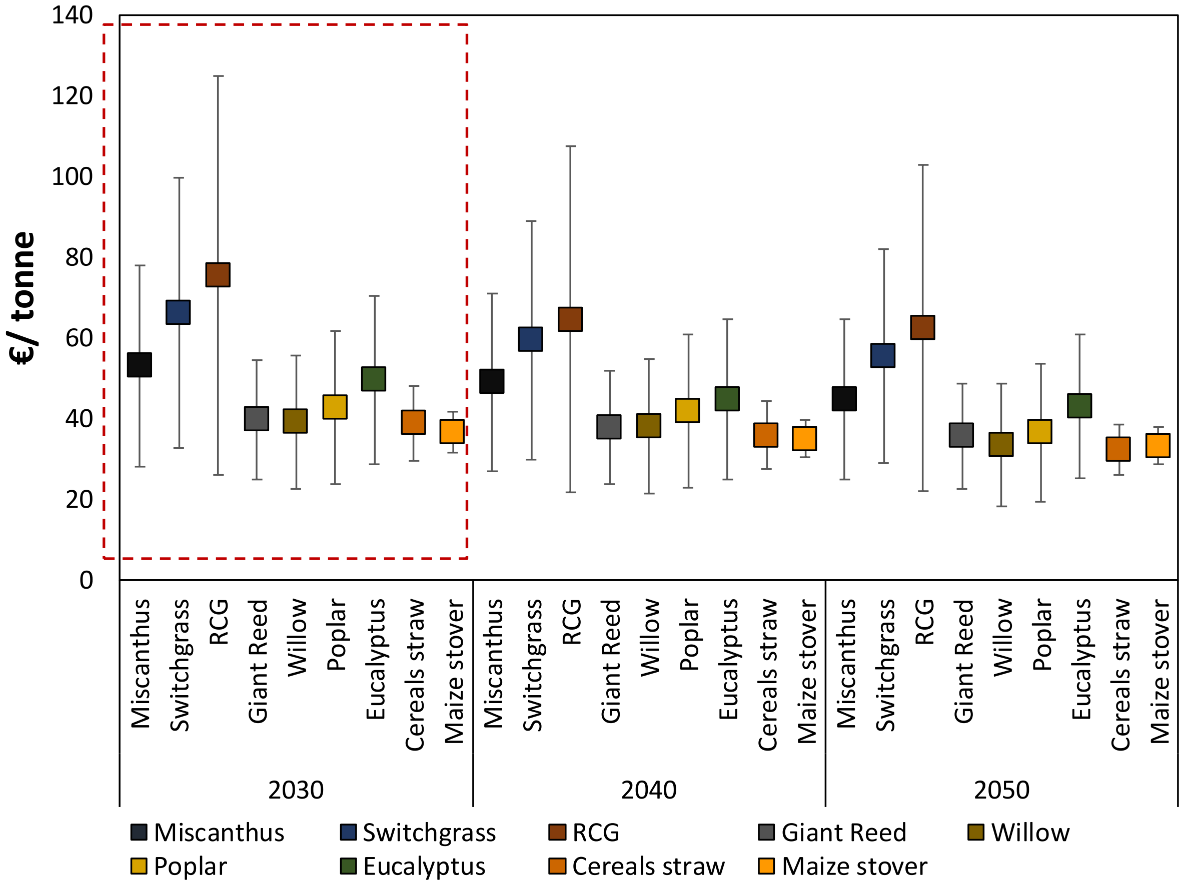
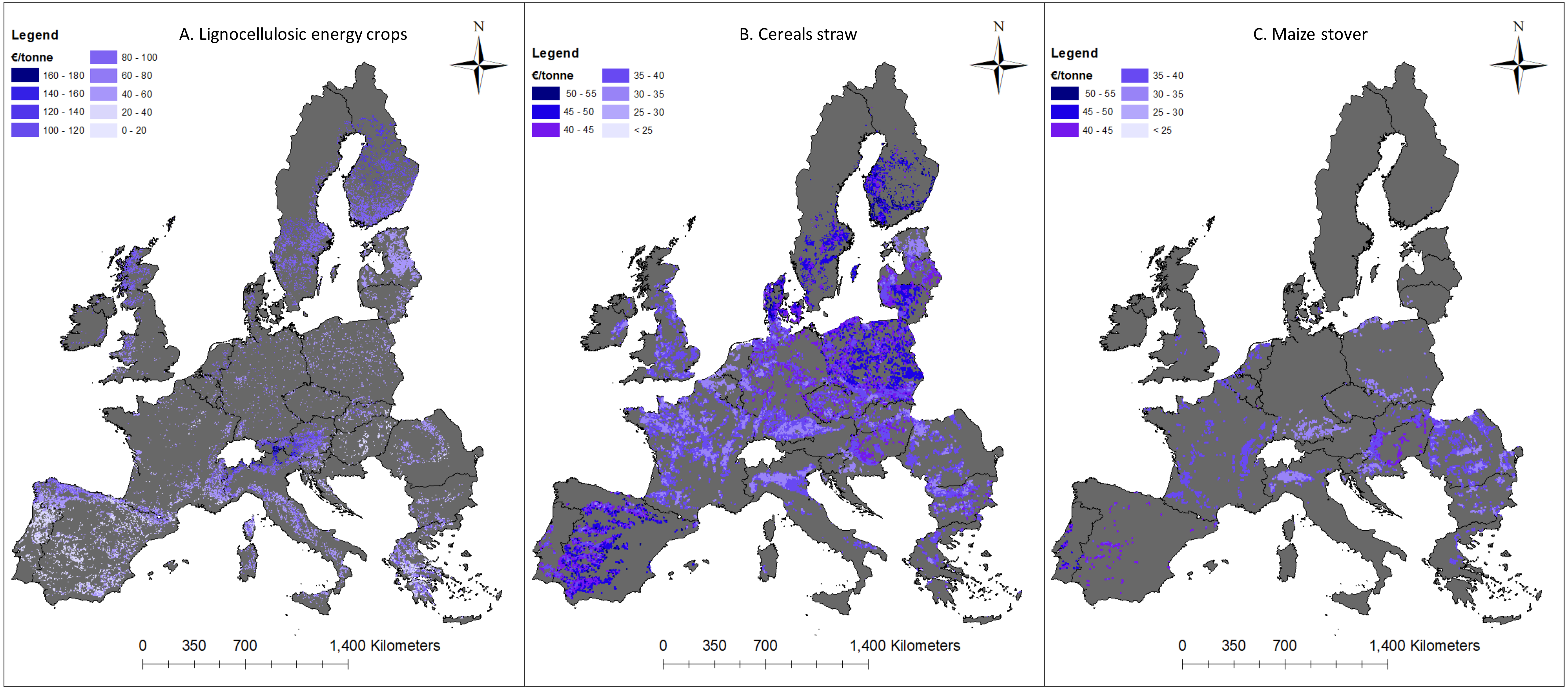
# Key finding 2: Costs of agriculture biomass at the roadside




