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### **Techno-economic and life-cycle assessment of forest residue supply chain and combined heat and power generation in rural communities: a case study in Canada**

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# Techno-economic and life-cycle assessment of forest residue supply chain and combined heat and power generation in rural communities: A case study in Canada

The aim of this study is to validate a new integrated economic and environmental assessment framework for deploying **micro-scale biomass gasification** systems in **remote and rural communities**. In this study, harvesting **forest residues** are used as feedstock to produce heat and power based on gasification and internal combustion systems. Three supply chain scenarios of wood biomass are considered: **wood chips, wood pellets, and torrefied pellets** (Figure 1).

**Main objectives:**

- Evaluate the **economic feasibility** of bioenergy alternatives using forestry residues.
- Perform a comparative **life cycle impact assessment** of the three biomass supply chains and the combined heat and power conversion for each feedstock type.

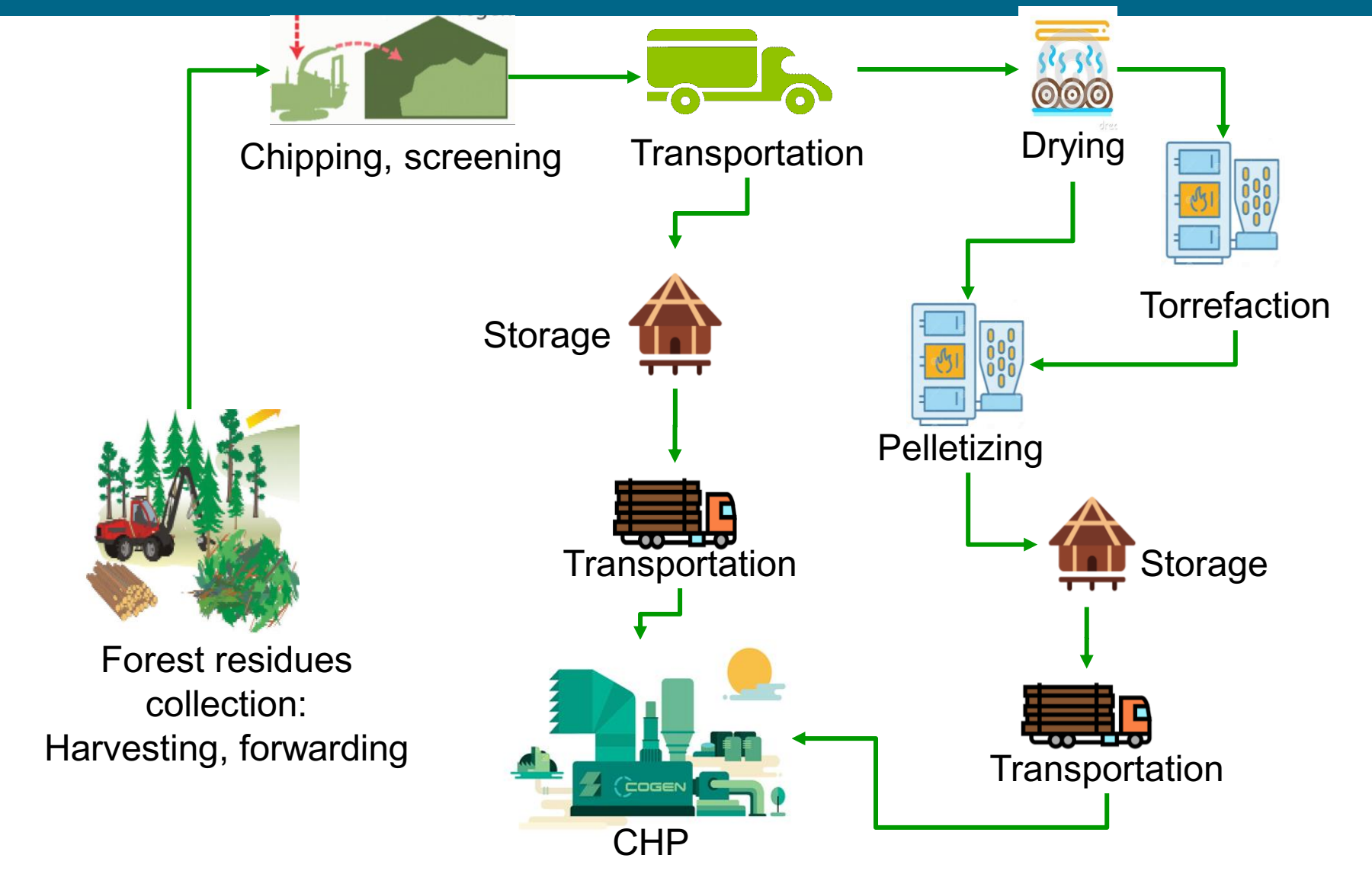


Fig 1. Supply chain of three wood biomass feedstock

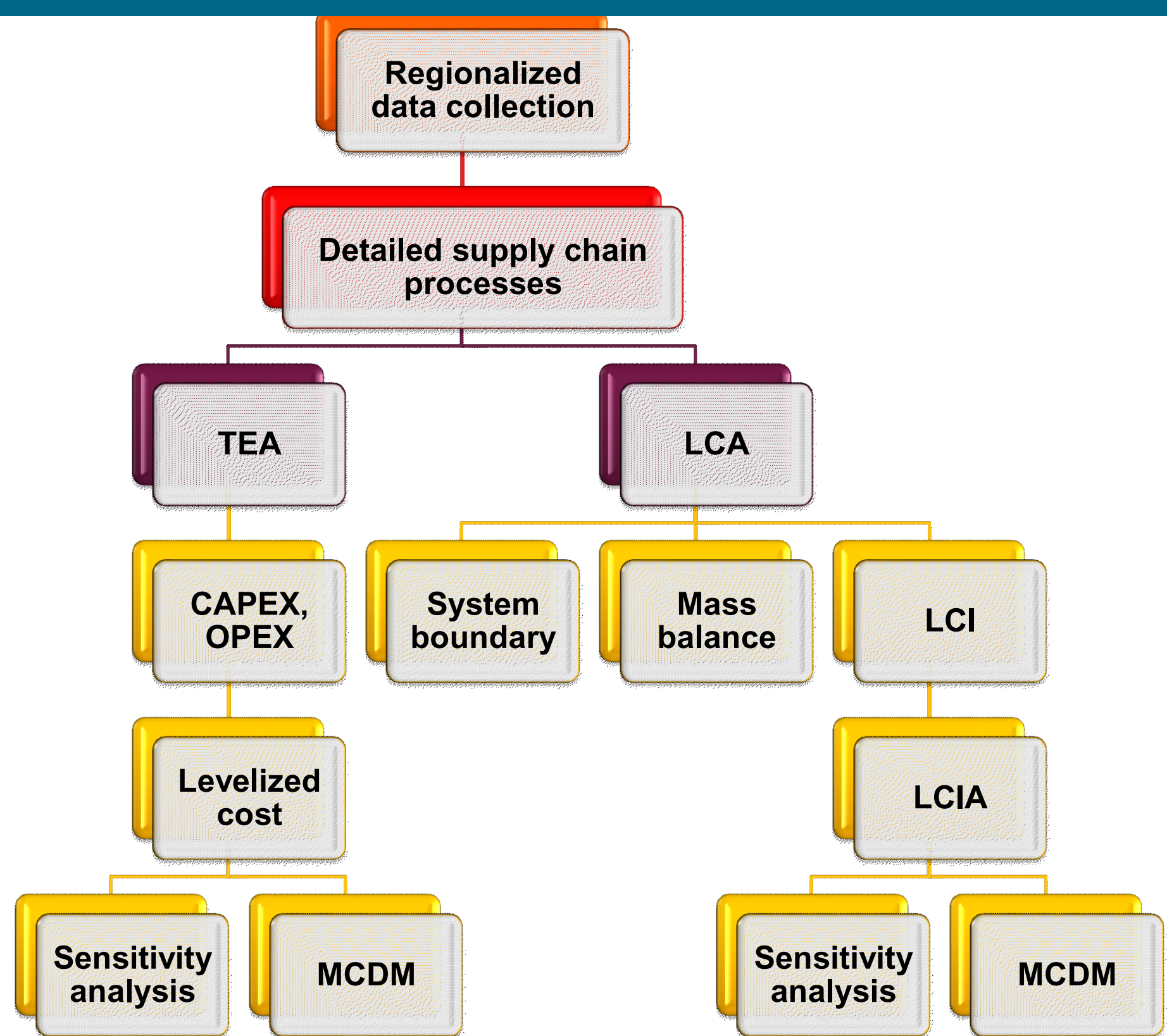


Fig 2. Sustainability assessment framework to evaluate bioenergy pathways

