

Wind turbine components' life cycle assessment for eco-design purposes: state of the art

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**TECHNOLOGICAL SYSTEMS,
SUSTAINABILITY
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SYMPOSIUM **TS³**

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The banner features a hand holding a glowing dollar sign, surrounded by various icons representing technology, sustainability, and safety.



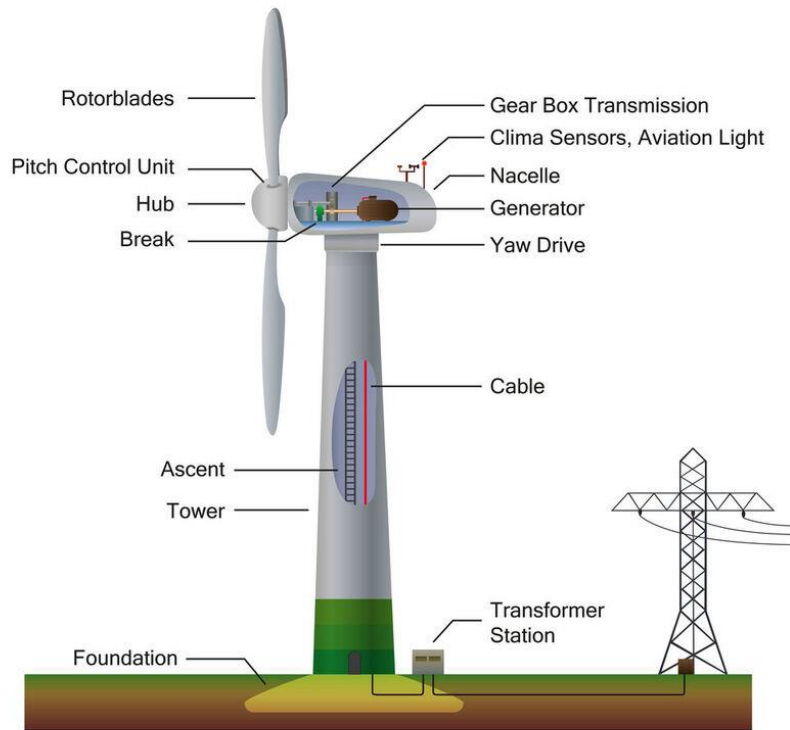
“Life cycle analysis of piezoelectric energy harvesters for wind power: environmental assessment and contributions to the sustainable energy transition”

Keywords: Life cycle analysis, ecodesign, energy harvesting, piezoelectric materials, green energy, wind turbine, environment, sustainability, security



