LIFE CYCLE ASSESSMENT FOR COMPARISON OF ALTERNATIVE MANAGEMENT METHODS FOR PHOSPHOGYPSUM WASTE

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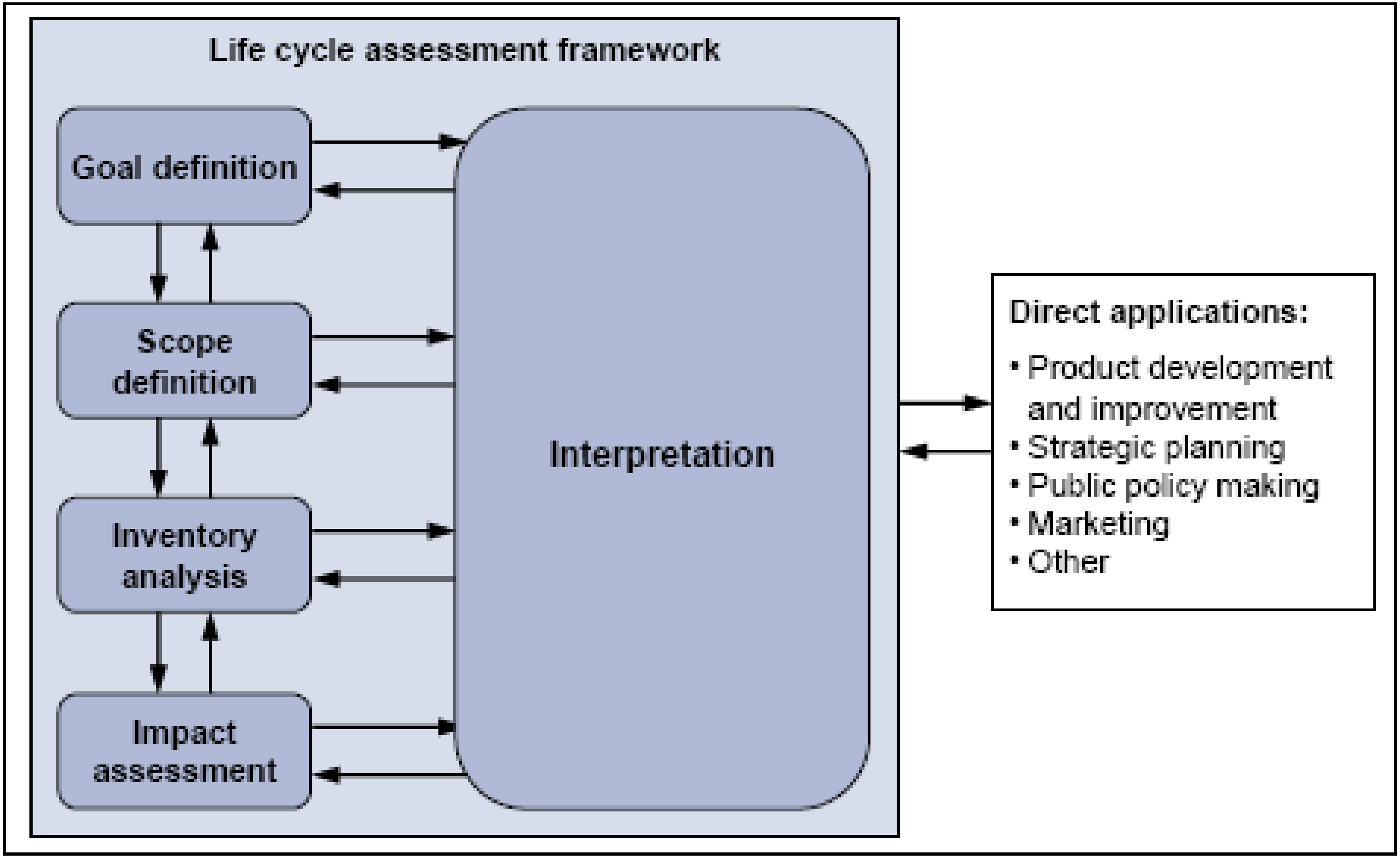
LIFE CYCLE ASSESSMENT (LCA)

LCA is a technique, which addresses the environmental aspects and potential environmental impacts throughout the life cycle of a product, from raw material acquisition through production, use, end-of-life treatment and disposal (SETAC, 2010).