EU27 + UK average costs of production and harvesting of lignocellulosic energy crops and collection of agricultural residues. The ranges indicate the spatial variability of cost due to the heterogeneity of yield

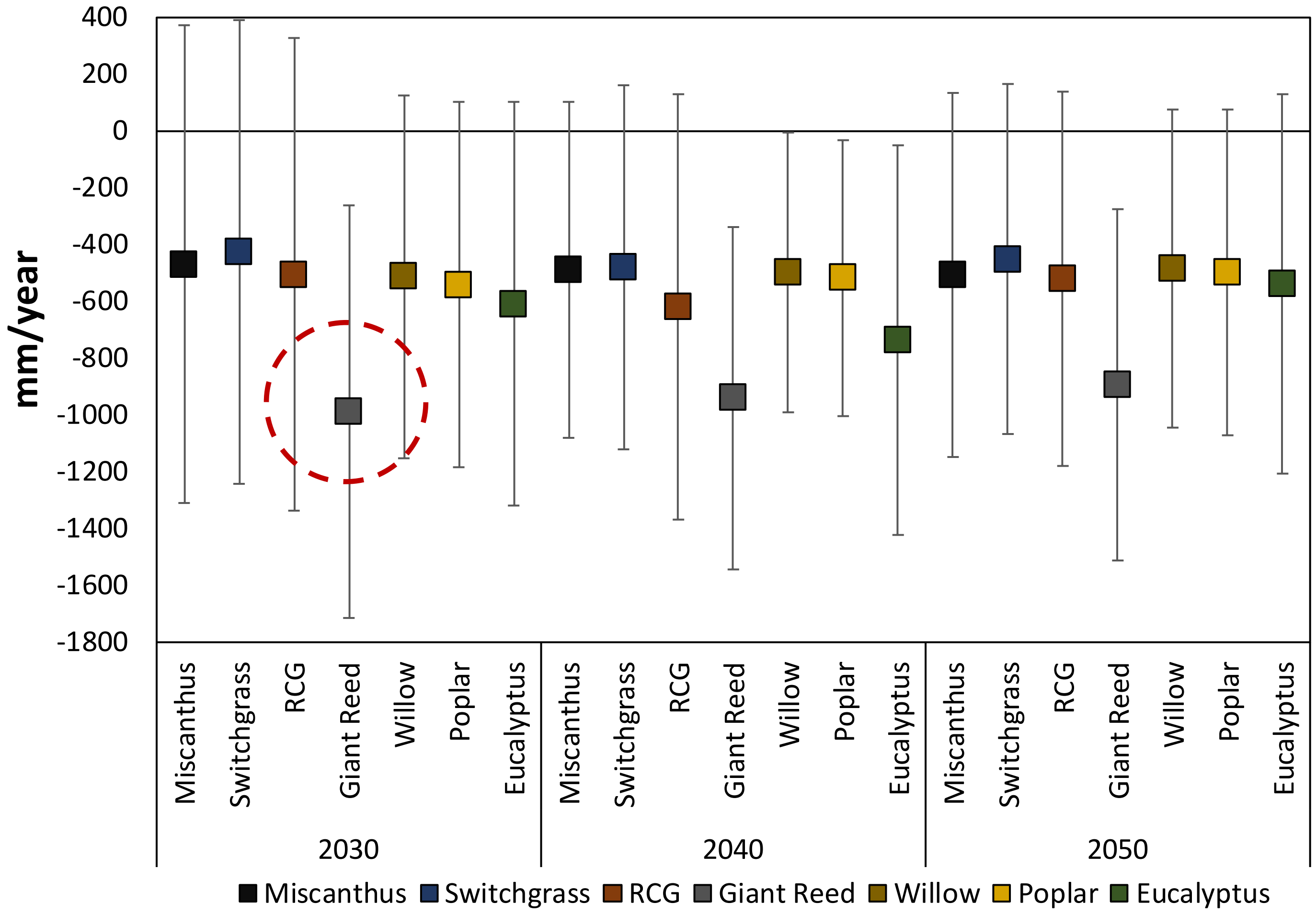
- Costs are driven by the specific activities related to the production and harvesting of each biomass type.
- The spatial difference in costs is driven by the difference in yield and local prices of different parameters such as labour, diesel and land rent.
- Generally, locations with low costs are associated with high yields.

# Key finding 2: Costs at the roadside




Spatial distribution of (A) lignocellulosic energy crops, (B) cereals straw and (C) maize stover costs for 2030 (€/tonne). The pixel size is enhanced for displaying purposes

