

progetto di ricerca PRIN 2022 cod. 202288L9YN

ECOWHEATALY

Evaluation of policies for enhancing sustainable wheat production in Italy

Task 1.2

Life Cycle Assessment (LCA) setup

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machinery



fertilizers



pesticides



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Phases of LCA

According to ISO 14040 standard, LCA Analysis has to go through four phases:

- Goal and scope Definition
- inventory analysis
- impact assessment
- interpretation

We focus on inventory analysis and impact assessment because they are more technical.

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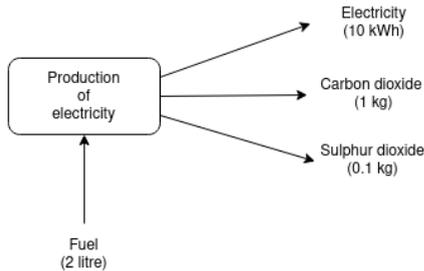
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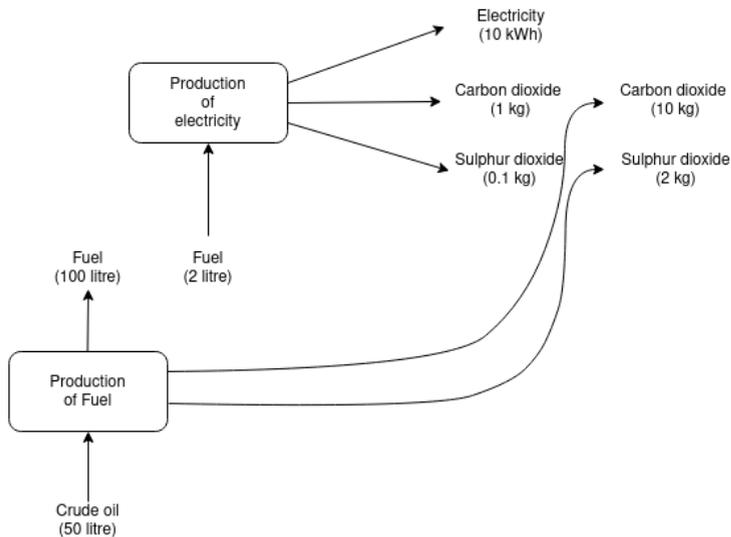


Life Cycle Inventory (LCI)

Unit process



A product system is made up of linked unit processes.



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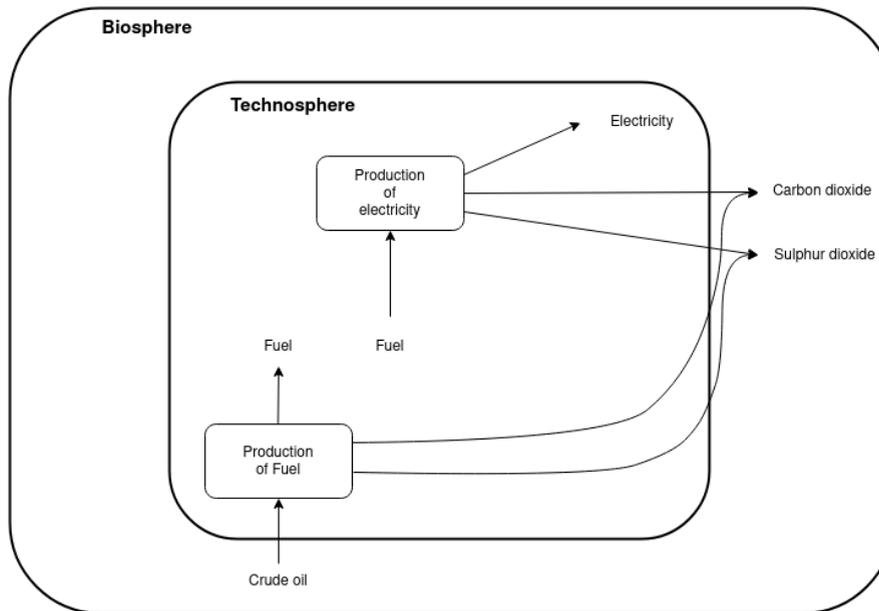
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LCI biosphere and technosphere