LIFE CYCLE ASSESSMENT (LCA)

- LCA includes input of raw materials and energy and output of products, waste and emissions.
- LCA should be conducted according to ISO 14044 standards (ISO, 2006) and the most recent framework from the International Reference Life Cycle Data System (ILCD) Handbook (EC, 2010).

FRAMEWORK FOR LCA (ISO, 2006)



PHOSPHOGYPSUM (PG)

- PG is a waste byproduct from phosphate rock processing, for production of phosphoric acid used in fertilizer industry:

$$Ca_5F(PO_4)_3+5H_2SO_4+10H_2O \rightarrow$$
$$3H_3PO_4+\mathbf{5CaSO_4.2H_2O}+HF$$

- 5 tn PG/tn of phosphoric acid
- Annual world PG waste production: 100 – 280 Mtn
- Annual PG waste production in Greece: 1Mt

PG COMPOSITION

- Mainly gypsum (**$CaSO_4.2H_2O$**)
- Phosphates <1% [H_3PO_4, $Ca(H_2PO_4)_2.H_2O$, $CaHPO_4.2H_2O$ and $Ca_3(PO_4)_2$]
- Residual acids
- Fluorides (NaF, CaF_2, Na_3AlF_6, Na_3FeF_6 and Na_2SiF_6)
- Trace metals (Cd, Zn, Cu, Cr)
- Organic matter (amines, ketones adhered to gypsum crystals)
- Naturally occurring radionuclides (Ra, U, Th)

CURRENT MANAGEMENT

- Disposal in stacks (85%)
- Valorization (15%)
  - Building materials
  - Soil amendment
  - Portland cement
  - Road construction

ENVIRONMENTAL IMPACT FROM STACKS

- Atmospheric pollution due to fluorides, toxic metals, radioactive dust, radon.
- Groundwater pollution due to phosphate, sulfate, acidity, trace metals, radionuclides.
- Surface runoff.
- Exposure of workers to radiation.
- Problems with geotechnical stack stability.
- Large disposal areas.

OVERALL OBJECTIVE

To assess the environmental impact of four alternative management methods for PG waste, using LCA, and select the one with the lowest environmental footprint.

ALTERNATIVE MANAGEMENT METHODS

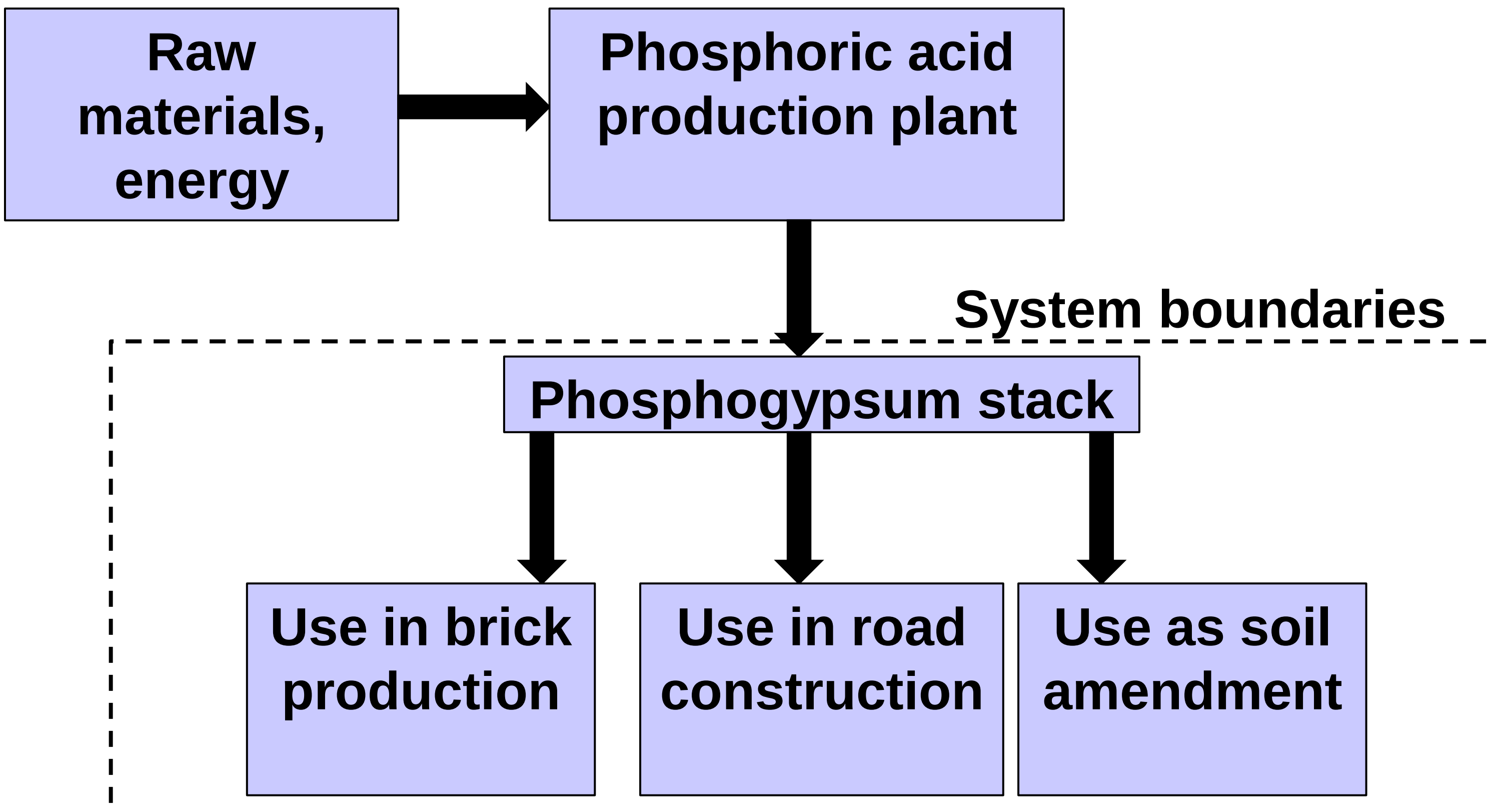
- Valorization of PG in brick production.
- Use of PG as soil amendment.
- Use of PG in road construction.
- Disposal of PG in a stack.

