

Article

# Life Cycle Assessment Analysis of Alfalfa and Corn for Biogas Production in a Farm Case Study

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Received: 6 August 2020; Accepted: 10 October 2020; Published: date

**Supplemental Table S1 - Unit processes considered.**

|                 | <b>Maize</b> | <b>Alfalfa</b> |
|-----------------|--------------|----------------|
| Soil occupation | X            | X              |
| Plowing         | X            | X              |
| Harrowing       | X            | X              |
| Sowing          | X            | X              |
| Fertilization   | X            | X              |
| Weeding         | X            |                |
| Irrigation      | X            |                |
| Forage harvest  | X            | X              |

Supplemental Table S2 – Maize's impacts in a single year.

| Impact category                  | Unit       | Total          | Forage<br>harvest | Fertilization   | Harrowing       | Irrigation      | Occupation | Plowing         | Weeding         | Sowing          |
|----------------------------------|------------|----------------|-------------------|-----------------|-----------------|-----------------|------------|-----------------|-----------------|-----------------|
| Carcinogens                      | mPt        | 0.698379       | 0.007493          | 0.216794        | 0.002817        | 0.007449        | 0          | 0.009357        | 0.011531        | 0.44294         |
| Resp. organics                   | mPt        | 0.006372       | 0.00065           | 0.003084        | 0.000235        | 0.000608        | 0          | 0.000765        | 0.000815        | 0.000215        |
| Resp. inorganics                 | mPt        | 7.59451        | 0.545157          | 4.600043        | 0.204577        | 0.543415        | 0          | 0.682324        | 0.753155        | 0.265839        |
| Climate change                   | mPt        | 1.528453       | 0.105808          | 0.941222        | 0.039619        | 0.105253        | 0          | 0.132156        | 0.15365         | 0.050745        |
| Radiation                        | mPt        | 0.003346       | 3.14E-05          | 0.002819        | 1.51E-05        | 3.35E-05        | 0          | 4.27E-05        | 0.000296        | 0.000108        |
| Ozone layer                      | mPt        | 0.000791       | 3.78E-06          | 0.000702        | 1.29E-06        | 2.4E-06         | 0          | 3.11E-06        | 6.71E-05        | 1.11E-05        |
| Ecotoxicity                      | mPt        | 0.329391       | 0.000825          | 0.320209        | 0.00031         | 0.000801        | 0          | 0.001008        | 0.003335        | 0.002904        |
| Acidification/<br>Eutrophication | mPt        | 0.414656       | 0.038342          | 0.212168        | 0.0144          | 0.038271        | 0          | 0.048052        | 0.047235        | 0.016189        |
| Land use                         | mPt        | 0.155751       | 3.6E-06           | 0.096193        | 0.000131        | 0.000196        | 0          | 0.000261        | -0.00526        | 0.064223        |
| Minerals                         | mPt        | 0.000548       | 2.14E-05          | -5.1E-05        | 7.96E-06        | 2.12E-05        | 0          | 2.66E-05        | 0.000307        | 0.000214        |
| Fossil fuels                     | mPt        | 9.552907       | 0.611423          | 6.371511        | 0.22658         | 0.596251        | 0          | 0.749232        | 0.802983        | 0.194927        |
| <b>Total</b>                     | <b>mPt</b> | <b>20.2851</b> | <b>1.309757</b>   | <b>12.76469</b> | <b>0.488693</b> | <b>1.292301</b> | <b>0</b>   | <b>1.623228</b> | <b>1.768117</b> | <b>1.038316</b> |

**Supplemental Table S3 - Comparison of alfalfa's impacts in a useful life of 4 years.**

| Impact category                  | Unit       | Alfalfa 1st year | Alfalfa 2nd year | Alfalfa 3rd year | Alfalfa 4th year |
|----------------------------------|------------|------------------|------------------|------------------|------------------|
| Carcinogens                      | mPt        | 1.517699         | 0.021918         | 0.021918         | 0.038814         |
| Resp. organics                   | mPt        | 0.022063         | 0.001923         | 0.001923         | 0.003386         |
| Resp. inorganics                 | mPt        | 32.2036          | 1.592847         | 1.592847         | 2.822342         |
| Climate change                   | mPt        | 5.275576         | 0.309233         | 0.309233         | 0.547855         |
| Radiation                        | mPt        | 0.003017         | 9.43E-05         | 9.43E-05         | 0.000165         |
| Ozone layer                      | mPt        | 0.000496         | 1.22E-05         | 1.22E-05         | 2.06E-05         |
| Ecotoxicity                      | mPt        | 0.185056         | 0.002431         | 0.002431         | 0.00429          |
| Acidification/<br>Eutrophication | mPt        | 2.563247         | 0.111996         | 0.111996         | 0.198472         |
| Land use                         | mPt        | 12.50825         | 1.2E-05          | 1.2E-05          | 2E-05            |
| Minerals                         | mPt        | 0.0017           | 6.25E-05         | 6.25E-05         | 0.000111         |
| Fossil fuels                     | mPt        | 26.98409         | 1.794924         | 1.794924         | 3.173188         |
| <b>Total</b>                     | <b>mPt</b> | <b>81.2648</b>   | <b>3.835453</b>  | <b>3.835453</b>  | <b>6.788664</b>  |