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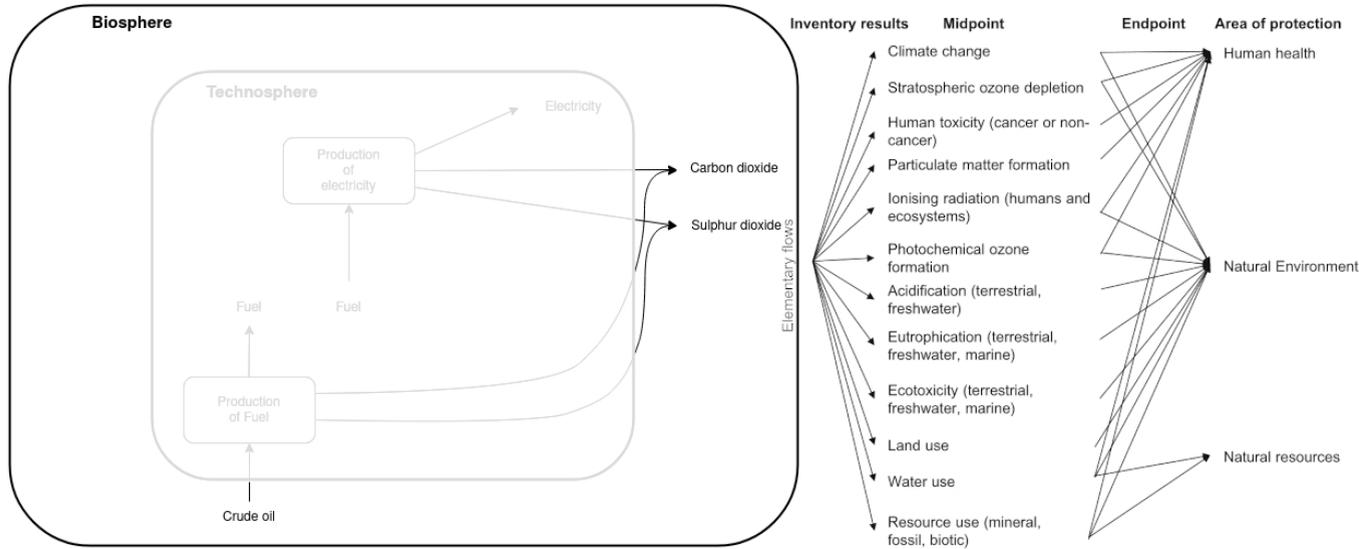
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Life Cycle Impact Assessment (LCIA)



- LCIA uses impact assessment methods.
- An assessment method links environmental flows to **impact categories** via **characterization factors** (CFs)
- Developed by institutions and researchers
- There are many assessment methods.

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ECOWHEATALY LCA

- Thecnosphere modeling: modeling wheat production process (identification of inputs and outputs according to data available in RICA)
- find third party LCI datasets for inputs
- choose LCA software; implement wheat production process; adapt third party LCI datasets
- perform LCI for wheat production
- choose impact categories and methods
- perform LCIA

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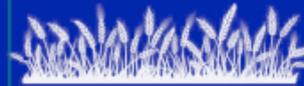
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RICA data

```
▼ Farm ID
  > count_in_farms_file(years)
  > geo
  ▼ years
    ▼ 2012
      > SAU(ha)
      > Produzione_Standard_Aziendale(Euro)
      > KW_Macchine
      ▼ colture
        ▼ Frumento tenero
          > produced_quantity(qt)
          > land_use(ha)
          > Ore_Macchina
          > fertilizzanti
          > fitofarmaci
        > Frumento duro
    > 2013
    > 2014
```

Inputs of the wheat production process:

- Time of machinery use
- quantity of fertilizers
- quantity of pesticides

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Machinery use third party process

- Federal LCA commons (set of freely available databases)
- database: University of Washington Design for Environment Laboratory/Field Crop Production
- dataset: **work; ag. tractors for growing win wheat, 2014 fleet, all fuels; 100-175HP - US-AR**
- contents: inputs and outputs of a agriculture tractor producing 1 megajoule of work employed in winter wheat production in Arizona.