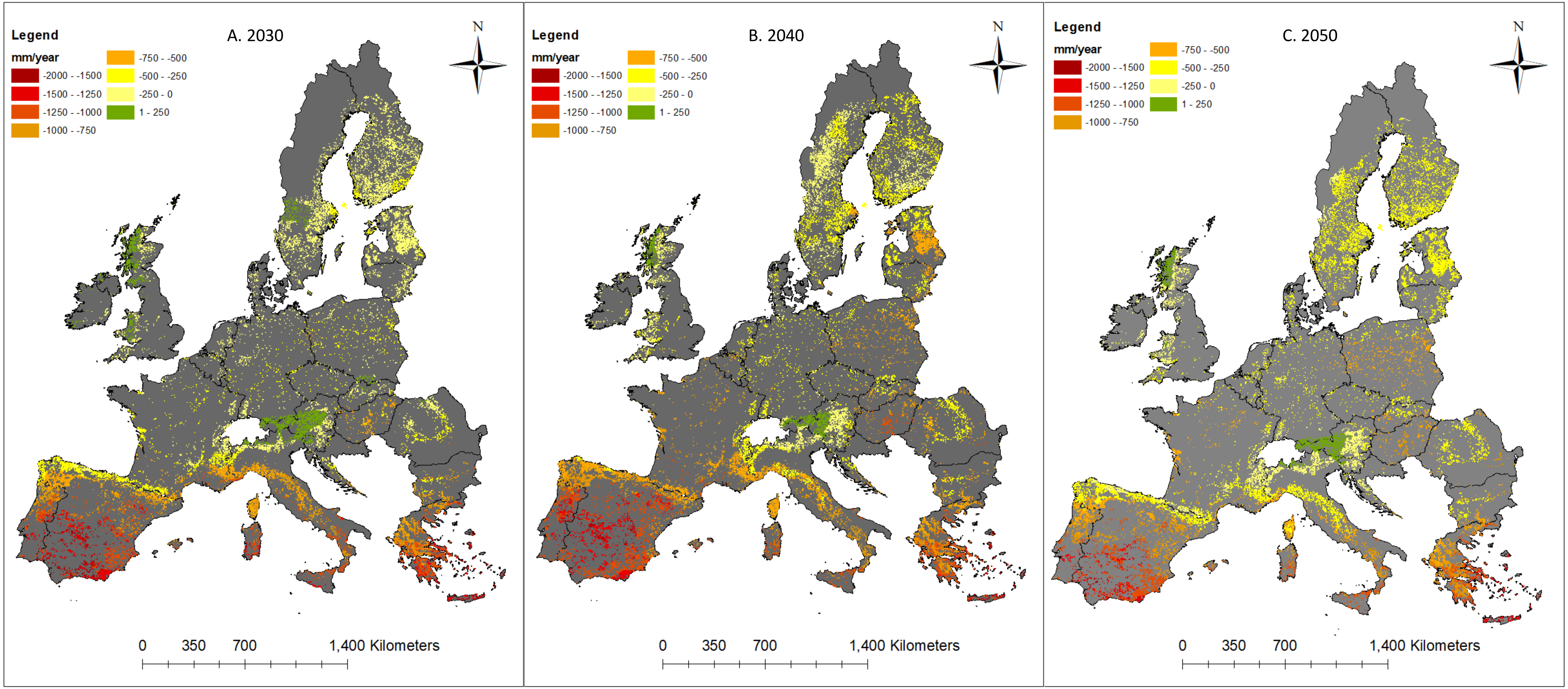
# Key finding 3: Water deficit of lignocellulosic energy crops




Water balance of lignocellulosic energy crops. The ranges indicate the spatial variability of water shortage due to the heterogeneity in biophysical conditions

- On average additional water besides precipitation is required to meet each crop's water demand and achieve the estimated potential yields.
- Water deficit is driven by local biophysical conditions (e.g. precipitation) and crop phenological characteristics to produce biomass under such conditions.
- Generally, high-water deficit areas are related to high yields.

# Key finding 3: Water deficit of lignocellulosic energy crops




Spatial distribution of lignocellulosic energy crops water balance over time (mm/year). The pixel size is enhanced for displaying purposes

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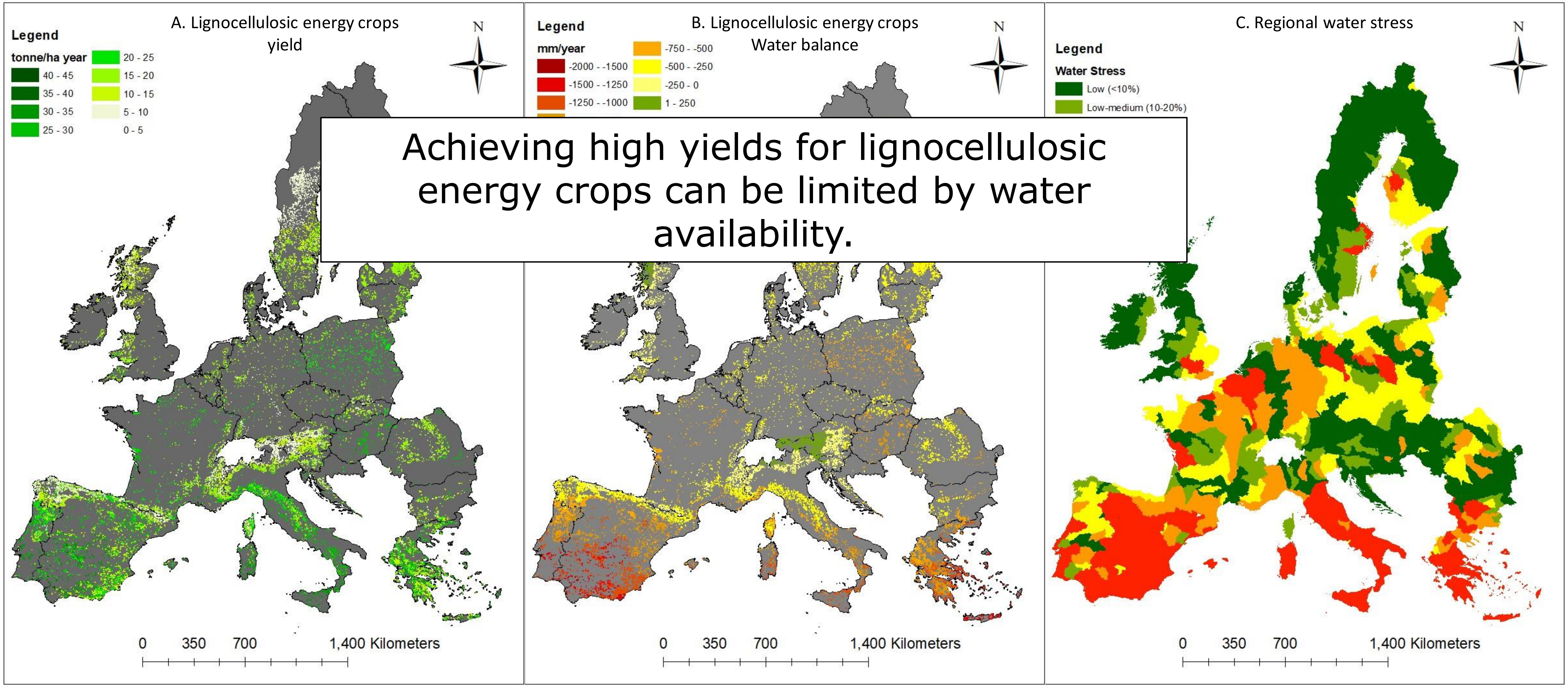
# Key finding 4: Impact on biomass potentials




Achieving high yields for lignocellulosic energy crops can be limited by water availability.

