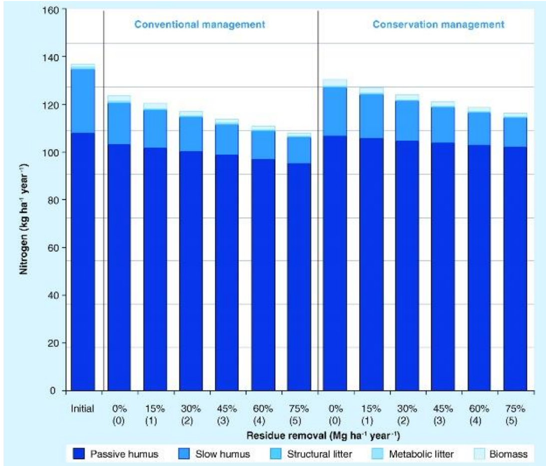
<table>
<tr><th>Indicator</th><th>Value Type/Unit/Scale</th><th>Definition</th><th>Suggested Quantitative Value Ranges</th><th>Suggested Qualitative Value Ranges</th></tr>
<tr><td>Bioenergy carriers and biomaterials per hectare of cultivated area</td><td>tonne per ha or GJ/ha/yr</td><td>Measured in dry mass and/or energy content. Crop yields/feedstock productivity depend on the cultivation system, input levels, bioclimatic conditions, and overall land suitability.</td><td>Minimum net energy yield from Fritsche et al (2012)
<table>
<tr><th>Land type</th><th>2020</th><th>2030</th></tr>
<tr><td>smallholder, marginal/degraded land</td><td>>25 GJbio/ha</td><td>>35 GJbio/ha</td></tr>
<tr><td>plantation, marginal/degraded land</td><td>>50 GJbio/ha</td><td>>75 GJbio/ha</td></tr>
<tr><td>plantation, arable land</td><td>>100 GJbio/ha</td><td>>150 GJbio/ha</td></tr>
</table></td><td>N/A</td></tr>
<tr><td>Direct/indirect land use change</td><td>Descriptive</td><td>Direct anthropogenic changes and descriptive documentation of how the land cover changed. Types of land use change include deforestation, afforestation, and rewilding. Indirect impacts from land use change require more substantial qualitative/quantitative data to document the impacts.</td><td>ILUC factor of 3.5 t CO2/ha/year for any bioenergy feedstock cultivation established on previously used agricultural land. 0 ILUC factor for bioenergy cultivation on land not in competition and not in conflict with biodiversity protection (Fritsche et al, 2012)

The range of GHG Emissions from ILUC in for maize-based ethanol is 40-50 g CO2eq/MJbiofuel, and 50-75 g CO2eq/MJbiofuel for soybean-based biodiesel (OEKO, 2011)

Estimated indirect land-use change emissions from biofuel, bioliquid and biomass fuel feedstock from the Recast of the Renewable Directive (European Commission, 2018):
<table>
<tr><th>Feedstock group</th><th>Mean (g CO2eq/MJ)</th><th>Interpercentile range (g CO2eq/MJ)</th></tr>
<tr><td>Cereals and other starch-rich crops</td><td>12</td><td>8 to 16</td></tr>
<tr><td>Sugars</td><td>13</td><td>4 to 17</td></tr>
<tr><td>Oil crops</td><td>55</td><td>33 to 66</td></tr>
</table></td><td>N/A</td></tr>
<tr><td>Primary and secondary products</td><td>Net economic value of output (€) per tdm (tonne dry mass) of input

Second resource use as % of the</td><td>Covers biomass production section of the value chain, and is similar to total factor productivity. Economic value of the outputs – economic value of the inputs</td><td>calculated as follows: economic value of the outputs (€/GJ x GJ energy carriers + €/ton x ton materials) – economic value of the inputs (excl. the biomass) (€/GJ x GJ energy carriers + €/ton x ton materials), per dry tonne biomass input.</td><td><table>
<tr><td>- -</td><td>Fresh material (high value), which can also be used for material / food</td></tr>
<tr><td>-</td><td>Residues, which can also be used/recycled for material or animal feed</td></tr>
</table></td></tr>
</table>