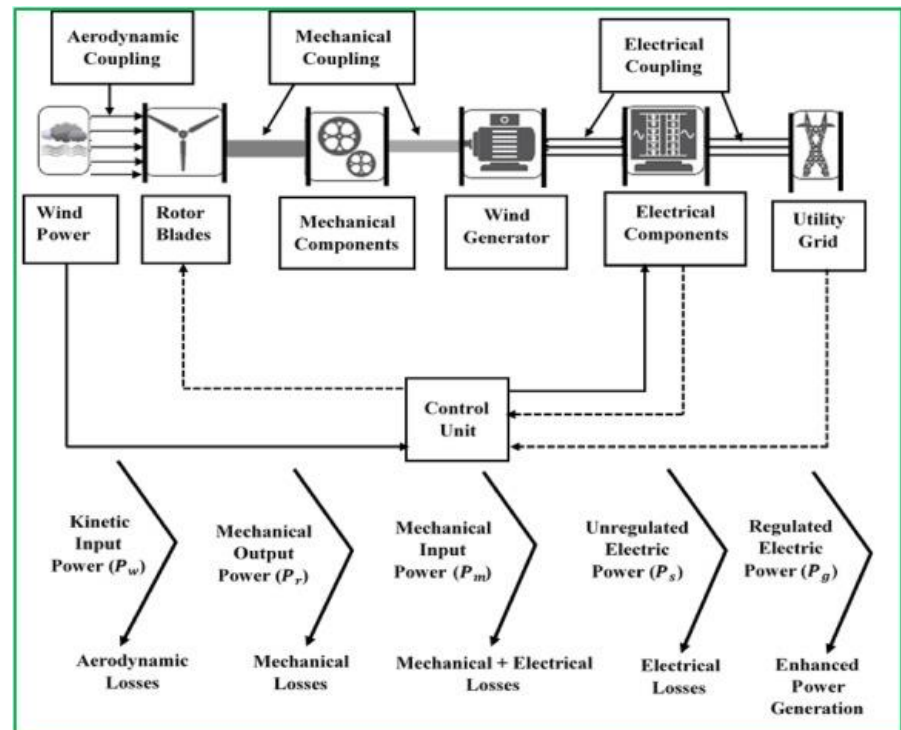
Content

1. Introduction
2. Life cycle assessment – A prior art
3. Piezoelectric materials - IoT features
4. Case study : synthesis of KNN nanoblocks
5. Conclusions & prospectives



A wind turbine is a mechanical structure that uses the kinetic energy of the wind to generate electricity.

Typical wind energy conversion networks and power transformation phases for enhanced electricity generation.

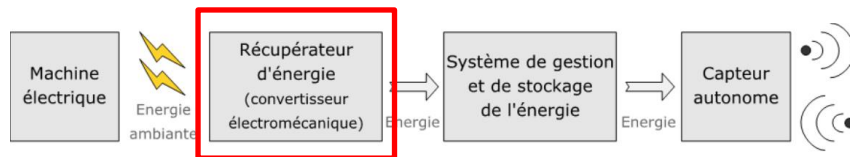


Reference: (B. Desalegn, 2022)

Structural monitoring of wind turbine

The main objective of monitoring wind turbines is to **plan maintenance** actions and **guarantee the best availability** of the machines.

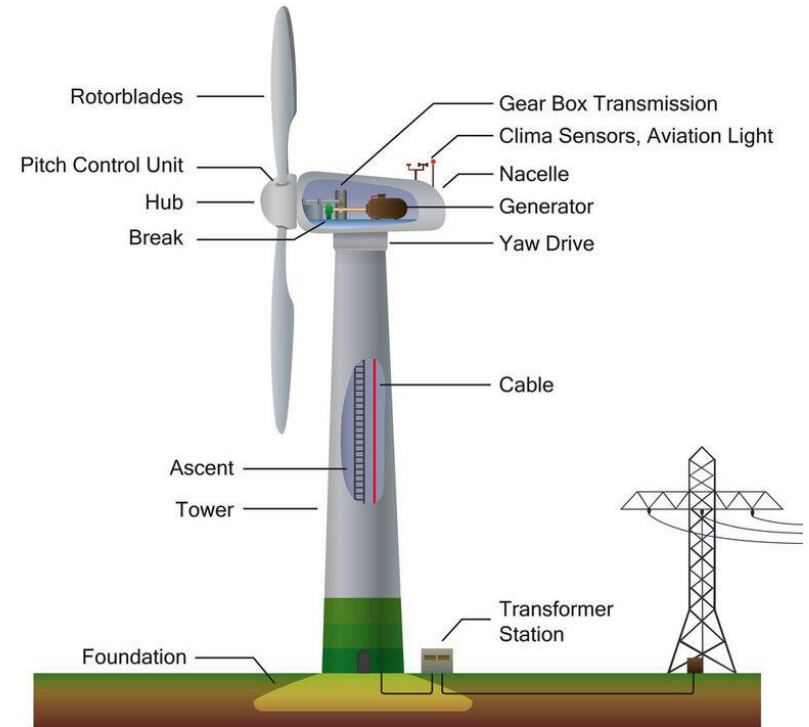
CMS « Condition Monitoring System »



Piezoelectric energy harvesters (PEH)