Supplemental Table S4 – Alfalfa's impacts in the first year.

| Impact category               | Unit       | Total          | harrowing       | occupation | plowing         | forage harvest  | sowing          | fertilization   |
|-------------------------------|------------|----------------|-----------------|------------|-----------------|-----------------|-----------------|-----------------|
| Carcinogens                   | mPt        | 1.517699       | 0.019075        | 0          | 0.063916        | 0.051498        | 1.276331        | 0.106879        |
| Resp. organics                | mPt        | 0.022063       | 0.001571        | 0          | 0.005244        | 0.004454        | 0.002008        | 0.008786        |
| Resp. inorganics              | mPt        | 32.2036        | 1.389091        | 0          | 4.658188        | 3.747871        | 5.140468        | 17.26798        |
| Climate change                | mPt        | 5.275576       | 0.269035        | 0          | 0.902206        | 0.727371        | 0.584572        | 2.792393        |
| Radiation                     | mPt        | 0.003017       | 9.22E-05        | 0          | 0.000299        | 0.000214        | 0.001078        | 0.001334        |
| Ozone layer                   | mPt        | 0.000496       | 7.16E-06        | 0          | 2.25E-05        | 2.54E-05        | 0.000111        | 0.00033         |
| Ecotoxicity                   | mPt        | 0.185056       | 0.00207         | 0          | 0.006906        | 0.00566         | 0.020974        | 0.149447        |
| Acidification/ Eutrophication | mPt        | 2.563247       | 0.097809        | 0          | 0.328023        | 0.263612        | 0.874739        | 0.999065        |
| Land use                      | mPt        | 12.50825       | 0.000654        | 0          | 0.001961        | 2.4E-05         | 12.46092        | 0.044692        |
| Minerals                      | mPt        | 0.0017         | 5.41E-05        | 0          | 0.000182        | 0.000147        | 0.001327        | -8.9E-06        |
| Fossil fuels                  | mPt        | 26.98409       | 1.529809        | 0          | 5.121496        | 4.199156        | 1.669802        | 14.46383        |
| <b>Total</b>                  | <b>mPt</b> | <b>81.2648</b> | <b>3.309266</b> | <b>0</b>   | <b>11.08844</b> | <b>9.000032</b> | <b>22.03233</b> | <b>35.83472</b> |

Supplemental Table S5 - Alfalfa's impacts in the second and third year.

| Impact category               | Unit       | Total           | forage harvest  |
|-------------------------------|------------|-----------------|-----------------|
| Carcinogens                   | mPt        | 0.021918        | 0.021918        |
| Resp. organics                | mPt        | 0.001923        | 0.001923        |
| Resp. inorganics              | mPt        | 1.592847        | 1.592847        |
| Climate change                | mPt        | 0.309233        | 0.309233        |
| Radiation                     | mPt        | 9.43E-05        | 9.43E-05        |
| Ozone layer                   | mPt        | 1.22E-05        | 1.22E-05        |
| Ecotoxicity                   | mPt        | 0.002431        | 0.002431        |
| Acidification/ Eutrophication | mPt        | 0.111996        | 0.111996        |
| Land use                      | mPt        | 1.2E-05         | 1.2E-05         |
| Minerals                      | mPt        | 6.25E-05        | 6.25E-05        |
| Fossil fuels                  | mPt        | 1.794924        | 1.794924        |
| <b>Total</b>                  | <b>mPt</b> | <b>3.835453</b> | <b>3.835453</b> |

Supplemental Table S6 - Alfalfa's impacts in the fourth year.

| Impact category               | Unit       | Total           | forage harvest  |
|-------------------------------|------------|-----------------|-----------------|
| Carcinogens                   | mPt        | 0.038814        | 0.038814        |
| Resp. organics                | mPt        | 0.003386        | 0.003386        |
| Resp. inorganics              | mPt        | 2.822342        | 2.822342        |
| Climate change                | mPt        | 0.547855        | 0.547855        |
| Radiation                     | mPt        | 0.000165        | 0.000165        |
| Ozone layer                   | mPt        | 2.06E-05        | 2.06E-05        |
| Ecotoxicity                   | mPt        | 0.00429         | 0.00429         |
| Acidification/ Eutrophication | mPt        | 0.198472        | 0.198472        |
| Land use                      | mPt        | 2E-05           | 2E-05           |
| Minerals                      | mPt        | 0.000111        | 0.000111        |
| Fossil fuels                  | mPt        | 3.173188        | 3.173188        |
| <b>Total</b>                  | <b>mPt</b> | <b>6.788664</b> | <b>6.788664</b> |