	input material (in tonne dry mass)	(excl. the biomass), per dry tonne biomass input. The use of residues is not by definition positive, so the indicator requires a descriptive part.	This value could be compared to the economic value of the heat which could be produced from burning the (dried) biomass inputs (reference = heat from natural gas ~ 10€/GJ).	o: Fresh material, but difficult to use for material / food +: Residues, difficult to use for material / food ++: Non-recyclable waste as input
Cumulative energy demand Non-renewable energy requirement	GJ input/ GJ output GJ input	Full value chain energy content (heating value and/or primary energy to produce them) of all inputs in the value chain, compared to the energy content of all outputs of the value chain. Also considers the non-renewable energy inputs in the value chain, in comparison to all outputs of the value chain.	Primary energy demand around 9.5 PJ/a renewable and 0.8 PJ/a non-renewable (Cherubini & Ulgiati, 2010)	N/A
Life cycle GHG emissions	gCO_2eq/MJ	Main greenhouse gases being CO_2, methane (CH_4) and nitrous oxide (N_2O) considered over the full value chain. Carbon stock changes in the supply side (e.g. through land use change) are also considered.	137 kt CO_2 eq for corn stover and 130 for wheat straw (Cherubini & Ulgiati, 2010) CAP (biomass production) RED (not biomaterials)	N/A

<table>
<tr>
<td>Sustainable harvest level</td>
<td>% of net annual growth harvested</td>
<td>Harvest of trees, wood resources and the removal of wood harvest residues (including stumps), but also the removal of agricultural residues such as straw and stubbles and pruning residues from permanent crops. Long-term harvest levels should remain lower than net growth and forests are allowed to expand their carbon storage.</td>
<td>Mean soil nitrogen balance with different rates of residue harvest and management systems (Gregg & Izaurralde, 2014)


Proportional impact (%) of initial soil organic content on harvest rates (Zhao et al, 2015). Harvest rates of 25 – 50% can be sustained when considering SOC content as a limiting factor for residue harvest. Agricultural lands with low initial SOC content have a higher sustainable limits with more than 25% of crop residue sustainably harvestable. Croplands with high initial SOC content have low sustainable limits and required high residue input to maintain SOC:
<table>
<tr><th>Initial SOC Content ($t\ ha^{-1}$) / Harvest Rate Regimes (%)</th><th>9-23</th><th>23-29</th><th>26-36</th><th>36-48</th><th>48-116</th></tr>
<tr><td>0-25</td><td>30%</td><td>45%</td><td>45%</td><td>55%</td><td>65%</td></tr>
<tr><td>25-50</td><td>10%</td><td>20%</td><td>20%</td><td>20%</td><td>20%</td></tr>
<tr><td>50-75</td><td>20%</td><td>20%</td><td>20%</td><td>20%</td><td>15%</td></tr>
<tr><td>75-100</td><td>40%</td><td>15%</td><td>15%</td><td>5%</td><td>0%</td></tr>
</table>
</td>
<td>Residue harvest thresholds with respect to tolerable soil loss (Gregg & Izaurralde, 2014):
<table>
<tr><th rowspan="2">Crop Rotation</th><th rowspan="2">Slope (%)</th><th colspan="6">Residue Harvest Rate (%)</th></tr>
<tr><th>0</th><th>15</th><th>30</th><th>45</th><th>60</th><th>75</th></tr>
<tr><td>Corn-soy</td><td>0.1</td><td>B</td><td>B</td><td>B</td><td>B</td><td>B</td><td>B</td></tr>
<tr><td>Cotton-peanut</td><td>1</td><td>A</td><td>A</td><td>A</td><td>B</td><td>B</td><td>B</td></tr>
<tr><td>Corn-soy</td><td>5</td><td>B</td><td>C</td><td>C</td><td>C</td><td>C</td><td>C</td></tr>
<tr><td>Winter Wheat-Sunflower</td><td>10</td><td>A</td><td>A</td><td>B</td><td>B</td><td>B</td><td>B</td></tr>
<tr><td>Spring Wheat-Canola</td><td>10</td><td>A</td><td>A</td><td>A</td><td>A</td><td>B</td><td>B</td></tr>
</table>
A: Erosion less than tolerable soil loss; B: Erosion within tolerable soil loss range; C: Erosion exceeds tolerable soil loss.
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<tr>
<td>Conservation or protection of biodiversity</td>
<td>Risk of disturbing conservation land

Carbon stock (tonne/ha)</td>
<td>Direct effects of land use and management changes on species and habitats and ultimately on ecosystem capacity to provide services. Species diversity and carbon stock are key indicators, and conservation areas are usually protected sites and include natural and semi-natural forest land, wetland and grassland.</td>
<td colspan="2">Both the farmland bird index and high nature value farming can be used for identifying land requiring conservation action (European Commission, Impact Indicator fiches, 2018):
<table>
<tr><td></td><td>Farmland bird index</td><td>High Nature Value farming</td></tr>
<tr><td>Definition</td><td>Rate of change in the relative abundance of common bird species dependent on farmland for feeding and nesting and are not able to thrive in other habitats</td><td>Percentage of Utilised Agricultural Area farmed to generate High Nature Value, defined as having either a high proportion of semi-natural vegetation, a mosaic of low intensity agriculture and natural elements, or supporting rare species</td></tr>
<tr><td>Data collection</td><td>Population counts are carried out by a network of volunteer ornithologists coordinated within national schemes. Index is calculated with reference to a base year, when the index value is set at 100%. Trend values express the overall population change over a period of years</td><td>Member State