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Machinery use (inputs and outputs)

Inputs/Outputs: work; ag. tractors for growing win wheat, 2014 fleet, all fuels; 100-175HP - US-AR

▼ Inputs

Flow	Category	Amount	Unit
CUTOFF diesel; for offroad use; at refinery; S%0.002	Manufacturing/Petroleum Products	0.06266	kg
CUTOFF equ. retirement; ag. tractors; 100-175HP	Water supply; sewerage, waste management and remediation activities/Wast...	8.08812E-7	Item(s)
CUTOFF gasoline; for offroad use; at refinery; RVP8, S%0.034, ETOH m%0.81b%0.087	Manufacturing/Petroleum Products	2.13973E-5	kg
CUTOFF local area trucking; class 6, average fuel	Transportation and Warehousing/Truck	0.00464	t*km
CUTOFF lubricating oil management; at farm	Manufacturing/Petroleum Products	2.60511E-5	kg
CUTOFF lubricating oil; for use in agricultural equipment; at refinery	Manufacturing/Petroleum Products	0.00013	kg
CUTOFF production; ag. tractors; 100-175HP	Agriculture, forestry and fishing/Support activities for crop production	8.08812E-7	Item(s)
CUTOFF spare part set; ag. tractors; 100-175HP	Agriculture, forestry and fishing/Support activities for crop production	8.08812E-7	Item(s)
CUTOFF storage; of farm equipment; at farm	Agriculture, forestry and fishing/Support activities for crop production	1.46032E-5	m2

▼ Outputs

Flow	Category	Amount	Unit
work; ag. tractors for growing win wheat, 2014 fleet, all fuels; 100-175HP	Agriculture, forestry and fishing/Support activities for crop production	1.00000	MJ
1,2,3,4,6,7,8-Heptachlorodibenzo-p-Dioxin	Emission to air unmapped/low population density unmapped	2.10937E-10	kg
1,2,3,4,6,7,8-Heptachlorodibenzofuran	Emission to air unmapped/low population density unmapped	5.86686E-11	kg
1,2,3,4,7,8,9-Heptachlorodibenzofuran	Emission to air unmapped/low population density unmapped	6.67971E-12	kg
1,2,3,4,7,8-Hexachlorodibenzo-p-Dioxin	Emission to air unmapped/low population density unmapped	8.96485E-12	kg
1,2,3,4,7,8-Hexachlorodibenzofuran	Emission to air unmapped/low population density unmapped	2.83447E-11	kg
1,2,3,6,7,8-Hexachlorodibenzo-p-Dioxin	Emission to air/low population density	1.75781E-11	kg
1,2,3,6,7,8-Hexachlorodibenzofuran	Emission to air unmapped/low population density unmapped	1.29200E-11	kg
1,2,3,7,8,9-Hexachlorodibenzo-p-Dioxin	Emission to air/low population density	3.22997E-11	kg
1,2,3,7,8,9-Hexachlorodibenzofuran	Emission to air unmapped/low population density unmapped	7.51465E-12	kg
1,2,3,7,8-Pentachlorodibenzo-p-Dioxin	Emission to air/low population density	6.37209E-12	kg
1,2,3,7,8-Pentachlorodibenzofuran	Emission to air unmapped/low population density unmapped	7.58074E-12	kg
2,2,4-Trimethylpentane	Emission to air unmapped/low population density unmapped	9.23560E-8	kg
2,3,4,6,7,8-Hexachlorodibenzofuran	Emission to air unmapped/low population density unmapped	1.87208E-11	kg
2,3,4,7,8-Pentachlorodibenzofuran	Emission to air unmapped/low population density unmapped	1.67872E-11	kg
2,3,7,8-Tetrachlorodibenzofuran	Emission to air unmapped/low population density unmapped	1.90067E-11	kg
Acenaphthene	Emission to air/low population density	1.12499E-8	kg
Acenaphthylene	Emission to air/low population density	9.47301E-9	kg
Acetaldehyde	Emission to air/low population density	6.64227E-6	kg
Acrolein	Emission to air/low population density	3.79395E-7	kg
Ammonia	Emission to air/low population density	0.00162	kg
Anthracene	Emission to air/low population density	5.39606E-11	kg
Arsenic	Emission to air/low population density	4.37077E-9	kg
Benz(a)anthracene	Emission to air/low population density	8.04994E-11	kg
Benzene	Emission to air/low population density	2.55064E-6	kg
Benzene, ethyl-	Emission to air/low population density	3.89857E-7	kg
Benzo(a)pyrene	Emission to air/low population density	4.00173E-11	kg