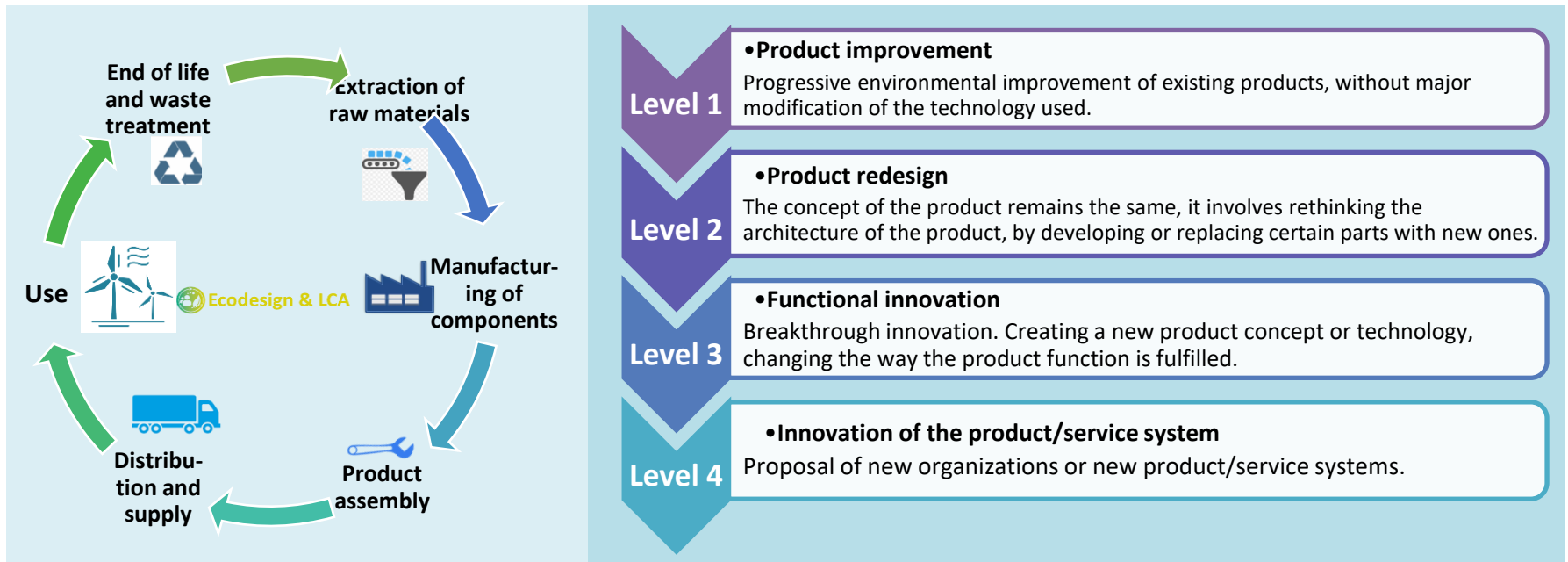
Monitoring technique: The vibration signature with accelerometers



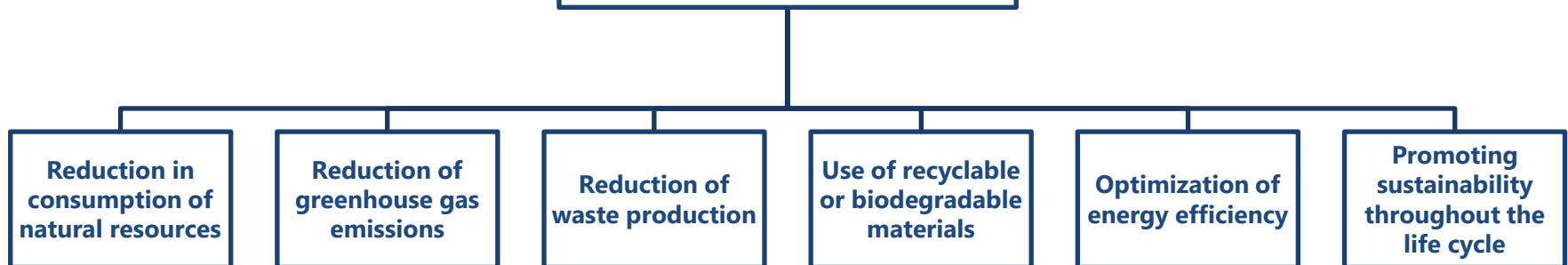
A wind turbine is a mechanical structure that uses the kinetic energy of the wind to generate electricity.

