Life Cycle Assessment of Curcumin synthesis

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Introduction

Curcuma (*kum-kuma* in Sanskrit) is an Indian spice, derived from Curcuma plants.

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Rank	Name
Kingdom	Plantae
(Unranked)	Angiosperms
(Unranked)	Monocots
(Unranked)	Commelinids
Order	Zingiberales
Family	Zingiberaceae
Subfamily	Zingiberideae
Genus	Curcuma
Specie	**Curcuma longa**

Spice composition

- Curcuminoids, mixtures of derivatives of methane cinnamon as: curcumin, demethoxycurcumin and bisdemethoxycurcumin.

  → constitutes 3,14% (on average) of powdered turmeric.

- Volatile fraction: terpenic compounds as zingiberene, il curcumolo e il ß-turmerone.

Use and property

- Therapeutic purposes (Ayurvedic and traditional Chinese medicine)
- Dye, textile and food industry (E100)
- Spice food, as curcuma and in curry too.

Currently is increasingly asserting the use of turmeric for the synthesis of modern pharmaceutical and cosmetic products.

The pharmaceutical industry tends to isolate and exploit Curcumin considering the substance responsible for the healing properties of turmeric.

The main biologically active component of turmeric

Therapeutic effect antioxidant, anti-inflammatory and anti-cancer properties

(E. Ferrari et al 2011, J. Epstein et al. 2010, …).

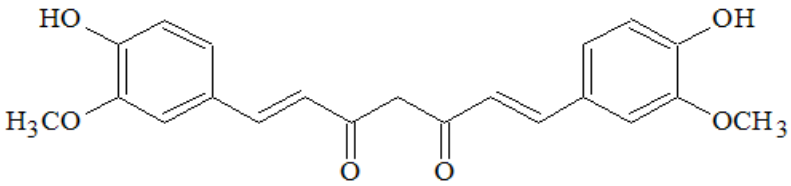
In order to prove and validate its therapeutic properties, intensive research activity is continuously performed at international level.

National level → University of Modena and Reggio Emilia

*E. Ferrari et al. Newly Synthesized Curcumin Derivatives: Crosstalk between Chemico-physical Properties and Biological Activity. J. Med. Chem. 54, 8066-8077, (2011)
J. Epstein et al. Curcumin as a therapeutic agent: the evidence from in vitro, animal and human studies. British Journal of Nutrition 103, 1545-1557, (2010)

Curcumin (*diferuloylmethan*)

- Chemical formula: $C_{21}H_{20}O_6$
- Structural formula:



- Curcumin production: two pathways

Extraction 1) Cultivation → processing of the roots → Curcumin extracted and concentrated

Synthesis 2) Chemical compounds (precursor compounds) → reaction

In collaboration with DIEF *(ex DIMA) and DSCG**, opt to assess the environmental burden of this reaction (green chemistry approach).

*Department of Engineering "Enzo Ferrari"
**Chemical and Geological Sciences Department

1. LCA of the synthesis of curcumin
2. LCA of the extraction of curcumin (two pathways)
3. **LCA comparative analysis** of the synthesis and direct extraction of curcumin

In progress

Goal and scope

1)Assessment of the potential impacts on environment and human health caused by the synthesis of Curcumin on a lab scale.

2)Valuation of the benefit obtained from Curcumin on cancer patients.

Studied system is the production of Curcumin.

Function of the system curative effect of a cancer symptom (cancer cachexia).

Functional unit 1g of Curcumin produced in lab (30h).