Spatial distribution of (A) lignocellulosic energy crops yields (tonne/ha year), (B) lignocellulosic energy water balance (mm/year), and (C) regional water stress (Kuzma et al., 2023) for 2050. The pixel size is enhanced for displaying purposes

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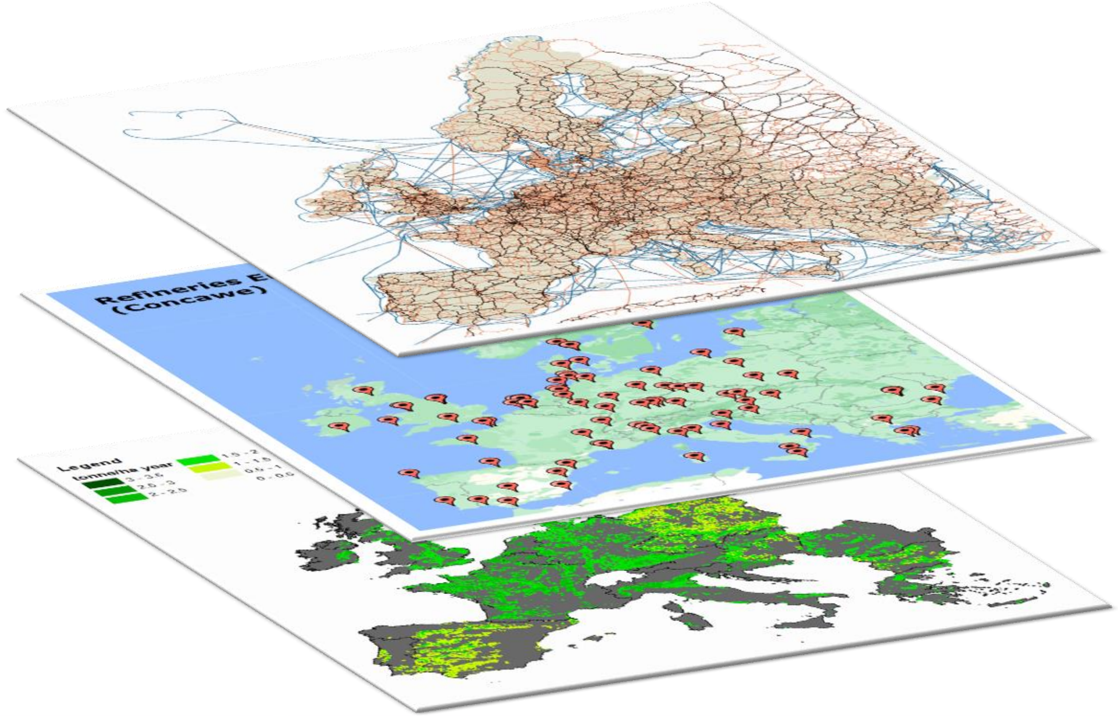
# Next steps: Cost-supply curves and GHG intensity

**Techno-economic data**

Feedstock → Pre-treatment* → Conversion → Blending terminal

- CAPEX (dependent on scale & site)
- OPEX (dependent on site)
- Constraint on maximum capacity

*Pelletization, torrefaction, pyrolysis, hydrothermal liquefaction



**Transport infrastructure (Task 3)**

- Road
- Rail
- Inland waterways
- Sea
- Terminals

**Possible (co-)location options (Task 2)**

- 1st gen. biofuels
- Wood processing industries
- Oil refineries
- Gas/$H_2$ terminal/pipeline connection

**Feedstock supply & prices (Task 1)**

- Forest biomass
- Energy crops
- Agricultural residues
- Biowastes

**Linear optimization model**

Optimizing system cost for biofuel demand scenarios

↓

**Cost and GHG intensities****

For individual supply chains

**REDIII methodology

Adapted from de Jong, et al. "Cost optimization of biofuel production–The impact of scale, integration, transport and supply chain configurations." Applied energy 195 (2017): 1055-1070.

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# Conclusions

- The updated potentials of agriculture composed of lignocellulosic energy crops grown on marginal land, cereals straw and maize stover available at the EU27 + UK show that **smart choices on location, crop type, and management characteristics** design are of paramount to release the maximum benefits of the supply.
- Lignocellulosic energy crops could potentially reduce the pressure on forest biomass but also have **sustainability considerations**.
- **Each step in the supply chain**, from feedstock production to final conversion and supply to end-use markets and their respective locations is important to consider in developing advanced biofuels.

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# Thank you

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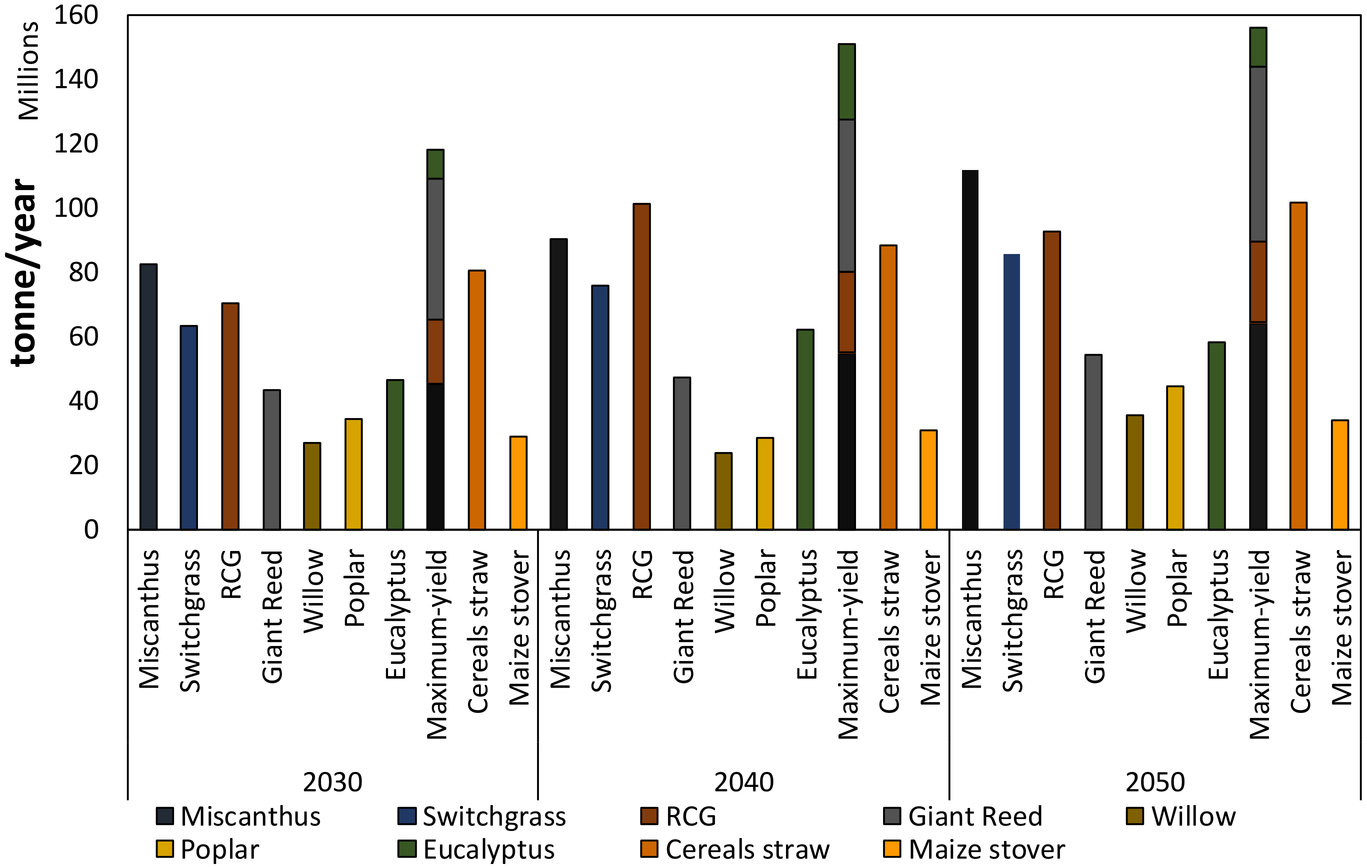
# Biomass supply scenarios