APPLICATION

- The functional unit of LCA will be the management of 1 tn of PG, taken from a stack.
- Limitation: Site-specific data from Greek PG production sites were not available. Therefore, assumptions were made and results of previously published studies were used as a basis to compute emission inventories.

SYSTEM BOUNDARIES

- PG withdrawal from the stack and application of alternative management methods for a period of 100 years.



LIFE CYCLE INVENTORY

- Emissions resulting from conventional material use were subtracted from emissions resulting from PG use.
- Raw material savings, due to partial replacement by PG waste.
- Emission modeling based on previously published papers.
- Data base: Ecoinvent 2.0 (Ecoinvent Centre, 2007) of Swiss Centre for Life Cycle Inventories.

CHEMICAL ANALYSIS OF NORTH AFRICAN PG

Component	%	Trace element	ppm	Trace element	ppm
SiO_2	0.86±0.01	Ba	98±23	Sc	4.7±0.7
Al_2O_3	0.19±0.001	Cd	6±1	Se	<1.75
Fe_2O_3	0.21±0.01	Cr	20±2	Sr	709±115
CaO	38.14±1.70	Cu	21±2	Th	4±0.64
SO_3	48.12±9.04	Ga	1±0.2	Ud	8.3±1.8
K_2O	0.01±0.001	La	86±19	V	4.75±0.63
Na_2O	0.17±0.01	Nb	1±0.2	Y	144±38
P_2O_5	0.69±0.01	Ni	<1	Zn	8±1
TiO_2	0.01±0.0004	Pb	6.2±1.7	Zr	6.2±0.8
F^-	0.15	Rb	2±0.1		
LOI	22				

RADIONUCLIDE CONCENTRATION (Bq/kg)

Radionuclide	North African PG	Nea Karvali, Greece
^{238}U	100	35±18
^{226}Ra	785	515±150
^{210}Pb	827	-

USE OF PG IN BRICK PRODUCTION

USE OF PG IN BRICK PRODUCTION

- Production of PG bricks (1 tn PG→4 tn bricks) and construction of an external house wall.
- Replacement of 0.2 tn clay and 0.8 tn sand.
- Additional amount of water (51 L).
- Additional transport distance 10 km.
- Reduced firing temperature (1000→830^{o}C).
- Fuel savings (44.5 kg pet-coke/tn PG added).
- Air emissions during brick production.
- Air radioactive emissions during wall life cycle.
- No liquid emissions.

USE OF PG AS SOIL AMENDMENT

USE OF PG AS SOIL AMENDMENT

- Use of PG to correct calcium levels in agricultural land.
- It replaces 1 tn of conventional gypsum and saves 6.2 kg of P_2O_5.
- Same transport distance.
- Emission of radioactive dust to the atmosphere.
- Liquid emissions based on HELP model.
- Leaching of heavy metals, radium, fluoride and sulfate.