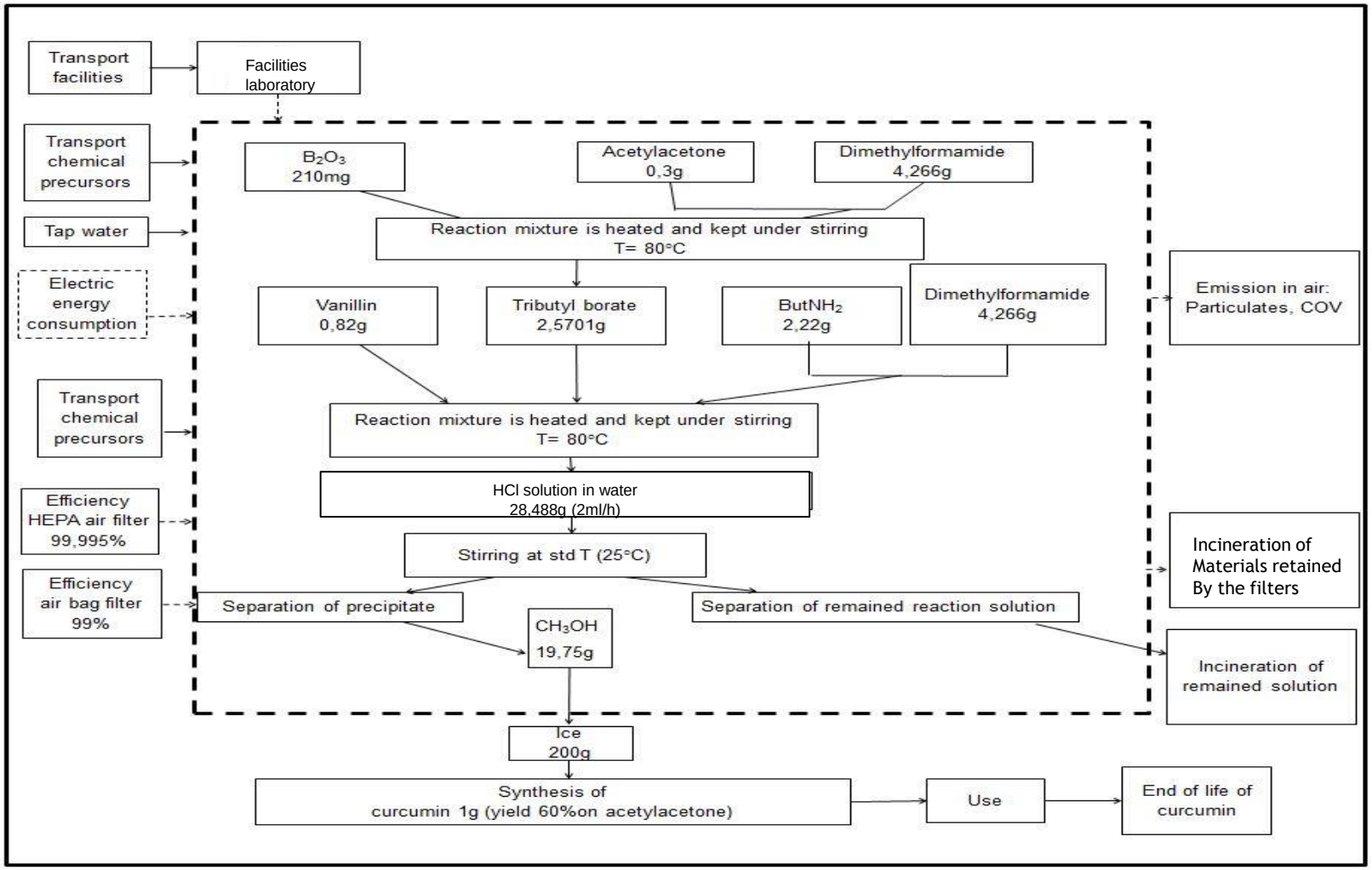
System boundaries all the stages of the product‘s life from-cradle-to-grave. In the processes are taking into account the technological solutions aimed at minimizing emissions in different environmental compartments, both produced in the laboratory (indoor) that ecosystem (outdoor).

Data quality Primary data, literature data, database (Ecoinvent, Unimore-LWG)

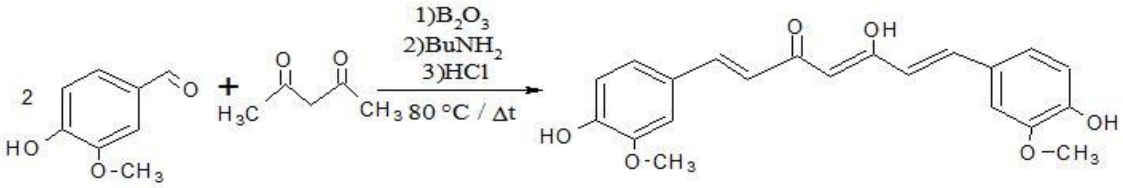
Software SimaPro7.3.2

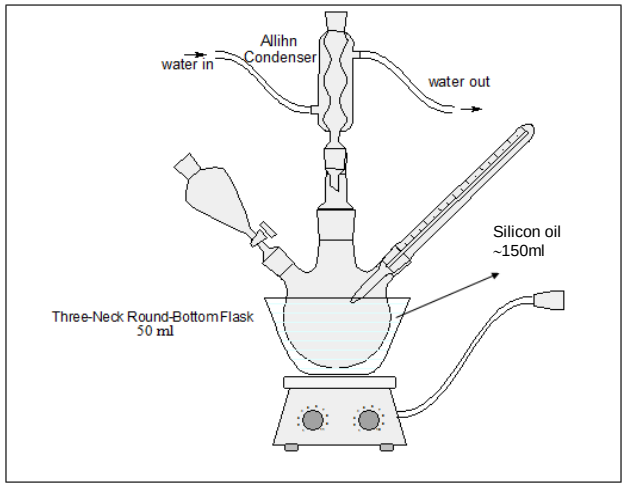
Valution method Impact 2002+ and USEtox.