Main assumption for supply scenarios of lignocellulosic energy crops and residues

| | Low Scenario | Medium Scenario | High Scenario |
|---|---|---|---|
| Use of potential available marginal land that meets REDII sustainability criteria and suitably parameters for lignocellulosic energy crop production | 50% | 75% | 100% |
| Annual yield increase over time in biomass potential (lignocellulosic energy crop, cereals and maize) to reflect productivity increases from improved crop management practices | 0.5% | 0.75% | 1% |
| Removal rates of agricultural residues | 30% | 40% | 50% |

# Biomass supply potentials ligno + residues




Biomass potentials of lignocellulosic energy crops, cereal straw and maize stover for the high scenario in the EU27 + UK. The maximum yield biomass potential represents the case based on which for each location the lignocellulosic energy crop with the highest attainable yield is selected. The individual energy crops bars represent the case when all available marginal land is dedicated to a single crop.

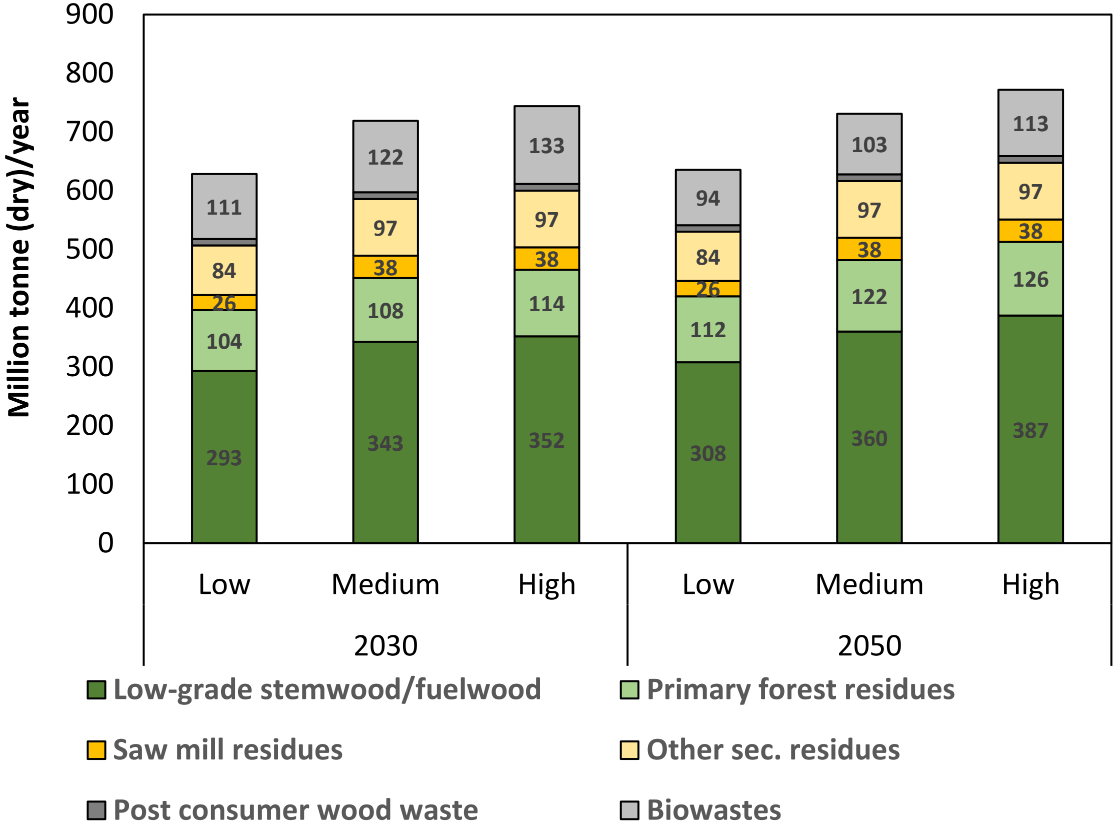
# Comparison of parameters with Imperial study

| | Mid-term report Sustainable biomass feedstock supply chains for advanced biofuels | Sustainable biomass availability in the EU to 2050 report |
|---|---|---|
| Lignocellulosiuc energy crops assessed | Miscanthus, Switchgrass, RCG, Giant Reed, Willow, Poplar and Eucalyptus | Fiber Sorghum, Kenaf, Miscanthus, Switchgrass, Cardoon Poplar and Willow |
| Assessment type | Spatially explicit (yields) while considering biophysical conditions and crop phenological characteristics align with climate projections based on IPCC climatic models. | Statistics |
| Land availability for lignocellulosic energy crops | Using 50% for the low scenario, 75% for the medium scenario and 100% for the high scenario of the available land that is considered marginal, meets REDII land sustainability criteria and the crop adaptability to each land location's specific biophysical conditions. | Using 25% of the available marginal land in the Low Scenario-, 50% in the Medium Scenario (Scenario 2) and 75% in the High Scenario (Scenario 3). |
| Crops mix potential | The maximum-yield biomass potential is quantified by selecting the lignocellulosic energy crop for each location with the highest attainable yield. | Not specified |
| Yield increases for lignocellulosic energy crops | 0,.5% for the low, 0,75% for the medium and 1% for the high scenario annual increase | 1% for the low, 1% for the medium and 2% for the high scenario annual increase |
| Yield increases for crops related to agricultural residues | 0,5% for the low, 0,75% for the medium and 1% for the high scenario annual increase | 1,9% annual increase divided in 0.9% for crop yield improvements and 1% for management practice improvements |
| Removal rate of field residues | 30% for the low, 40% for the medium and 50% for the high scenario | 40% for the low, 45% for the medium and 50% for the high scenario |