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Machinery use (process adaptation)

- We have to interface our data to the process.
- The process unit of measure is megajoule, however, we have hours of machinery use in RICA.
- Conversion:
1 Megajoule = 0.2778 Chilowattora
Therefore, a 100kw tractor used for 1 hour produces $100/0.2778=360$ megajoule

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Fertilizers in RICA

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 - > count_in_farms_file(years)
 - > geo
 - ▼ years
 - ▼ 2012
 - > SAU(ha)
 - > Produzione_Standard_Aziendale(Euro)
 - > KW_Macchine
 - ▼ colture
 - ▼ Frumento tenero
 - > produced_quantity(ql)
 - > land_use(ha)
 - > Ore_Macchina
 - ▼ fertilizzanti
 - > numero_items_in_file
 - > superficie fertilizzata(ha)
 - > azoto per ha(kg)
 - > fosforo per ha(kg)
 - > potassio per ha(kg)
 - > fitofarmaci
 - > Frumento duro
 - > 2013
 - > 2014

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Fertilisers in the literature

- The environmental effects of such mineral fertilizers is analyzed in Isherwood, K. F. (1998).

Mineral fertilizer use and the environment. Technical report, International Fertilizer Industry Association (IFA) and United Nations Environment Program (UNEP). <https://digitallibrary.un.org/record/468871>.

- Another interesting document concerning fertilizers is IFA and Systemiq (2022).

Reducing emissions from fertilizers use. Technical report, Systemiq for International Fertilizer Industry Association (IFA). <https://www.systemiq.earth/reducing-emissions-fertilizer/>.

The report points out that Nitrogen is the main responsible of emissions (see in particular chapter 1, paragraphs 6-11).

- To integrate Nitrogen fertilization in our LCA we build a process based on Brentrup et al (2004).

Environmental impact assessment of agricultural production systems using the life cycle assessment (LCA) methodology II. The application to N fertilizer use in winter wheat production systems. European Journal of Agronomy 20(3), 265–279.

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Fertilizers (inputs and outputs)

Appendix A: Emissions and consumption of resources per ha and ton of grain for the different production intensities