authorities are responsible for conducting this assessment using methods suited to the prevailing bio-physical characteristics and farming systems</td></tr>
<tr><td>Unit of measureme nt</td><td>Index - (base year 2000 = 100)</td><td>Percentage (%) and absolute area of UAA and of HNV farmland (ha)</td></tr>
<tr><td>Data source(s)</td><td>Eurostat, Environment statistics, Biodiversity:

http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=ENV_BIO2&lang=en#</td><td>CORINE and other land cover data, IACS/LPIS, agricultural census data, species and habitat databases, GIS, specific sampling surveys, RDP monitoring data, designations; NATURA 2000 designations found here: https://ec.europa.eu/assets/agri/cap-context-indicators/documents/c34_en.pdf</td></tr>
</table>
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<tr>
<td>Cultivation practises in line with biodiversity</td>
<td>Management practices and behaviour in number of species

(Descriptive)</td>
<td>Cultivation practices compatible with biodiversity conservation by using local crop varieties, avoiding monocultures and invasive species, promoting cover cropping, agroforestry and intercropping, low fertiliser and pesticide</td>
<td>Correlations between landscape use indicators and species richness (Billeter et al, 2007)
<table>
<tr><td>Landscape
Action
Taxon</td><td>Crop diversity</td><td>Fertilizer input (kg N ha year)</td><td>Semi-natural elements (%)</td></tr>
</table>
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<td>
<table>
<tr><td>--</td><td>Land management practices for producing this type of biomass generally have a negative impact on biodiversity (e.g. monocultures)</td></tr>
<tr><td>-</td><td></td></tr>
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<tr>
<td></td>
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<td>use and including buffer zones. End use characteristics are also relevant to species health.</td>
<td>
<table>
<tr><td>Vascular Plants</td><td></td><td>Decrease</td><td>Increase</td></tr>
<tr><td>Birds</td><td></td><td>Decrease (60 birds for 0 kg and 45 birds for 400 kg)</td><td>Increase (45 birds for 0% and 60 birds for 60%)</td></tr>
<tr><td>Bees</td><td>Increase</td><td></td><td>Slight increase</td></tr>
<tr><td>Carabid beetles</td><td>Increase</td><td></td><td>Increase</td></tr>
<tr><td>Heteroptera bugs</td><td>Increase (35 bugs for one crop, 70 for 8 crop types)</td><td></td><td>Increase</td></tr>
<tr><td>Hoverflies</td><td>Slight increase</td><td></td><td>Increase (20 for 0% and 40 for 60%)</td></tr>
<tr><td>Spiders</td><td>Slight increase</td><td></td><td>Increase</td></tr>
</table>
</td>
<td>
<table>
<tr><td>o</td><td>No impact on biodiversity (e.g. no land use involved)</td></tr>
<tr><td>+</td><td></td></tr>
<tr><td>++</td><td>Positive impact on biodiversity</td></tr>
</table>
</td>
</tr>
<tr>
<td>Soil quality</td>
<td>Soil carbon (unit of mass/ha)