# Imperial college biomass supply potentials

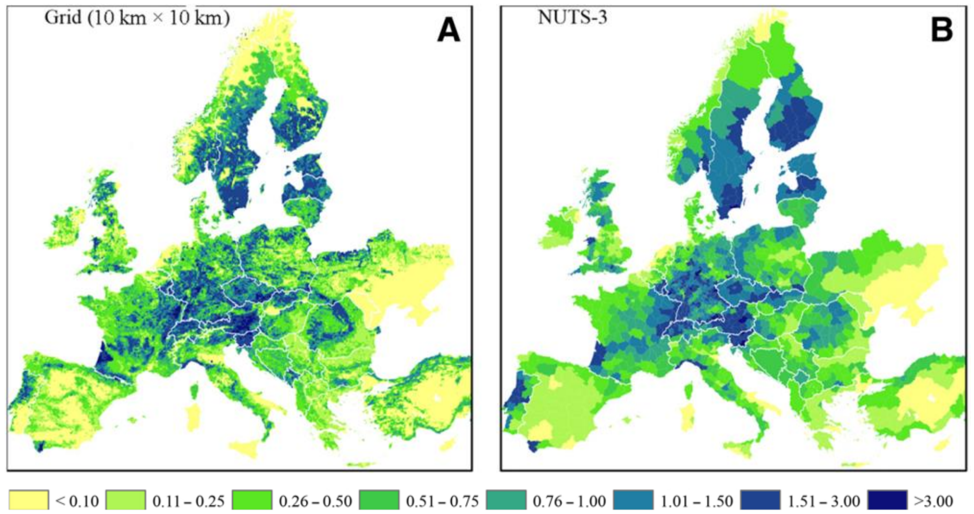
- In the Sustainable biomass availability in the EU toward 2050 report (García-Condado et al., 2019; Panoutsou & Maniatis, 2021), lignocellulosic energy crops are estimated to be between 36 to 108 million tons for 2030 and 42 to 127 million tonnes for 2050, depending on the scenario.
- Cereal straw is estimated to vary between 118 to 141 million tonnes in 2030 to 130 to 156 million tonnes in 2050, depending on scenario.
- Maize stover is projected to vary between 25 to 28 million tonnes in 2030 to 28 to 31 million tonnes in 2050. The main differences in potentials between this and the IC study are driven by the following:

# Key finding 1: Biomass supply potentials from forests and bio-waste



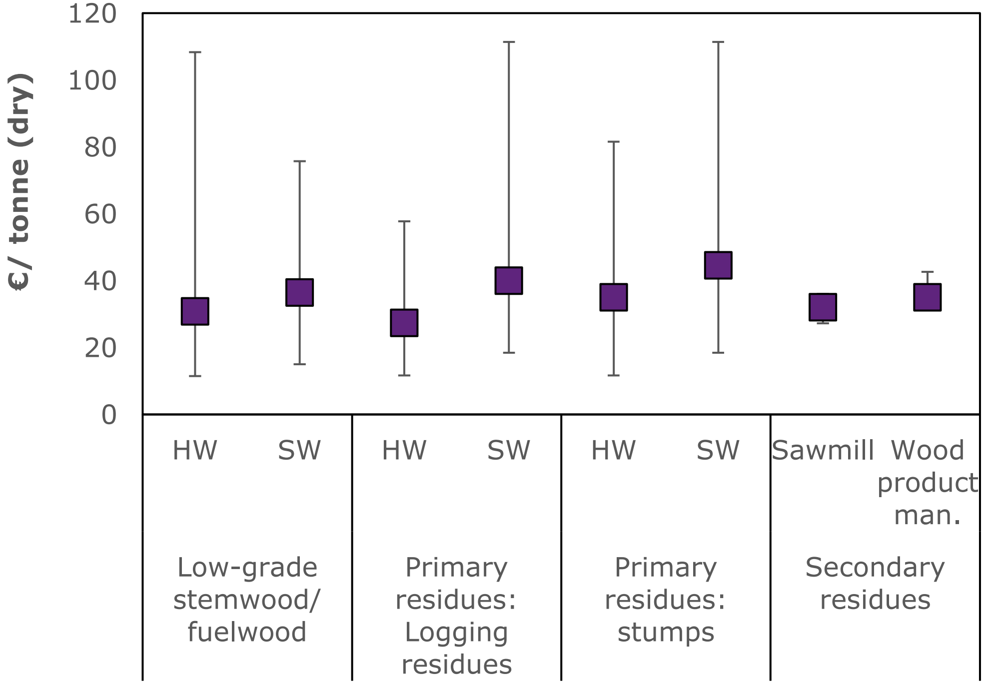

**Forest and bio-waste potentials in the EU27 + UK for the low, medium and high scenario**
Stemwood, primary forest residues, biowastes: Imperial College (2021)
Saw mill residues and other wood processing residues: NUTS3, assumed constant 2030-2050 (EU S2Biom)
Post-consumer wood waste: EUwood (Mantau et al. 2010)

- Potentials were aligned with the Imperial College report when possible.
- Mapped based on relative spatial distribution within member states based on available literature and data.



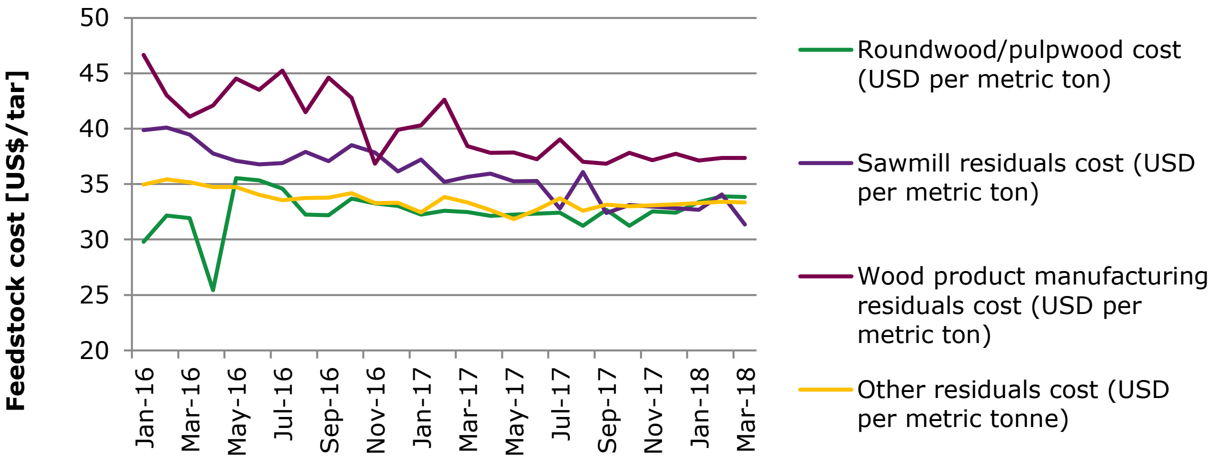

**Estimated spatial distribution of forest biomass availability in 2020 for all uses** [in t ha-1 y-1] at (A) grid cell [10km x 10 km], and (B) at NUTS-3 level (Verkerk et al., 2019)