Emission/resource	Unit	Plot (N rate in kg N/ha)													
		N0 (0)		N1 (48)		N2 (96)		N3 (144)		N4 (192)		N5 (240)		N6 (288)	
		per ha	per t	per ha	per t	per ha	per t	per ha	per t	per ha	per t	per ha	per t	per ha	per t
Resources															
Phosphate rock	kg	48.41	23.39	114.8	23.86	169.3	23.81	202.9	23.79	219.9	23.78	221.5	23.9	219.6	24.11
Potash salt	kg	203.7	98.4	511.3	106.3	745	104.8	889.8	104.3	964.8	104.3	991.6	107	1018	111.8
Hard coal	kg	39.61	19.13	42.12	8.757	44.96	6.324	47.12	5.524	48.87	5.283	50.3	5.426	52.24	5.734
Lignite	kg	1.951	0.943	2.019	0.42	2.071	0.291	2.285	0.268	2.438	0.264	2.444	0.264	2.449	0.269
Heavy oil	kg	5.083	2.456	7.212	1.499	8.83	1.242	10.13	1.188	10.83	1.171	10.89	1.175	10.92	1.199
Light oil/diesel	kg	70.02	33.83	74.33	15.45	75.68	10.64	76.89	9.014	77.67	8.396	77.94	8.408	78.17	8.581
Natural gas	kg	4.404	2.128	45.88	9.539	86.97	12.23	127.7	14.97	167.7	18.13	207.1	22.34	246.4	27.05
Total energy	MJ	4371	2112	6686	1390	8851	1245	10967	1286	13006	1406	14958	1614	16916	1857
Land	m ² × year	10 000	4831	10 000	2079	10 000	1406	10 000	1172	10 000	1081	10 000	1079	10 000	1098
Emissions to air															
CH ₄	kg	0.0004	0.0002	0.0047	0.0010	0.0089	0.0013	0.0129	0.0015	0.0168	0.0018	0.0205	0.0022	0.0242	0.0027
CO	kg	0.012	0.006	0.036	0.008	0.058	0.008	0.074	0.009	0.086	0.009	0.095	0.01	0.103	0.011
CO ₂	kg	294.7	142.4	407.5	84.71	509	71.59	607.9	71.26	701.3	75.81	788.5	85.06	875.8	96.13
N ₂ O	kg	0.0000	0.0000	1.775	0.369	3.557	0.5	5.332	0.625	7.108	0.768	8.883	0.958	10.66	1.171
NH ₃	kg	0.0001	0.0000	1.178	0.245	2.356	0.331	3.534	0.414	4.712	0.509	5.89	0.635	7.069	0.776
Nox	kg	3.463	1.673	3.977	0.827	4.318	0.607	4.63	0.543	4.913	0.531	5.169	0.558	5.424	0.595
Particles/dust	kg	0.404	0.195	0.472	0.098	0.519	0.073	0.553	0.065	0.572	0.062	0.576	0.062	0.578	0.063
SO ₂	kg	1.612	0.779	2.042	0.425	2.366	0.333	2.58	0.303	2.701	0.292	2.739	0.296	2.766	0.304
NMVOC	kg	0.029	0.014	0.034	0.007	0.038	0.005	0.041	0.005	0.042	0.005	0.043	0.005	0.043	0.005
Emissions to water															
NO ₃ -N	kg	0	0	0	0	0	0	1.483	0.174	8.99	0.972	36.88	3.978	63.3	6.949
Ntot	kg	0	0	0.005	0.001	0.01	0.001	0.016	0.002	0.021	0.002	0.026	0.003	0.031	0.003
Ptot	kg	0.025	0.012	0.059	0.012	0.086	0.012	0.104	0.012	0.112	0.012	0.113	0.012	0.112	0.012
Emissions to soil															
Cd	kg	0.0012	0.0006	0.0030	0.0006	0.0044	0.0006	0.0052	0.0006	0.0057	0.0006	0.0057	0.0006	0.0057	0.0006

F. Brentrup et al. / Europ. J. Agronomy 20(2004) 265–279

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Also includes emissions from fertilizers production.



Fertilizers (to do)

What about Phosphorous (P) and Potassium (K)?

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Pesticides in RICA

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 - > count_in_farms_file(years)
 - > geo
 - ▼ years
 - ▼ 2012
 - > SAU(ha)
 - > Produzione_Standard_Aziendale(Euro)
 - > KW_Macchine
 - ▼ colture
 - ▼ Frumento tenero
 - > produced_quantity(ql)
 - > land_use(ha)
 - > Ore_Macchina
 - > fertilizzanti
 - ▼ fitofarmaci
 - > numero_items_in_file
 - ▼ Herbicides
 - > diserbante1
 - ▼ Insecticides
 - > insetticida1
 - > acaricida1
 - > anticrittogamico1
 - > geodisinfestante1
 - > repellente1
 - > molluschicida, nematocida, rodenticida1
 - ▼ Co-adjuvants
 - > coadiuvante1
 - > bagnante, coadiuvante1
 - > fitoregolatore1
 - > Frumento duro
 - > 2013
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Pesticides in RICA

- **toxicity classification:** 0=Attenzione manipolare con prudenza; 1=Molto Tossico (T+); 2=Tossico (T); 3=Nocivo (Xn); 4=Irritante (Xi).
- **type:** Acaricida; Anticrittogamico; Bagnante, coadiuvante; Coadiuvante; Diserbante; Fitoregolatore; Geodisinfestante; Insetticida; Molluschicida, nematocida, rodenticida.
- **applied quantity** per hectare.