- Approach: **Integrated economic and environmental assessment** (Figure 2).
- Supply chain information based on existing forest biomass practices in a **site-specific** Canadian rural community.
- Supply chain of **wood chips (WC), wood pellets (WP), and torrefied pellets (TOP)**.
- Techno-economic analysis (TEA): Life cycle costs, operating conditions, and parameters data based on equipment manufacturer price quotes and local supply chain costs.
  - Levelized cycle cost (LCC)** of electricity, heat, wood pellets, torrefied pellets
- Life cycle assessment (LCA): Product system, **supply chain system boundaries**, life cycle inventory (LCI), and life cycle impact assessment.
  - Foreground data**, fuel and electricity consumption and related emissions data based on local operating conditions; mass balance based on previous studies.
  - Background data** from Ecoinvent database 3.7 version
- Life cycle impact assessment (LCIA): 18 impact categories, including **climate change**.
- Cost and environmental impact sensitivity analysis as a function of wood fuel **delivery distance**.
- Multicriteria decision making (MCDM)** to rank viability of bioenergy system options.

Table 1. Energy costs for locating gasifier CHP unit at 30 km and 300 km distance

| Power and energy costs                        | CHP unit located at 30 km distance |              |                   | CHP unit located at 300 km distance |              |                   |
|-----------------------------------------------|------------------------------------|--------------|-------------------|-------------------------------------|--------------|-------------------|
|                                               | Wood chips                         | Wood pellets | Torrefied pellets | Wood chips                          | Wood pellets | Torrefied pellets |
| Feedstock delivery cost (\$ t <sup>-1</sup> ) | 87                                 | 156          | 247               | 130                                 | 176          | 279               |
| Electricity cost (\$ MWh <sup>-1</sup> )      | 398                                | 438          | 478               | 469                                 | 461          | 478               |
| Energy cost (\$ MWh <sup>-1</sup> )           | 143                                | 157          | 172               | 168                                 | 165          | 172               |

**Wood chips** feedstock is the most economically viable option for **short distances**. When electricity generation is included, **pellets** are economically more viable than wood chips for delivery distance higher than **260 km**. The **torrefied pellets** became the most economically viable at distances of **515 km or more**.