Flow Chart 1g of Curcumin



Reaction





Reaction YIELD 60%

- 210 mg B2O3
- 0,3g Acetylacetone

  In 4,5ml DMF (N,N-Dimethylformamide)

  → 30min at 80°C
- 3ml Tributyl borate
- After 30min, 825g of Vanillin
- In 1 hour, added 300 µl of N-Butylamine (ButNH2) in 1,5ml of DMF
- 6hours of agitation at 80°C
- 24 ml di HCl 0,5 M
- Cooling at T°C amb → Orange precipitate
- After 1hour filtration and washing
- Water suspension for 1night(T°amb-agitation)
- Curcumin crystallized with 25ml of Methanol

Life Cycle Inventory

Precursor compounds

Acetylacetone
Tributyl borate
N-Butylamine
Vanillin

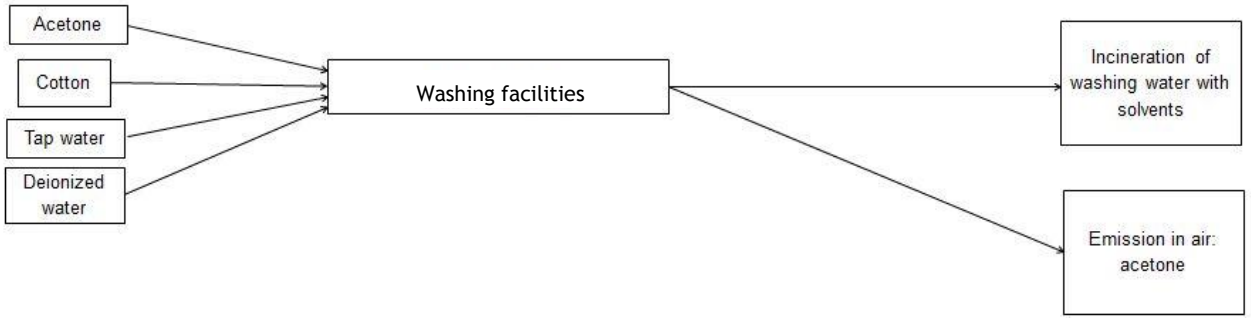
Vanillyl mandelic acid
Guaiacol
Glycolic acid
Glyoxylic acid

→ Synthesis reaction (Literature)
→ Transports
→ Air filtering plant
→ Electric en.
→ Thermal en.
→ Plant

Chemical plant, organics: 4E-10 p/kg (Approximation for infrastructure)
Electricity, medium voltage: 0,333 kWh
Natural gas, burned in industrial furnace > 100kW: 2MJ
Waste heat to air: 1,2MJ (calculated from electricity input)

Life Cycle Inventory

Laboratory facilities



Air filtering plant

Active carbon (Hsicheng et al 1998) chemical pathway H3PO4

→UNI EN 14175-7:2012 (Bag filter + Active carbon filter)→Chemical hood

Disposal

Non special waste (~RSU): HERA

Special waste - Contaminated $H_2O_{organic}$
- Dangerous solid waste

} CER cod. → UN cod. → SEAM Italia → incineration

*T. Hsishenget al. Preparation of activated carbon from bituminous coal with phosphoric acid activation, Carbon Vol. 36, No. 9, 1387:1395. Elsevier Science Ltd, 1998.