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Problem with pesticides in RICA and solution

Problem: Impact assessment methods need the applied active ingredients which is not included in RICA.

Solution: Using type and toxicity level, retrieve active ingredients from Fitogest®+ database

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Pesticides active ingredients

After performing the matching we obtain the following table:

type	tox level	active ing	product	quantity	concentration	active ing per ha
acaricida	irritante	sali di potassio degli acidi grassi	flipper	4-10l/ha	479,8g/l	1920-4800g/ha
anticrittogamico	prudenza	zolfo	cosavet df edge	3-8 kg/ha	80%	2400-6400g/ha
anticrittogamico	irritante	protioconazolo	pecari 300	0.65l/ha	300g/l	195g/ha
anticrittogamico	nocivo	Tebuconazolo	ares 430 sc	0.58l/ha	430g/l	250g/ha
diserbante	prudenza	Glifosate	clean-up	1-4-6-12l/ha	360g/l	360-4320g/ha
diserbante	irritante	2,4 D (sale)	pimiento 600	0.6-1.2l/ha	600g/l	360-720g/ha
diserbante	nocivo	MCPA (sale)	erbitox m pro	1.6-2l/ha	500g/l	800-1000g/ha
Fitoregolatore	irritante	clormequat	stabilan	2-3.5l/ha	461g/l	922-1613.5g/ha
Fitoregolatore	nocivo	Trinexapac etile	moddus	0.5l/ha	250g/l	125g/ha
Insetticida	irritante	Deltametrina	antal	0.3-0.5l/ha	25g/l	7.5-12.5g/ha
Insetticida	nocivo	Deltametrina	antal	0.3-0.5l/ha	25g/l	7.5-12.5g/ha
Insetticida	tossico	Pirimicarb	aphox 50	260g/ha	50%	130g/ha
Molluscidica	prudenza	Fosfato ferrico	ferrex	6kg/ha	25g/kg	150g/ha
Molluscidica	irritante	Metaldeide	luma-kl	7kg/ha	50g/kg	350g/ha

This allows the application of the usetox Impact assessment method.

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LCA software

- Among the available LCA software we choose **Brightway**: a freely available python language software.
- It provides a Biosphere database, many impact assessment methods, and functions to perform LCA analysis.

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Example

- Suppose we are analyzing a farm using 900 megajoule of tractor power and 50kg of nitrogen fertilizers for each hectare of wheat.
- We want to evaluate the impact on climate change
- chosen method: IPCC 2013: climate change: global warming potential (GWP100)
- output: kg of CO_2 equivalent

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Wheat production process coding

```
import bw2data as bd
#create a new dataset
ecowheatlydb = bd.Database("ecowheatly")
ecowheatlydb.register()
#create a new process called wheat_prod
wheat_prod=ecowheatlydb.new_activity(code='EcoWheatly production',
    name="EcoWheatly production",unit = "ha")
#tell that 900 units of work of ag. tractor is used
wheat_prod.new_exchange(input=('usda_item','tractor_use'),amount=900,
    unit="megajoule",type='technosphere').save()
#tell that 50 kg Nitrogen is used
wheat_prod.new_exchange(input=('bentrup_item','application of N fertilizer'),
    amount=50,unit="kilogram",type='technosphere').save()
wheat_prod.save()
```

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Performing LCA computations

```
import bw2calc as bc
functional_unit={ecowheatalydb.get('EcoWheataly production'): 1}
method_key=('IPCC 2013', 'climate change', 'global warming potential (GWP100)')
lca=bc.LCA(functional_unit,method_key)
lca.lci()
lca.lcia()
```