USE OF PG IN ROAD CONSTRUCTION

USE OF PG IN ROAD CONSTRUCTION

- Use of PG to replace clay in secondary road construction.
- Replacement of 1 tn of clay.
- Additional transport distance 10 km.
- Radioactive dust emission.
- Leaching of fluoride, heavy metals, ^{226}Ra, sulfate and phosphate was estimated, based on Rutherford et al. (1995).

DISPOSAL OF PG IN A STACK

DISPOSAL OF PG IN A STACK

- Most common way of PG management.
- Stack height chosen was 0.5 m, occupying a land area equal to 1,538 m^2.
- Estimated air emissions included hydrogen fluoride (HF), silicon tetrafluoride (SiF_4), radioactive dust and radon (^{222}Rn).
- Estimated liquid emissions were based on the L/S ratio and included fluoride, trace metals, sulfate anions, P_2O_5 and radon.

INPUT DATA-BRICK PRODUCTION

Avoided products-energy		
Clay	-0,2 (tn)	Clay, at mine/CH U
Sand	-0,8 (tn)	Sand, at mine/CH U
Pet-coke	-44,5 (kg)	Petroleum coke, at refinery/RER U
Resources-energy		
Water	0,051(tn)	Water, well, in ground
Transportation		
Lorry 3,3-16tn	10 (tkm)	Transport, lorry 3.5-16t, fleet average/RER U
Air emissions		
HF	1,417 (kg)	Hydrogen fluoride (high pop.)
P_2O_5	0,0062 (tn)	Phosphorus pentoxide (high pop.)
Cd	$2,92 \cdot 10^{-3}$ (kg)	Cadmium (high pop.)
Cr	$3,6 \cdot 10^{-3}$(kg)	Chromium (high pop.)
Cu	$11,77 \cdot 10^{-3}$(kg)	Copper (high pop.)
Zn	$6,26 \cdot 10^{-3}$(kg)	Zinc (high pop.)
Pb	$2,13 \cdot 10^{-3}$(kg)	Lead (high pop.)
^{222}Rn	370,7 (Bq)	Radon-222 (indoor)
^{238}U	35,79 (Bq)	Uranium-238 (high pop.)
^{226}Ra	526,6 (Bq)	Radium-226 (high pop.)