Soil nutrients (qualitative)</td>
<td>Soil organic carbon content of land being used for biomass feedstock cultivation must be at least maintained. Nutrient balance is expressed as a risk for being disturbed.</td>
<td>Soil organic carbon changes over time associated with different land conversion regimes (Anderson-Teixeira et al, 2009)
<table>
<tr><td>Land use change</td><td>Soil organic carbon change</td></tr>
<tr><td>Agricultural to corn with residue removal</td><td>0.2% loss (about 0.06–0.09 Mg C ha^{-1}) for every 1% increase in residue removal, which represents 4.2 Mg C ha^{-1} yr^{-1}</td></tr>
<tr><td>Native forest or grassland to sugarcane</td><td>22% or 20 Mg C ha^{-1} loss</td></tr>
</table>
</td>
<td>
<table>
<tr><td>--</td><td>High risk for losing soil organic carbon and/or nutrient balance when growing and harvesting this type of biomass</td></tr>
<tr><td>-</td><td></td></tr>
<tr><td>o</td><td>No relation to soil use / maintained soil organic carbon and/or nutrient balance</td></tr>
<tr><td>+</td><td></td></tr>
<tr><td>++</td><td>Growing and harvesting this type of biomass generally increases soil</td></tr>
</table>
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			Grassland to Miscanthus: 11% or 5.8 Mg C ha^{-1} loss Cropland to mixed native land: 68% or 16 Mg C ha^{-1} gain	organic carbon and/or nutrient balance.
Air quality	Acidification (g SO_2eq/MJ) Particulate matter (g PM10/MJ) NOx	Air quality is affected by combustion installations, engines and end product characteristics. Small scale combustion of wood can have a severe impact while bigger installations will adhere to stricter emission legislation.	Limited to a maximum of those of competing fossil energy (Fritsche et al, 2012) There are three main causes of NOx emissions:- High temperature combustion of fuels where the temperature is hot enough (above about 1300°C/ 2370°F) to oxidise some of the nitrogen in air to NOx gases. This includes burning hydrogen, as it burns at a very high temperature (https://clean-carbonenergy.com/nox-emissions.html).	N/A
Water use efficiency	Water use efficiency (m^3/GJ outputs)	Water use quantified for biomass production (cropping), irrigation and conversion must not exceed the average replenishment from natural flow in a watershed. Establishment of biomass cropping systems and conversion facilities must be placed outside areas with severe water stress.	FAO database aquastat the volume of water which is applied to soils for irrigation purposes must be regulate in terms of water abstraction it causes from total surface or ground water - Eurostat - statistics on the structure of agricultural holdings - SAPM 2010 - Table: Irrigation - number of farms, areas and equipment by size of irrigated area and NUTS 2 regions, data: volume of water used for irrigation per year, m3 - Eurostat - environment statistics - Table annual water abstraction by source and by 29 sector (env wat abs/ data water abstraction for irrigation purposes. Information on the share of water abstraction in agriculture (for irrigation purposes) as a percentage of the total gross (freshwater) abstraction is also available	N/A
Levelised life cycle costs	€/GJ outputs	Bioenergy carriers and biomaterials costs, including capital expenditures (investment costs, for a certain annual	Case specific	N/A

<table>
<tr><td></td><td></td><td>capacity) and operating costs in terms of feedstock, machinery, maintenance and other costs.</td><td></td><td></td></tr>
<tr><td>Technology readiness level for feedstock</td><td rowspan="2">Level 1 to 9 (qualitative)</td><td rowspan="2">Level 0: Idea/unproven concept; Level 1: basic research/no experimental proof; Level 2: technology formulation; Level 3: applied research/proof of concept; Level 4: small scale prototype; Level 5: large scale, tested prototype; Level 6: prototype with expected performance; Level 7: demonstration operational system; Level 8: first of a kind commercial system; Level 9: Full commercial application (NASA, 2007)</td><td></td><td></td></tr>
<tr><td>Technology readiness level for conversion</td><td colspan="2">Main activities of thermochemical conversion to obtain renewable fuels and chemicals as related to TRLs (Beims et al, 2019)
<table>
<tr><th>TRLs</th><th>Main activities</th><th>Main aspect to classify studies/patents</th></tr>
<tr><td>1-3</td><td>Formulation of principles intrinsic to proposing a new chemical concept or route, by evaluating different feedstocks and verifying the process by means of small-scale experiments.</td><td rowspan="3">Influenced mostly by mass processing capacity</td></tr>
<tr><td>4</td><td>Operation scale, main contribution being related to reaction scheme proposals</td></tr>
<tr><td>5</td><td>Experiments in bench-scale reactors, where the products are validated in the laboratory environment</td></tr>
<tr><td>6</td><td>Test experimental parameters obtained from bench-scale tests and kinetic models in a pilot plant</td><td>Systems prototypes testing</td></tr>
<tr><td>7</td><td>Higher production rates have to be tested to confirm the product characteristics and properties before securing large investments with high risk</td><td>Economic issues: attracting investors for high-risk investment</td></tr>
<tr><td>8-9</td><td>Industrial operation with high production rates, verifying the technical parameters for biofuel production</td><td>Feasibility and viability establishment</td></tr>
</table></td></tr>
</table>

FTE along the full value chain	number of full-time jobs/tonne or GJ of end products	Employment is included in the measurement of direct jobs created, either skilled or non-skilled along the full value chain, including the manufacturing of equipment, distribution and sales, installation of conversion plants and other equipment and major research and development.	25 MWe plants are equivalent to 4000 man years or around 160 FTE, for power-only plants typically 1.27 man years/GWhe (Thornley et al, 2007)	
Contribution to rural economy	€/GJ	This indicator reveals whether value chain contributes more to regional growth and development, or if it is directed to large scale industry and international companies.	Can be supported by Rural GDP per capita which is measured by Purchasing Power Standard (European Commission, Impact Indicator fiches, 2018)	N/A