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ECOWHEATALY LCA

RICA data

machinery



fertilizers



pesticides



Software

Example

process coding

computation

results

To do

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methods



LCA results

functional unit

```
{'EcoWheatly production' (ha, GLO, None): 1}
```

Applied Brightway2 Method: IPCC 2013: climate change: global warming potential (GWP100) that delivered 883.66 kg CO2-Eq

processes contribution

```
(701.51, 0.347, 'application of N fertilizer' (kilogram, None, 144 kg))
(182.14, 900.0, 'work; ag. tractors' (MJ, None, 1 megajoule))
(0.0, 1.0, 'EcoWheatly production' (ha, GLO, None))
```

EMISSION CONTRIBUTION #####

```
(490.24, 1.8513, 'Dinitrogen monoxide' (kilogram, None, ('air',)))
(389.94, 389.94, 'Carbon dioxide, fossil' (kilogram, None, ('air',
'low population density, long-term')))
(2.0280, 0.4992, 'Carbon monoxide, fossil' (kilogram, None, ('air',
'low population density, long-term')))
(1.1975, 0.0045, 'Dinitrogen monoxide' (kilogram, None, ('air',
'low population density, long-term')))
(0.1276, 0.0044, 'Methane, non-fossil' (kilogram, None, ('air',)))
(0.0640, 0.0256, 'Carbon monoxide, non-fossil' (kilogram, None, ('air',)))
(0.0511, 0.0017, 'Methane, fossil' (kilogram, None, ('air',
'low population density, long-term')))
```

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To dos

- Couple pesticides active ingredients to brightway biosphere database and apply usetox. Verify possibility to apply OLCA-pest.
- find more suitable third party LCI processes
- choose the set of impact categories and corresponding assessment methods
- perform clustering on the set of impact indicators
- building a web application where a farmer inputs machinery use, fertilizers and pesticides quantities and obtains the impact indicators

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Find more suitable LCI databases

- Il progetto «Italian Life Cycle Inventory Database of Agri-foods» (ILCIDAF), finanziato dal MUR (Progetto PRIN 2017), ha l'obiettivo di sviluppare una banca dati LCI italiana dei prodotti agroalimentari più significativi.

DATASET ESISTENTI

No. of datasets for each supply chain	Database					Total
	Agri-footprint v4.0	LCA FOOD DK	Ecoinvent v3.0	Agribalyse v3.0	WFLDB v3.5.1	
Wheat-based products (no. of total datasets)	236	48	23	50	64	421
Wheat-based products (no. of datasets related to Italian product systems)	6	0	0	0	3	9
Olive oil (no. of total datasets)	0	0	4	1	5	10
Olive oil (no. of datasets related to Italian product systems)	0	0	1	0	1	2
Wine (no. of total datasets)	0	0	2	12	15	29
Wine (no. of datasets related to Italian product systems)	0	0	0	0	1	1
Citrus fruit (no. of total datasets)	0	0	18	21	33	72
Citrus fruit (no. of datasets related to Italian product systems)	0	0	0	0	0	0
Total datasets per database	236	48	47	84	117	532
Total Italian datasets per database	6	0	1	0	5	12

From the presentation: Giacomo Falcone (Università di Reggio Calabria) meeting “Il contributo della valutazione LCA nel settore agroalimentare” Milano, 5 dicembre 2022.