ASSESSMENT METHOD ECO-INDICATOR 99

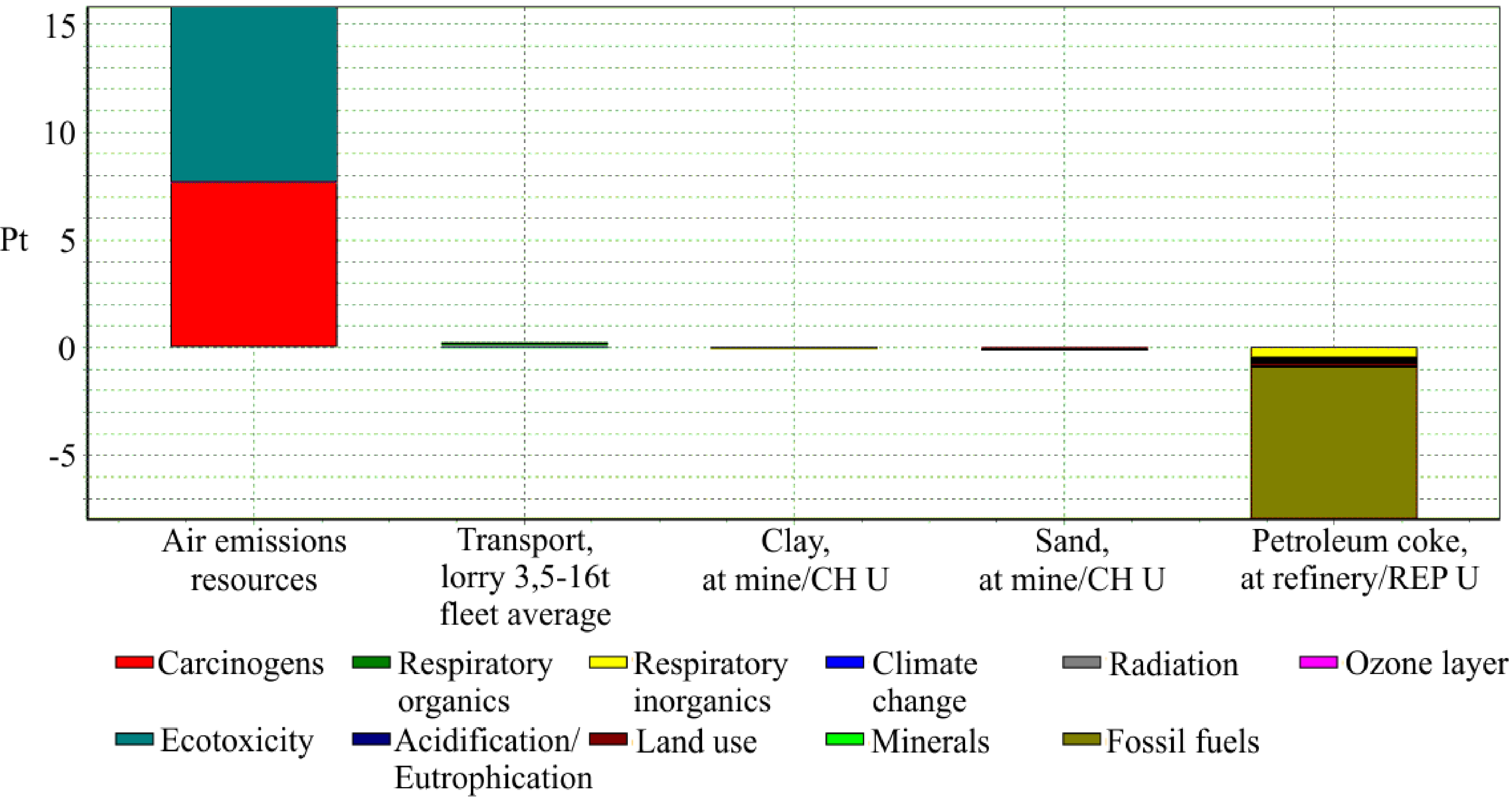
- Applies a non-metric unit, called “Points (Pt)”, to evaluate the impact of a process or a product and the final result is computed in a single score.
- Incorporates many European data and this was the main reason for using it.
- The method computes the following impact categories: Carcinogens, respiratory organics, respiratory inorganics, climate change, radiation, ozone layer, ecotoxicity, acidification/eutrophication, land use, minerals and fossil fuels.

ECO-INDICATOR 99

- The method considers three damage categories, namely human health, ecosystem quality and resources, which were used for normalization and weighting.
- Damage categories were normalized on a European level (damage caused in one year by one European).
- Results can be computed from three different perpectives, namely the egalitarian, the hierarchist and the individualist perspective.
- Weighting from the egalitarian perspective (main perspective used) was 40% for human health, 40% for ecosystem quality and 20% for resources.