**Supplemental Table S7 - Comparison between the two crops in the characterization phases.**

| Impact category               | Unit       | 1 m3 of biogas from<br>alfalfa | 1 m3 of biogas from<br>maize |
|-------------------------------|------------|--------------------------------|------------------------------|
| Carcinogens                   | DALY       | 3.51E-08                       | 6.12E-08                     |
| Resp. organics                | DALY       | 6.42E-10                       | 5.58E-10                     |
| Resp. inorganics              | DALY       | 8.37E-07                       | 6.66E-07                     |
| Climate change                | DALY       | 1.41E-07                       | 1.34E-07                     |
| Radiation                     | DALY       | 7.38E-11                       | 2.93E-10                     |
| Ozone layer                   | DALY       | 1.19E-11                       | 6.93E-11                     |
| Ecotoxicity                   | PAF*m2yr   | 0.027776                       | 0.188439                     |
| Acidification/ Eutrophication | PDF*m2yr   | 0.042702                       | 0.023722                     |
| Land use                      | PDF*m2yr   | 0.178894                       | 0.00891                      |
| Minerals                      | MJ surplus | 7.31E-05                       | 8.26E-05                     |
| Fossil fuels                  | MJ surplus | 1.273477                       | 1.441948                     |



Supplemental Table S8 - Comparison between the two crops in the single point phases.

| Impact category               | Unit      | 1 m3 of biogas from alfalfa | 1 m3 of biogas from maize |
|-------------------------------|-----------|-----------------------------|---------------------------|
| Carcinogens                   | Pt        | 1.600349                    | 2.793517                  |
| Resp. organics                | Pt        | 0.029294                    | 0.02549                   |
| Resp. inorganics              | Pt        | 38.21163                    | 30.37804                  |
| Climate change                | Pt        | 6.441897                    | 6.113811                  |
| Radiation                     | Pt        | 0.00337                     | 0.013383                  |
| Ozone layer                   | Pt        | 0.000541                    | 0.003164                  |
| Ecotoxicity                   | Pt        | 0.194208                    | 1.317566                  |
| Acidification/ Eutrophication | Pt        | 2.985711                    | 1.658623                  |
| Land use                      | Pt        | 12.5083                     | 0.623006                  |
| Minerals                      | Pt        | 0.001936                    | 0.00219                   |
| Fossil Fuels                  | Pt        | 33.74713                    | 38.21163                  |
| <b>Total</b>                  | <b>Pt</b> | <b>95.72437</b>             | <b>81.14042</b>           |

Supplemental Table S9 - Damage category values for the damage assessment phase.

| Damage category   | Unit          | 1 m3 of biogas from<br>alfalfa | 1 m3 of biogas from<br>maize |
|-------------------|---------------|--------------------------------|------------------------------|
| Human Health      | DALY          | 1,01E-06                       | 8,62E-07                     |
| Ecosystem Quality | PDF*m2yr      | 0,224374                       | 0,051476                     |
| Resources         | MJ<br>surplus | 1,27355                        | 1,442031                     |

Supplemental Table S10 – Maize's impacts in a single year (IPCC 2013).

| Category | Unit            | Total    | forage<br>harvest | fertilization | harrowing | irrigation | occupation | plowing | weeding  | sowing   |
|----------|-----------------|----------|-------------------|---------------|-----------|------------|------------|---------|----------|----------|
| IPCC     | Kg              |          |                   |               |           |            |            |         |          |          |
| GWP      | CO <sub>2</sub> | 0,160263 | 0,011081          | 0,098891      | 0,004149  | 0,011022   | 0          | 0,01384 | 0,016122 | 0,005158 |
| 100y     | eq              |          |                   |               |           |            |            |         |          |          |

Supplemental Table S11– Alfalfa's impacts in the first year (IPCC 2013).

| Categor<br>y | Uni<br>t        | Total   | harrowin<br>g | occupatio<br>n | plowin<br>g | forage<br>harvest | sowin<br>g | fertilizatio<br>n |
|--------------|-----------------|---------|---------------|----------------|-------------|-------------------|------------|-------------------|
| IPCC         | Kg              | 0.54896 |               |                | 0.09448     | 0.07617           | 0.0564     |                   |
| GWP          | CO <sub>2</sub> | 5       | 0.028174      | 0              | 2           | 8                 | 1          | 0.293722          |
| 100y         | eq              |         |               |                |             |                   |            |                   |

**Supplemental Table S12 – Impact values for the characterization phase (IPCC 2013).**

| Category      | Unit                     | 1 m <sup>3</sup> of biogas from<br>alfalfa | 1 m <sup>3</sup> of biogas from<br>maize |
|---------------|--------------------------|--------------------------------------------|------------------------------------------|
| IPCC GWP 100y | Kg CO <sub>2</sub><br>eq | 0.671116                                   | 0.641053                                 |