Life Cycle Impact Assessment

Valuation method

IMPACT 2002+ - USEtox

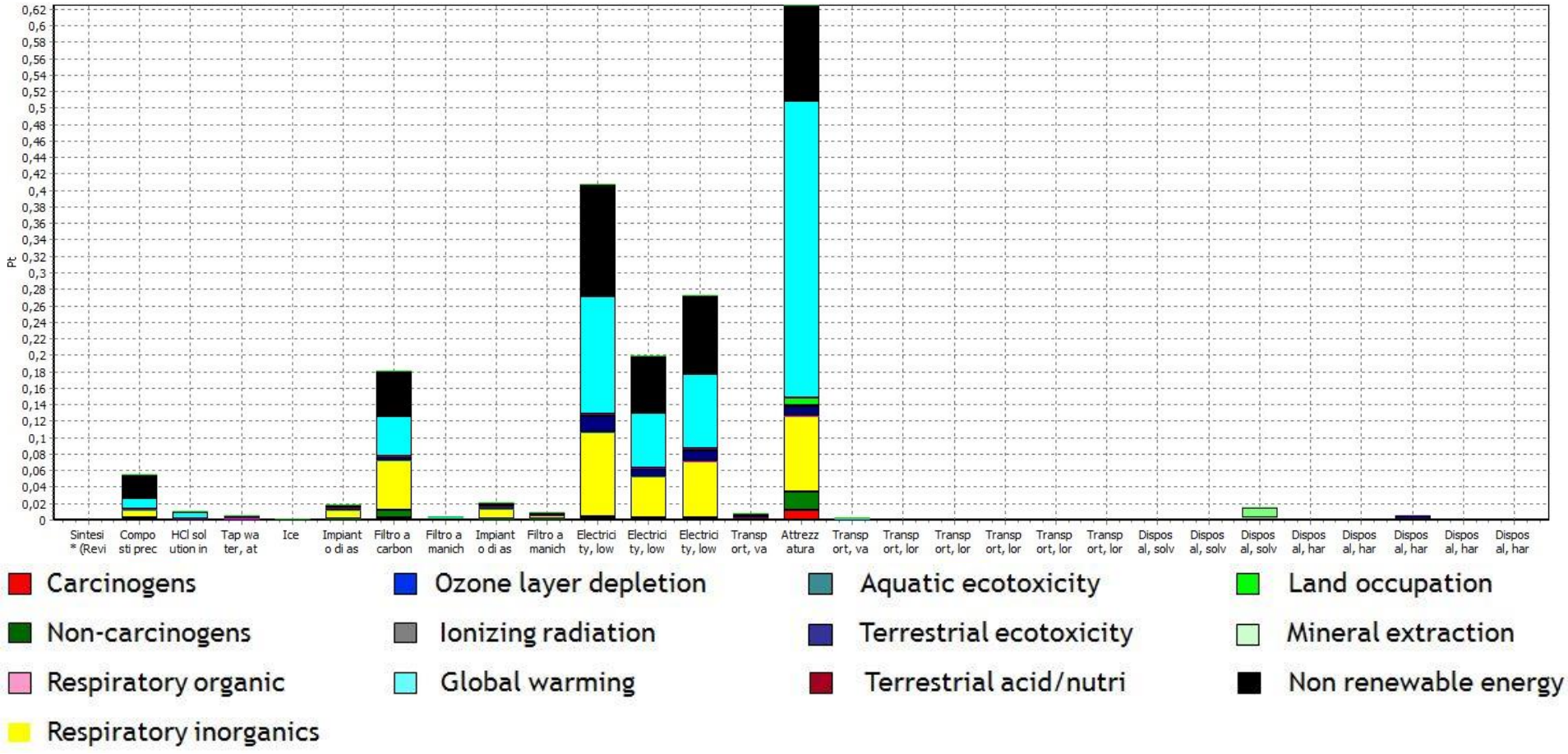
New indicator
Human health anticancer benefit cachexia

- 0,36g/die Curcumin per 30days → annul cachexia (+4% mass) (He Z.Y. et al. 2011).
- Laviano et al. 2005: Cachexia-Curcumin, Δt_{life} patients with colorectal cancer is inverse correlated to the increasing of cachexia.

Curcumin dose to annul cachexia: 0,36g/die*30gg
For an annual therapy: 0,36g/die*30gg*(365gg /30gg)= 131,4g

Δt_{life} increasing

Analysis of 1kg of Curcumin



Analysis of 1kg of Curcumin

- Functional Unit: 1kg
- Total Damage: 1,84Pt
- Major process contribution:

34% Laboratory facilities (washing + disposal)

22% Electrical energy for synthesis

15% Electrical energy for chemical hood → **48% Energy supply**

11% Electrical energy for the laboratory

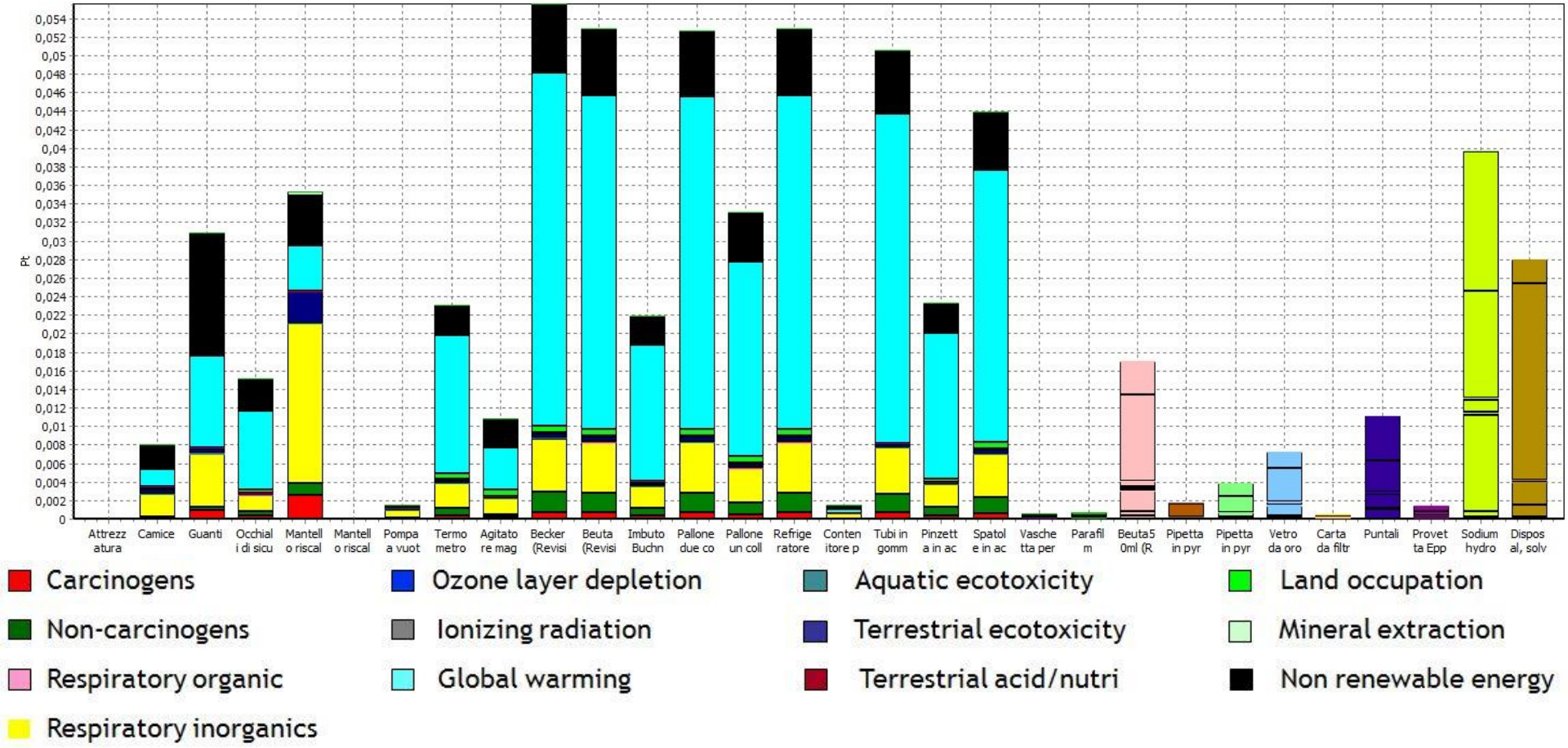
- Major impacts on:

41% Global Warming → CO_2

28% Non renewable energy → *Natural gas*

22% Respiratory inorganics → *PM 2,5*

Analysis of the laboratory facilities



Analysis of the laboratory facilities

- Functional Unit: 1p
- Total Damage: 5,45E-2Pt
- Major process contribution:

48% laboratory glassware

26% General tools

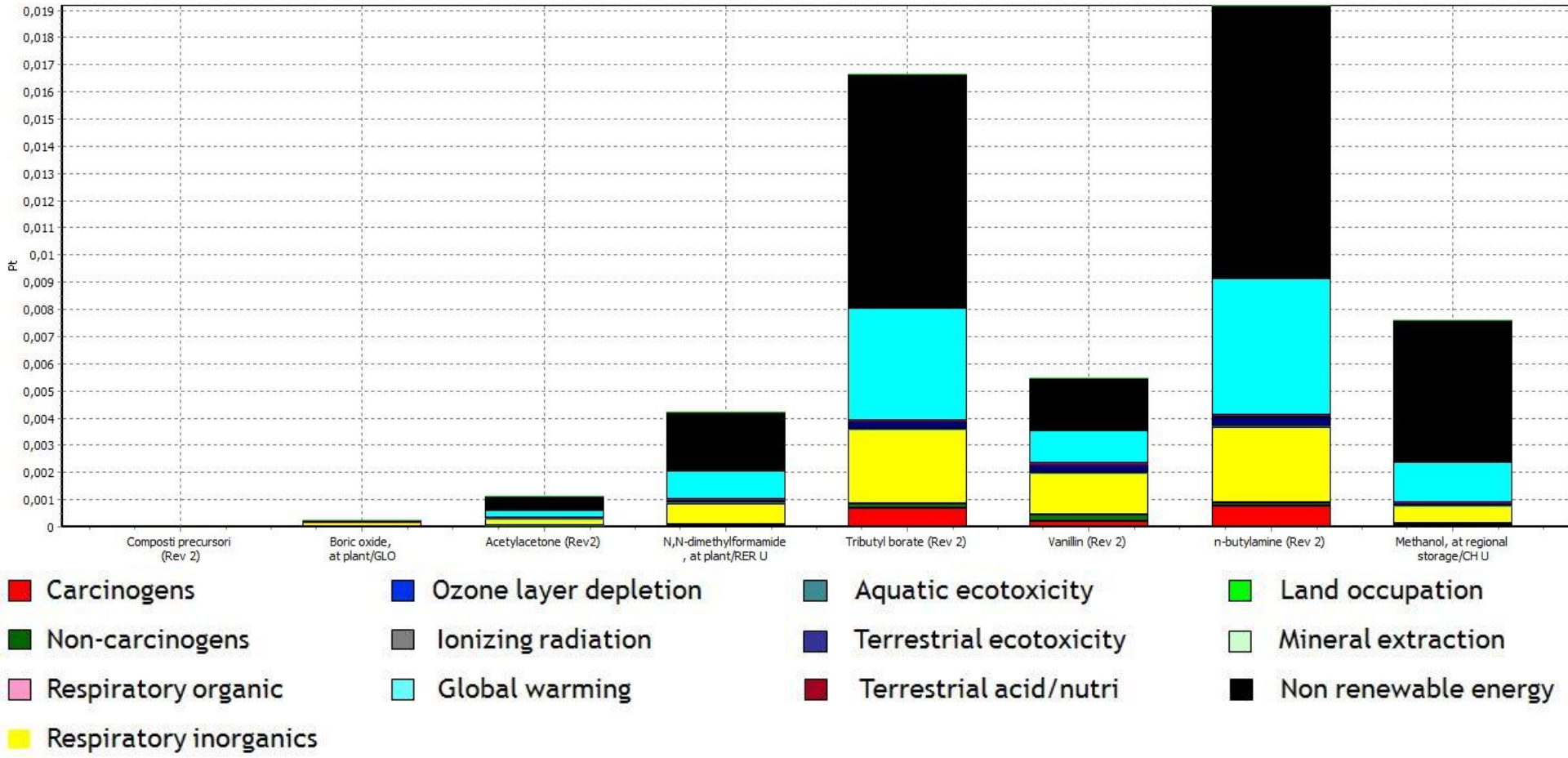
- Major impacts on:

58% Global Warming → CO_2

18% Non renewable energy → *Natural gas*

15% Respiratory inorganics → *PM 2,5*

Analysis of Precursor compound



Analysis of Precursor compound

- Functional Unit: 1p
- Total Damage: 5,45E-2Pt
- Major process contribution:

35% N-Butylamine

31% Tributyl borate

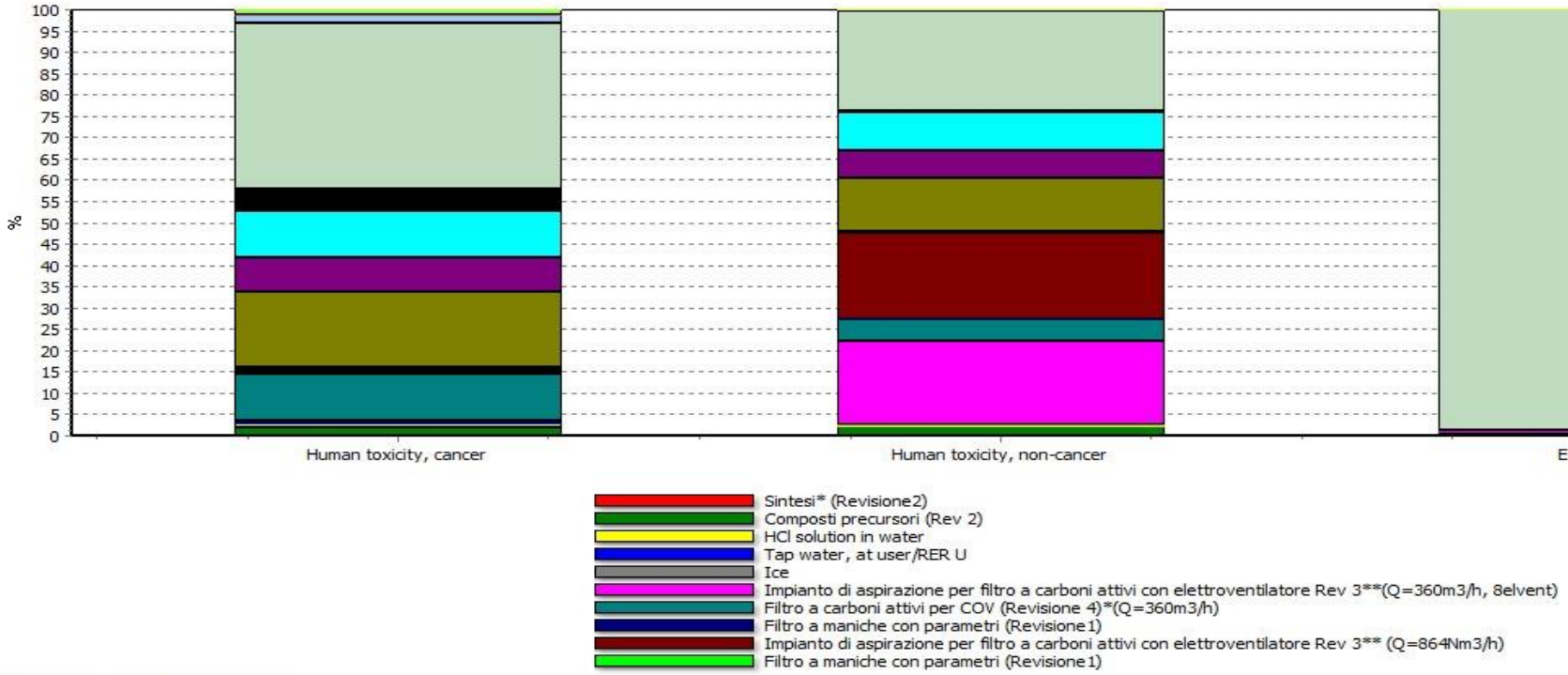
- Major impacts on:

52% Global Warming → CO_2

24% Non renewable energy → *Natural gas*

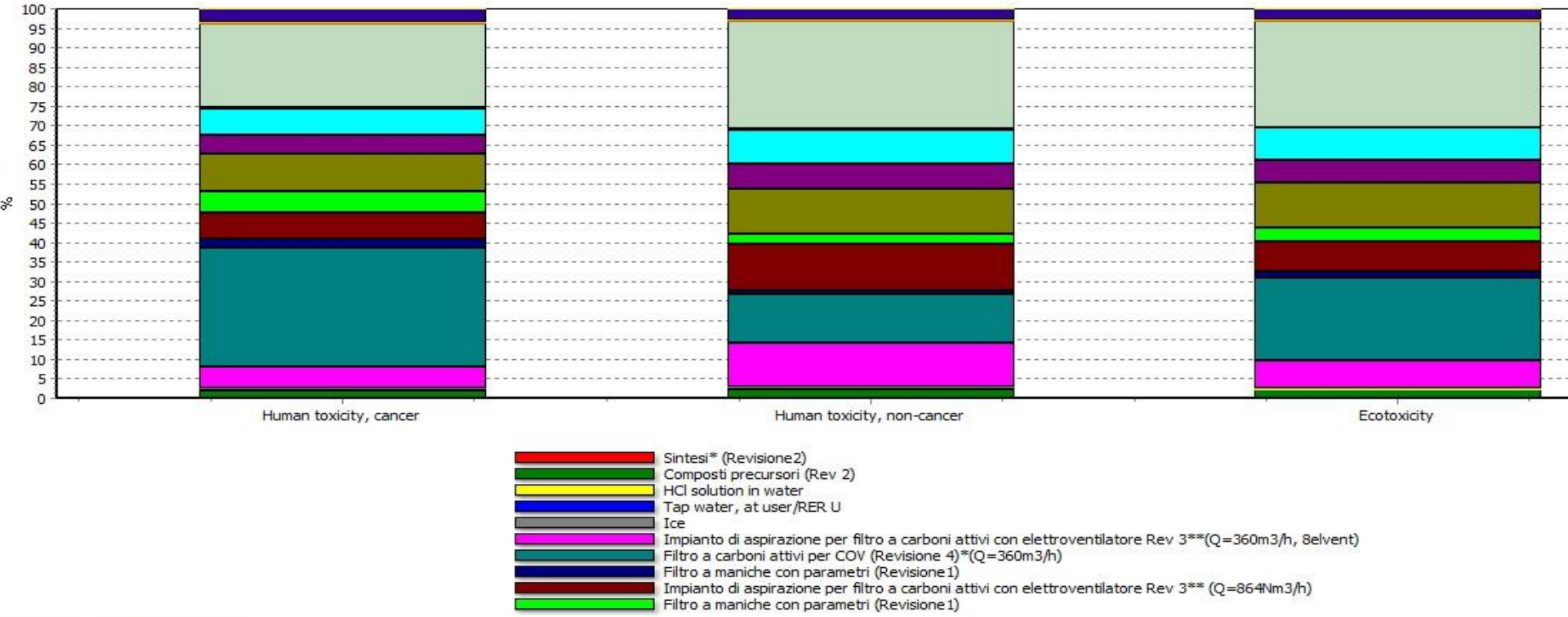
16% Respiratory inorganics → *PM 2,5*

Analysis of 1kg of Curcumin - USEtox recommended



Analysing 1 kg 'Sintesi* (Revisione2)';
Method: USEtox Recommended V1.01 / Characterisation