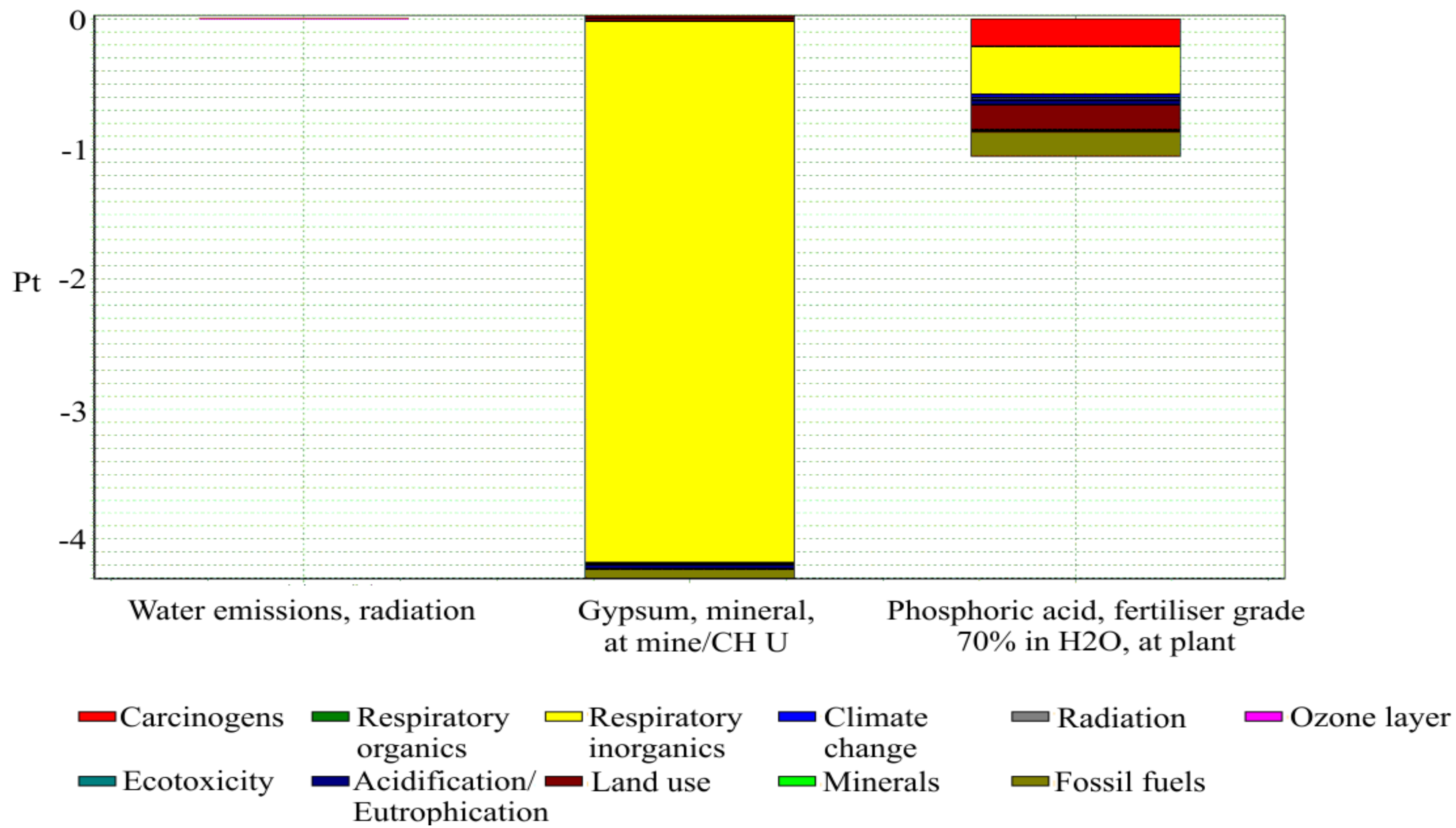
USE OF PG IN BRICK PRODUCTION

- Final score 7.882 Pt
- Higher than conventional environmental footprint



USE OF PG AS SOIL AMENDMENT

- Final score -5.334 Pt
- Lower than conventional environmental footprint

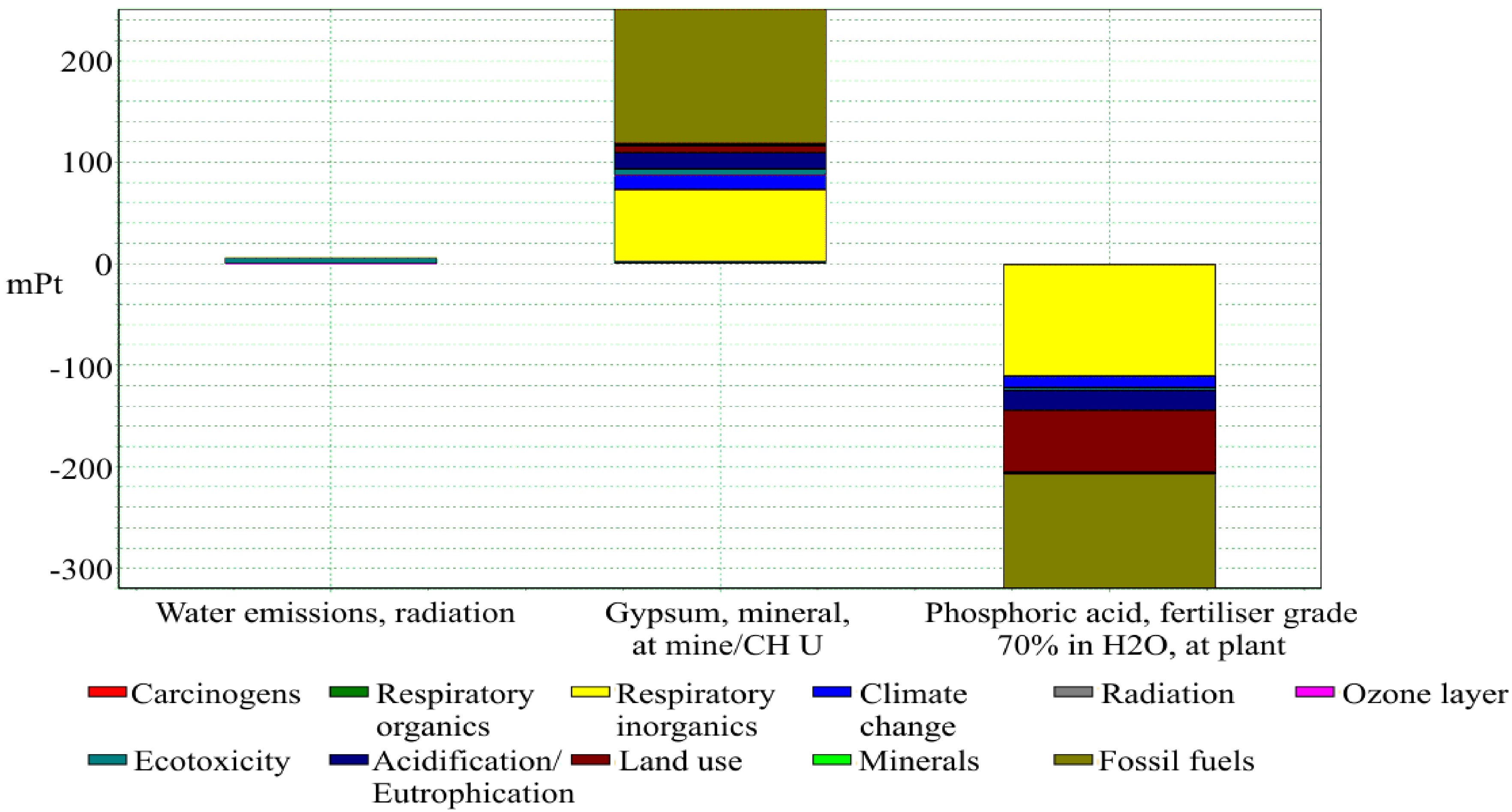


SENSITIVITY ANALYSIS WITH RESPECT TO NUMBER OF APPLICATIONS

Impact category	Unit	50 Applications	2 Applications
Total	***Pt***	***-5,3337***	***-5,3336***
Carcinogens	Pt	-0,2278	-0,2278
Respiratory organics	Pt	-0,0003	-0,0003
Respiratory inorganics	Pt	-4,5398	-4,5398
Climate change	Pt	-0,0319	-0,0319
Radiation	Pt	-0,0009	-0,0008
Ozone layer	Pt	0,0000	0,0000
Ecotoxicity	Pt	-0,0172	-0,0172
Acidification/eutrophication	Pt	-0,0656	-0,0656
Land use	Pt	-0,1645	-0,1645
Minerals	Pt	-0,0172	-0,0172
Fossil fuels	Pt	-0,2686	-0,2686