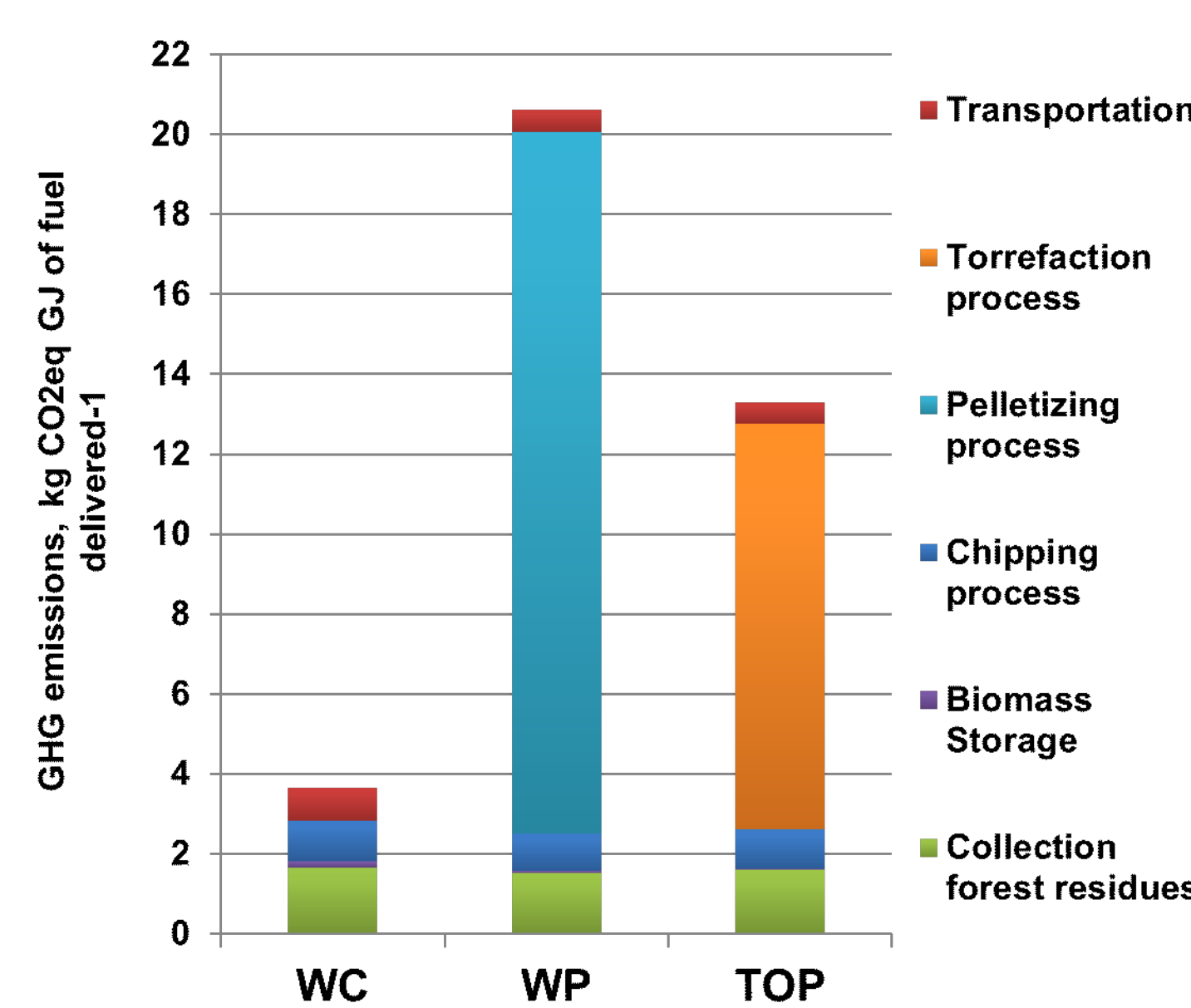


Fig 3. Breakdown of GHG emissions of three biomass supply chain scenarios for locating CHP unit at 30 km

**Collection of forest residues** represents 45% of total WC supply chain emissions. **Pelletizing and torrefaction** biomass upgrading represent 85% and 76% of total WP and TOP supply chain emissions, respectively.