Analysis of 1kg of Curcumin - USEtox recommended + interim

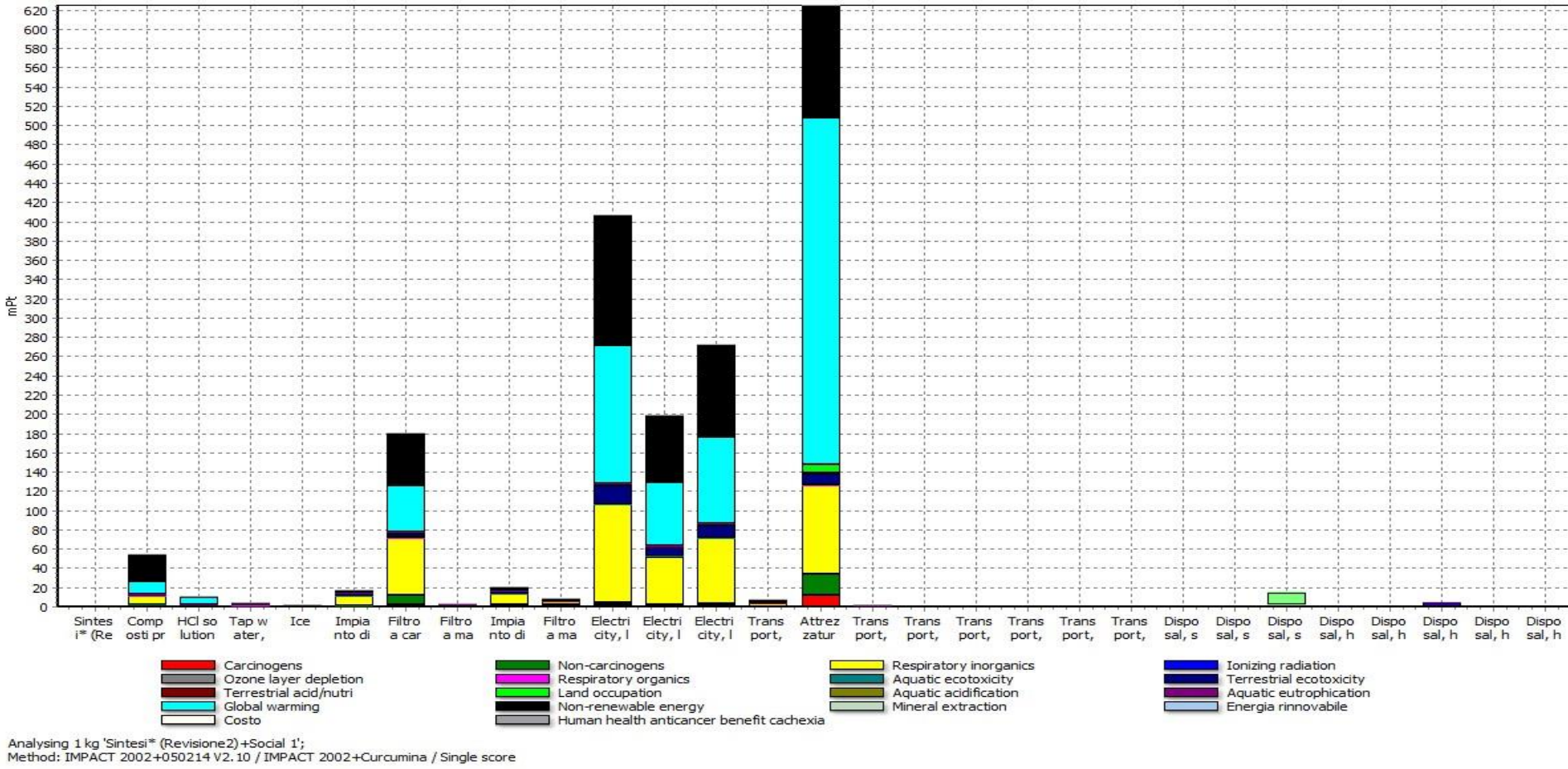


Analysing 1 kg 'Sintesi* (Revisione2)';
Method: USEtox Recommended + Interim V1.01 / Characterisation

Comparison: USEtox results

Recommended + Interim V1.01	Damage in Pt	Substance	Process contribution
Human toxicity, cancer	6E-4CTUh	86% Chromium VI	34% Active carbon filter
Human toxicity, non-cancer	10E-4CTUh	55% Arsenic, ion	17% Active carbon filter
Ecotoxicity	9E3CTUe	53% Chromium VI	35% Active carbon filter
Recommended			
Human toxicity, cancer	5E-7CTUh	57% Formaldehyde	29% Electrical en.
Human toxicity, non-cancer	2E-6CTUh	87% Carbon disulfide	23% Aspiration filter
Ecotoxicity	8E2CTUe	78% Cyfluthrin	99% Laboratory facilities

Analysis of 1kg of Curcumin + Function



Analysing 1 kg 'Sintesi* (Revisione2)+Social 1';
Method: IMPACT 2002+050214 V2.10 / IMPACT 2002+Curcumina / Single score

Analysis of 1kg of Curcumin + Function

- Functional Unit: 1kg
- Total Damage: 1,84Pt
- Total benefit: -1,11E-8Pt
- Benefit on the total damage:

  - 6E-5% **Human health anticancer benefit cachexia**

CONCLUSIONS

- In the analysis of 1kg Curcumin (IMPACT2002+)
  → The major environmental burdens are related to the energy supply (**48%** **!**)

- In the analysis of 1kg Curcumin (USEtox Recommended+InterimV1.01)
  → The major environmental burdens are related to the emission of substances during the process "Disposal, H3PO4 purification residue, 0% water, to residual material landfill/CH U".

- In the analysis of 1kg Curcumin (USEtox Recommended)
  → The major environmental burdens are related to the same major causes of damage of IMPACT 2002+

Possible improvements

Scale - up →
- Higher productivity
- Less incidence of energy supply

More efficiency in tools washing →
- Less impact of the process "Laboratories facilities"
- Green solutions to wash

Develop and compare more pathways to activate carbon →
- Another chemical activation ($ZnCl_2$)
- Physical activation
- Regeneration

Thank you for your attention