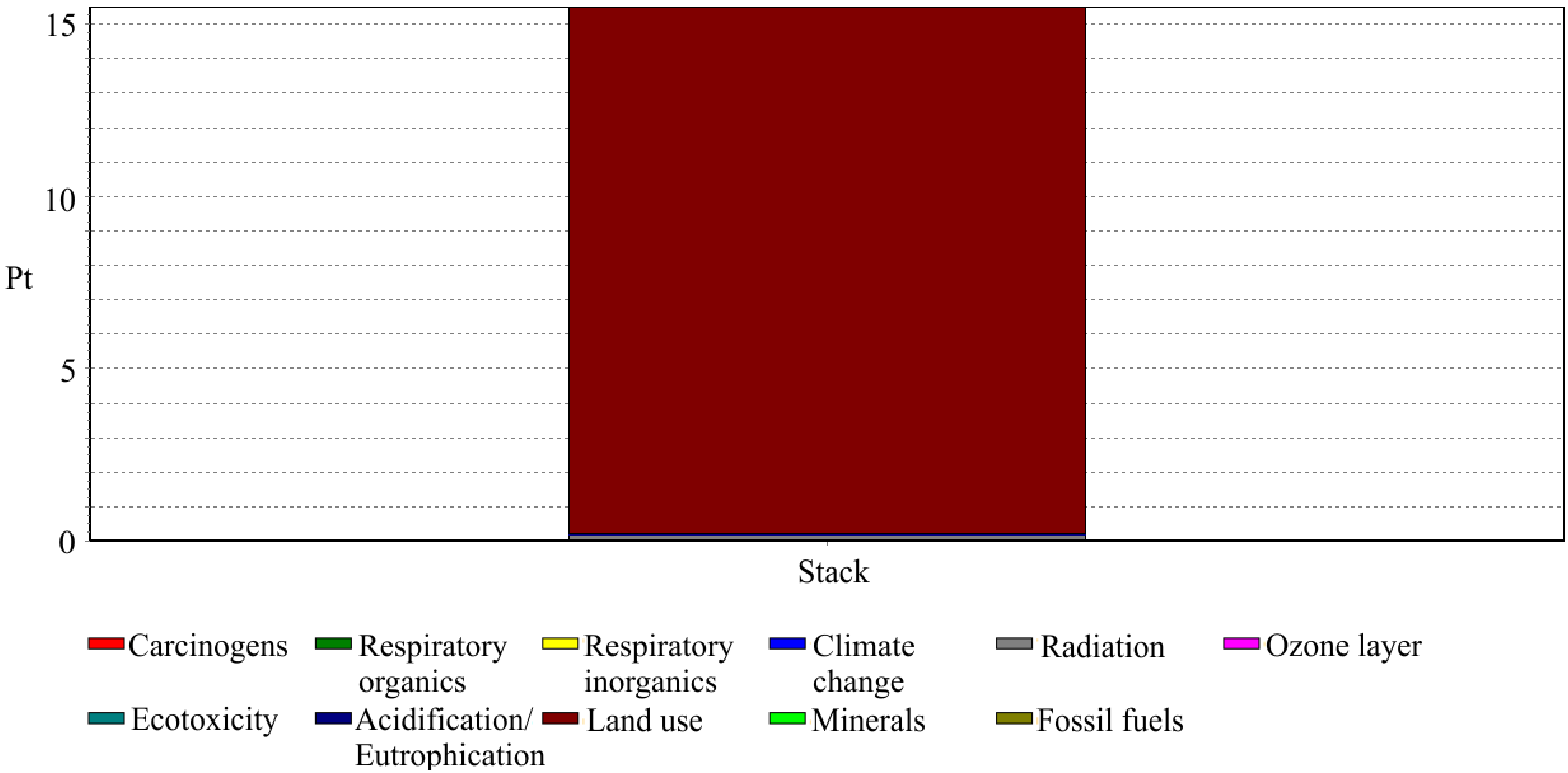
USE OF PG IN ROAD CONSTRUCTION

- Final score -0.06352 Pt
- Lower than conventional environmental footprint



DISPOSAL OF PG IN A STACK

- Final score 15.484 Pt



EFFECT OF PERSPECTIVE

Perspective	RANK			
	1st	2nd	3rd	4th
Egalitarian	Use as soil amendment	Use in road construction	Brick production	Stack disposal
Hierarchist	Use as soil amendment	Use in road construction	Brick production	Stack disposal
Individualist	Use as soil amendment	Use in road construction	Brick production	Stack disposal

EFFECT OF STACK HEIGHT (5m)

Perspective	RANK			
	1st	2nd	3rd	4th
Individualist	Use as soil amendment	Use in road construction	Stack disposal **(5m)**	Brick production

NEGLECT MATERIALS TRANSPORTATION

Perspective	RANK			
	1st	2nd	3rd	4th
Egalitarian	Use as soil amendment	Use in road construction	Brick production	Stack disposal **(0,5m)**

ASSESSMENT WITH METHOD CML 2 Baseline 2000

Impact category	RANK			
	1st	2nd	3rd	4th
Acidification	Brick production	Use as soil amendment	Use in road construction	Stack disposal
Eutrophication	Use as soil amendment	Use in road construction	Stack disposal	Brick production

CONCLUSIONS

- PG waste valorization to replace sand and clay in brick production has a higher environmental footprint than the conventional brick production method and, therefore, it is not recommended.
- Use of PG waste as soil amendment to correct calcium levels in agricultural land has a lower environmental footprint than using conventional gypsum and it is recommended.
- Use of PG waste as a sub base in road construction works has a lower environmental footprint than using conventional clay.

CONCLUSIONS

- The top ranked method is the use of PG waste as a soil amendment, with second the use of PG as a sub base in road works and third the use of PG waste in brick production.
- Disposal of PG waste in stacks, which is the most common management method, was ranked as the least preferred one.

CONCLUSIONS

- The number of PG applications as soil amendment do not affect the environmental footprint.
- Smaller stack occupation area results in smaller environmental footprint.
- Distance of materials transportation does not affect the final conclusion.