Table 2. Environmental and economic sustainability of bioenergy options in remote communities, functional unit: 1 kWh of energy produced

| Indicator           | T1: 30 km |      |      | 250 km |      |      | 500 km |      |      |
|---------------------|-----------|------|------|--------|------|------|--------|------|------|
|                     | WC        | WP   | TP   | WC     | WP   | TP   | WC     | WP   | TP   |
| GWP                 | 2         | 3    | 1    | 2      | 3    | 1    | 2      | 3    | 1    |
| OD                  | 2         | 2    | 1    | 3      | 2    | 1    | 3      | 2    | 1    |
| TA                  | 2         | 3    | 1    | 2      | 3    | 1    | 2      | 3    | 1    |
| FE                  | 1         | 3    | 2    | 1      | 3    | 2    | 1      | 3    | 2    |
| ME                  | 2         | 2    | 1    | 2      | 2    | 1    | 2      | 2    | 1    |
| HT                  | 1         | 3    | 2    | 1      | 3    | 2    | 1      | 3    | 2    |
| POF                 | 1         | 3    | 2    | 1      | 3    | 2    | 1      | 3    | 2    |
| PMF                 | 1         | 3    | 2    | 2      | 3    | 1    | 2      | 3    | 1    |
| TET                 | 1         | 2    | 3    | 1      | 1    | 1    | 1      | 1    | 1    |
| FET                 | 2         | 2    | 1    | 2      | 3    | 1    | 2      | 2    | 1    |
| MET                 | 1         | 3    | 1    | 2      | 3    | 1    | 2      | 3    | 1    |
| IR                  | 1         | 3    | 2    | 1      | 3    | 3    | 1      | 3    | 2    |
| ALO                 | 3         | 1    | 2    | 3      | 2    | 2    | 3      | 2    | 1    |
| ULO                 | 2         | 2    | 1    | 3      | 2    | 1    | 3      | 2    | 1    |
| NLO                 | 3         | 2    | 1    | 3      | 2    | 1    | 3      | 2    | 1    |
| WD                  | 1         | 3    | 2    | 1      | 2    | 3    | 1      | 3    | 2    |
| MD                  | 3         | 2    | 1    | 3      | 2    | 1    | 3      | 2    | 1    |
| FD                  | 1         | 3    | 2    | 1      | 3    | 1    | 2      | 3    | 1    |
| Average envi. score | 1.67      | 2.50 | 1.56 | 1.89   | 2.50 | 1.33 | 2.06   | 2.50 | 1.17 |
| LCC                 | 1         | 2    | 3    | 2      | 1    | 3    | 2      | 1    | 1    |
| Total score         | 2.67      | 4.50 | 4.56 | 3.89   | 3.50 | 4.33 | 4.06   | 3.50 | 2.17 |
| Overall ranking     | 1         | 2    | 3    | 2      | 1    | 3    | 3      | 2    | 1    |

Legend: 1 Best, 2, 3 Worst. GWP: global warming potential; FD: fossil depletion; MD: metal depletion; FET: freshwater ecotoxicity; MET: marine ecotoxicity; TET: terrestrial ecotoxicity; HT: human toxicity; ME: marine eutrophication; FE: freshwater eutrophication; TA: terrestrial acidification; PMF: particulate matter formation; POF: photochemical oxidants formation (summer smog); OD: ozone depletion; ALO: agricultural land occupation; ULO: urban land occupation; NLT: natural land transformation; IR: ionizing radiation; WD: water depletion; DB: dichlorobenzene. NMVOC: non-methane volatile organic compounds.

Proposed framework enabled us to establish the **best pathways** to deploy a forest residue powered CHP. Study showed **wood chips** are the **most economically and environmentally friendly pathway** for generating combined heat and power using forestry residue gasification. Regular **wood pellets** would be the preferred choice for **medium distances up to 500 km**. **Torrefied pellets** should be considered when much **larger delivery distances** are involved or specific environmental regulations and carbon credit scenarios exist. Although, the torrefied pellets route has the highest electricity production costs, it has the lowest GHG emissions when considering the electricity generation.