# Key finding 2: Costs of forest biomass at the roadside




**EU27 + UK average costs of forest biomass at roadside.**
The ranges indicate the variability between NUTS3 regions.
HW: hardwood, SW: softwood
Stemwood and primary forest residues: EU S2Biom
Secondary forest residues: IEA Bioenergy Task 40 (2019)

- Large variations in cost between regions of S2Biom cost projections.
- Driven by cost of labor, machinery, fuel, parcel sizes, etc.
- The cost of wood production (stumpage) is not included in the EU S2Biom calculations.
- A detailed analysis of the data is still required.

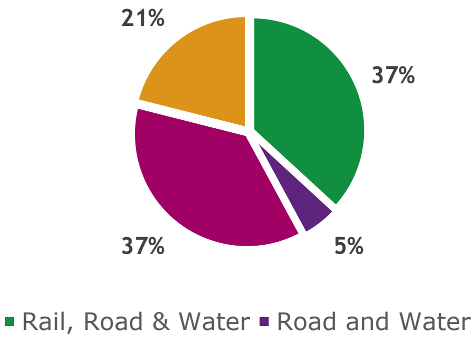



**Cost of feedstock delivered to pellet plant including all cost components (transportation, commodity costs, taxes, handling, etc.)**
Source: (IEA Bioenergy Task 40 2019)

# Key finding 5: main insights from the current plant analysis

- Selected: 19 existing plants in Europe that process lignocellulosic biomass and produce biofuels or intermediates
- Analysis based on Google Maps and Streetview

- 17 plants are located in industrial areas to benefit from agglomeration economies.
- Next to road, almost 80% also have access to rail and/or water infrastructure.




Source:Rothenburger (2023)

**Example: SunPine AB (Pitea, Sweden)**


Sources: Sunpine AB and Google Maps

# Key finding 6: main findings from the expert interviews

- While road transport shifts toward electrification, the marine and aviation will likely become the largest markets for advanced biofuels.
- Long-term stable and effective policies, are required to create certainty for investors and consumers.
- Reliable (all-year round), sustainable and affordable feedstock supply chains are important for successful operation of commercial scale advanced biofuel plants.
- Access to green hydrogen, power supply, and (international) markets through blending facilities or terminals, and in the future also options to export $CO_2$ for utilization or storage (BECCUS).
- Economic advantage of clustered activities. Existing chemical clusters and petrochemical areas could provide access to markets for products and by-products, co-location opportunities and access to utilities and energy and skilled labour.

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# Criteria, supply chain strategies and modelling approach

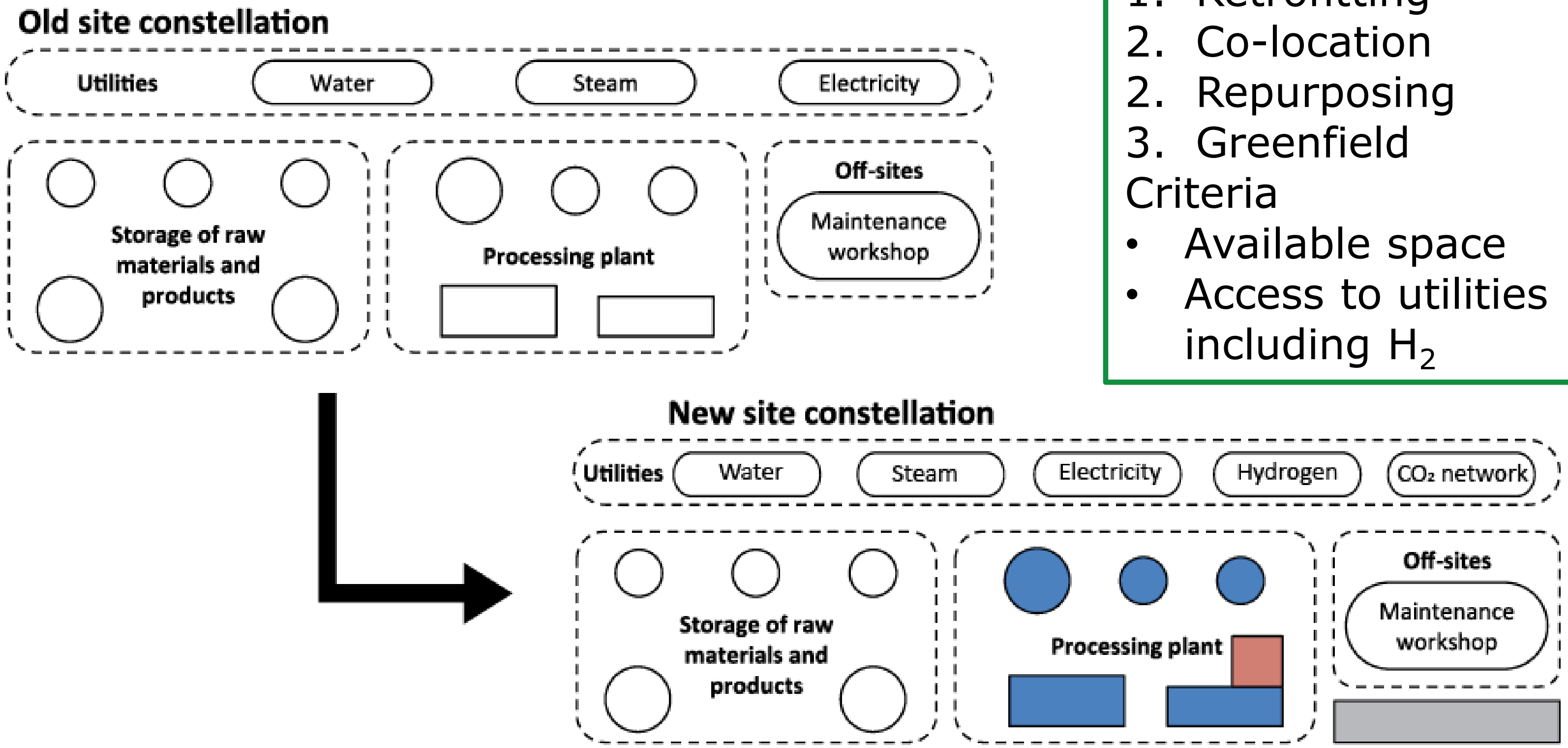
| | Feedstock | Transport | Pretreatment | Conversion/upgrading | Distribution/ end-use |
|---|---|---|---|---|---|
| **Criteria (from expert interviews)** | Feedstock delivered at specifications, all-year round, and affordable. | Available infrastructure<br>• Road, rail, water, sea<br>• Handling/ storage terminals | Close to feedstock supply | Access to utilities:<br>• (Green) power<br>• Hydrogen<br>• Future: $CO_2$ network | Access to markets:<br>• Road<br>• Marine<br>• Aviation<br>• Other products |
| **Supply chain strategies** | Close to biomass rich areas. Feedstock diversification. | • Intermodal transport<br>• Transport of intermediates | Integration with existing industries<br>• Pulp & paper, sawmills<br>• Chemical parks/clusters<br>• Oil refineries | | Close to end-use markets / blending terminals |
| **Modelling approach** | Geographic mapping of biomass feedstock supply | GIS based intermodal transport network analysis | Supply chain modeling for different configurations<br>• Centralized vs distributed supply chains<br>• Integration strategies | | Mapping of market access (blending terminal nodes) |