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Choose Methods

```

>>> len(bd.methods)
763
>>> for mt in bd.methods:
...     print(mt)
...
('CML v4.8 2016 no LT', 'acidification no LT', 'acidification (incl. fate, average Europe total, A&B) no LT')
('CML v4.8 2016 no LT', 'climate change no LT', 'global warming potential (GWP100) no LT')
('CML v4.8 2016 no LT', 'ecotoxicity: freshwater no LT', 'freshwater aquatic ecotoxicity (FAETP inf) no LT')
('CML v4.8 2016 no LT', 'ecotoxicity: marine no LT', 'marine aquatic ecotoxicity (MAETP inf) no LT')
('CML v4.8 2016 no LT', 'ecotoxicity: terrestrial no LT', 'terrestrial ecotoxicity (TETP inf) no LT')
('CML v4.8 2016 no LT', 'energy resources: non-renewable no LT', 'abiotic depletion potential (ADP): fossil fuels no LT')
('CML v4.8 2016 no LT', 'eutrophication no LT', 'eutrophication (fate not incl.) no LT')
('CML v4.8 2016 no LT', 'human toxicity no LT', 'human toxicity (HTP inf) no LT')
('CML v4.8 2016 no LT', 'material resources: metals/minerals no LT', 'abiotic depletion potential (ADP): elements (ultimate reserves) no LT')
('CML v4.8 2016 no LT', 'ozone depletion no LT', 'ozone layer depletion (ODP steady state) no LT')
('CML v4.8 2016 no LT', 'photochemical oxidant formation no LT', 'photochemical oxidation (high NOx) no LT')
('CML v4.8 2016', 'acidification', 'acidification (incl. fate, average Europe total, A&B)')
('CML v4.8 2016', 'climate change', 'global warming potential (GWP100)')
('CML v4.8 2016', 'ecotoxicity: freshwater', 'freshwater aquatic ecotoxicity (FAETP inf)')
('CML v4.8 2016', 'ecotoxicity: marine', 'marine aquatic ecotoxicity (MAETP inf)')
('CML v4.8 2016', 'ecotoxicity: terrestrial', 'terrestrial ecotoxicity (TETP inf)')
('CML v4.8 2016', 'energy resources: non-renewable', 'abiotic depletion potential (ADP): fossil fuels')
('CML v4.8 2016', 'eutrophication', 'eutrophication (fate not incl.)')
('CML v4.8 2016', 'human toxicity', 'human toxicity (HTP inf)')
('CML v4.8 2016', 'material resources: metals/minerals', 'abiotic depletion potential (ADP): elements (ultimate reserves)')
('CML v4.8 2016', 'ozone depletion', 'ozone layer depletion (ODP steady state)')
('CML v4.8 2016', 'photochemical oxidant formation', 'photochemical oxidation (high NOx)')
('Crustal Scarcity Indicator 2020', 'material resources: metals/minerals', 'crustal scarcity potential (CSP)')
('Cumulative Energy Demand (CED)', 'energy resources: non-renewable', 'energy content (HHV)')
('Cumulative Energy Demand (CED)', 'energy resources: non-renewable, biomass', 'energy content (HHV)')
('Cumulative Energy Demand (CED)', 'energy resources: non-renewable, fossil', 'energy content (HHV)')
('Cumulative Energy Demand (CED)', 'energy resources: non-renewable, nuclear', 'energy content (HHV)')
('Cumulative Energy Demand (CED)', 'energy resources: renewable', 'energy content (HHV)')
('Cumulative Energy Demand (CED)', 'energy resources: renewable, biomass', 'energy content (HHV)')
('Cumulative Energy Demand (CED)', 'energy resources: renewable, geothermal', 'energy content (HHV)')
('Cumulative Energy Demand (CED)', 'energy resources: renewable, geothermal, solar, wind', 'energy content (HHV)')
('Cumulative Energy Demand (CED)', 'energy resources: renewable, solar', 'energy content (HHV)')
('Cumulative Energy Demand (CED)', 'energy resources: renewable, water', 'energy content (HHV)')
('Cumulative Energy Demand (CED)', 'energy resources: renewable, wind', 'energy content (HHV)')
('Cumulative Energy Demand (CED)', 'total', 'energy content (HHV)')
('Cumulative Exergy Demand (CExD)', 'energy resources: non-renewable', 'exergy content')
('Cumulative Exergy Demand (CExD)', 'energy resources: non-renewable, biomass', 'exergy content')
('Cumulative Exergy Demand (CExD)', 'energy resources: non-renewable, fossil', 'exergy content')
('Cumulative Exergy Demand (CExD)', 'energy resources: non-renewable, nuclear', 'exergy content')
('Cumulative Exergy Demand (CExD)', 'energy resources: renewable', 'exergy content')
('Cumulative Exergy Demand (CExD)', 'energy resources: renewable, biomass', 'exergy content')
('Cumulative Exergy Demand (CExD)', 'energy resources: renewable, solar', 'exergy content')
    
```

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