# Integration strategies

**Refineries**

**Pulp / sawmill**

**1st gen. biofuel**




**Co-locating:** installing a separate entity which uses part of the feedstock, feedstock infrastructure and/or utilities of the existing facility

**Retro-fitting**: adding a 'bolt-on' or 'add-on' unit which uses by-products or unutilized components of the feedstock for alternate purposes

**Repurposing**: adjusting the existing production process to produce a different output

Ranking (1st is best):
1. Retrofitting
2. Co-location
2. Repurposing
3. Greenfield

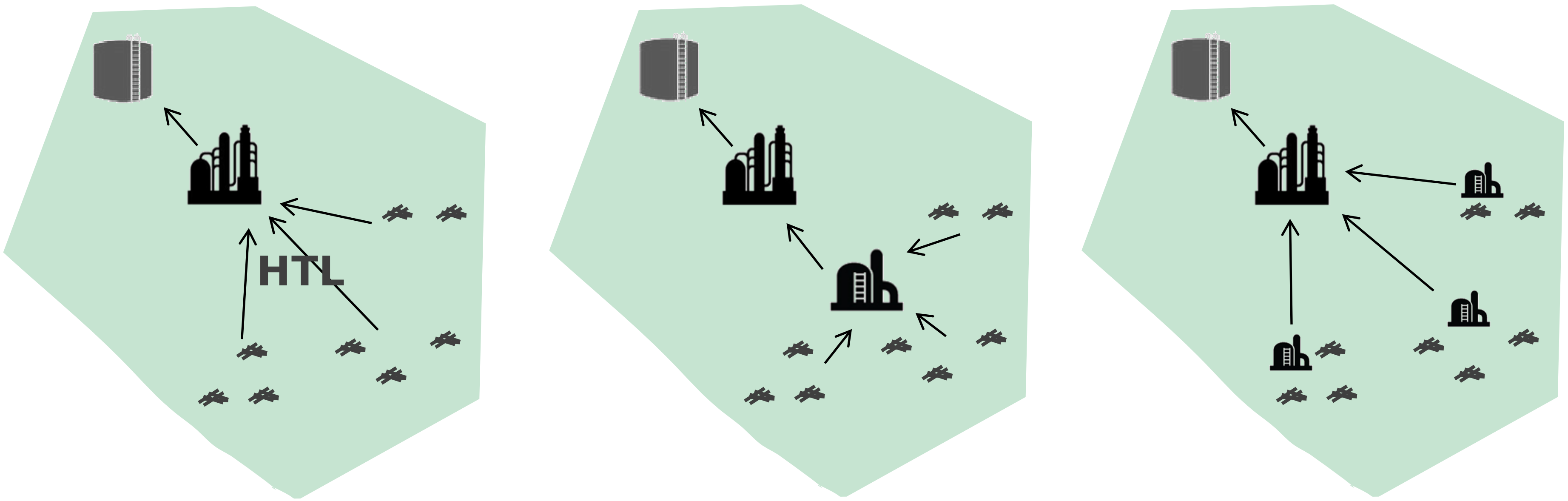
Criteria
- Available space
- Access to utilities including $H_2$

*Trade-off: flexible locations (greenfield) vs integration benefits*

De Jong, Sierk, et al. "The feasibility of short-term production strategies for renewable jet fuels–a comprehensive techno-economic comparison." *Biofuels, Bioproducts and Biorefining* 9.6 (2015): 778-800.

# Supply chain configurations

**Centralized supply chain** | **Distributed supply chain (Linear type)** | **Distributed supply chain (Hub-and-spoke type)**




Lower CAPEX/OPEX, higher upstream transportation cost

Higher CAPEX/OPEX, lower upstream transportation cost

Higher CAPEX/OPEX, lower upstream transportation cost

Feedstock   Pre-treatment unit   Upgrading unit   Storage terminal

*Trade-off: conversion cost vs transport cost*


de Jong, Sierk, et al. "Cost optimization of biofuel production–The impact of scale, integration, transport and supply chain configurations." Applied energy 195 (2017): 1055-1070.

# The current model can choose from 6 possible supply chain configurations (will be updated)

## Standalone

### Centralized (1)

**Pre-treatment + conversion/hydroprocessing**

**Potential locations:** natural gas grid connection, LNG terminal

### Distributed

**Pre-treatment**

**Potential locations:** forest terminal

(3)

**Conversion/Hydroprocessing**

**Potential locations:** natural gas grid connection, LNG terminal

## Integrated

### Centralized (2)

**Pre-treatment + conversion/hydroprocessing**

**Potential locations:** Refinery

**Integration:** Hydrogen

### Distributed

**Pre-treatment**

**Potential locations:** Pulp mill, sawmill & district heating

**Integration:** Heat & saw- and pulpmill byproducts

(4) (5) (6)

**Conversion/Hydroprocessing**

**Potential locations:** Refinery

**Integration:** Hydrogen

de Jong, Sierk, et al. "Cost optimization of biofuel production–The impact of scale, integration, transport and supply chain configurations." Applied energy 195 (2017): 1055-1070.