Reference	Common Name	Integration or Transposition into French law
REGULATION (EC) No. 1907/2006 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL, of 18 December 2006, concerning the registration, evaluation and authorization of chemical substances, as well as restrictions applicable to these substances (REACH)	REACH	Order No. 2009-229 of February 26, 2009
DIRECTIVE 2011/65/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of June 8, 2011 relating to the limitation of the use of certain dangerous substances in electrical and electronic equipment	RoHS	Articles R543-172 to 206 of the Environmental Code
DIRECTIVE 2012/19/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of July 4, 2012 on waste electrical and electronic equipment (WEEE)	DEEE ou WEEE	Articles R543-172 to 206 of the Environmental Code
DIRECTIVE 2006/66/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 6 September 2006 on batteries and accumulators and waste batteries and accumulators and repealing Directive 91/157/EEC	Batteries and accumulators	Articles R543-124 to 134 of the Environmental Code

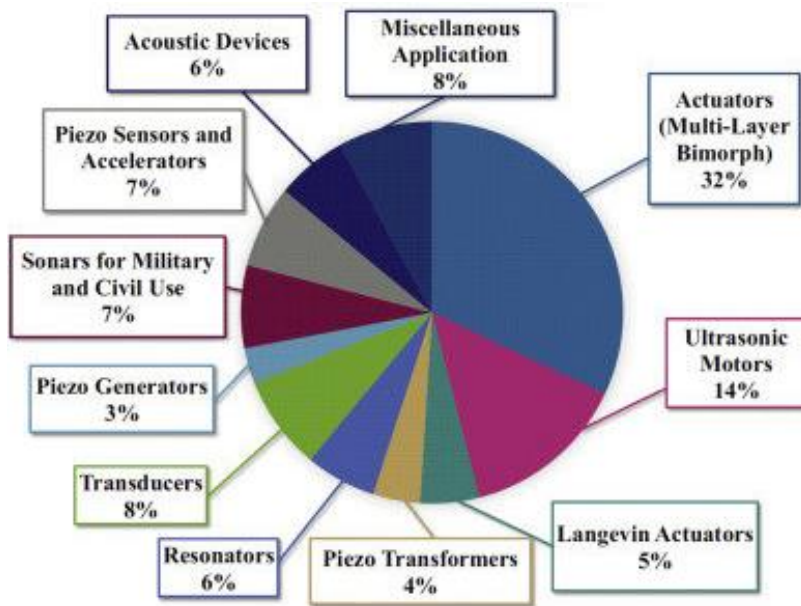
Reference	Title
ISO 14 001	Environmental management systems -- Requirements and guidelines for its use
ISO 14 006	Environmental management systems -- Guidelines for integrating ecodesign
ISO 14 040	Environmental management. Life cycle analysis: principles and framework
ISO 14044	Environmental management. Life Cycle Analysis – Requirements and Guidelines



The main aspects of ecodesign

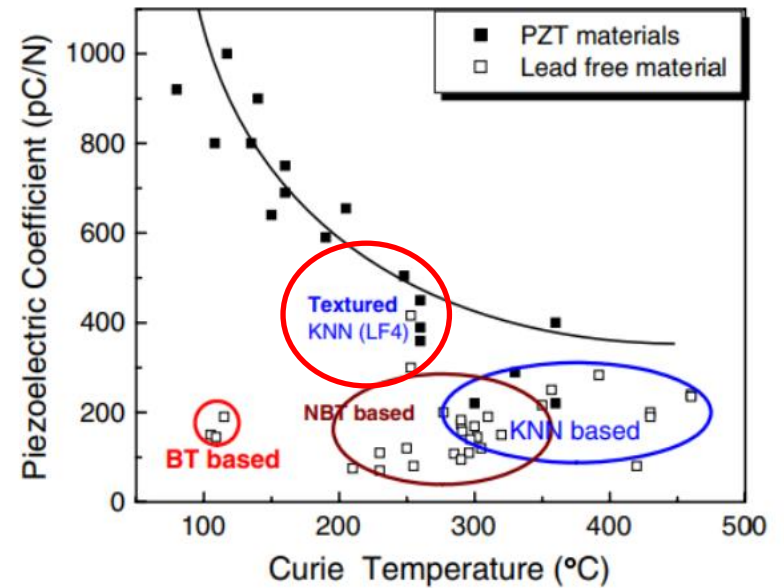


2017 Piezoelectric Market share (%)



Reference: (A.Prato, 2019)

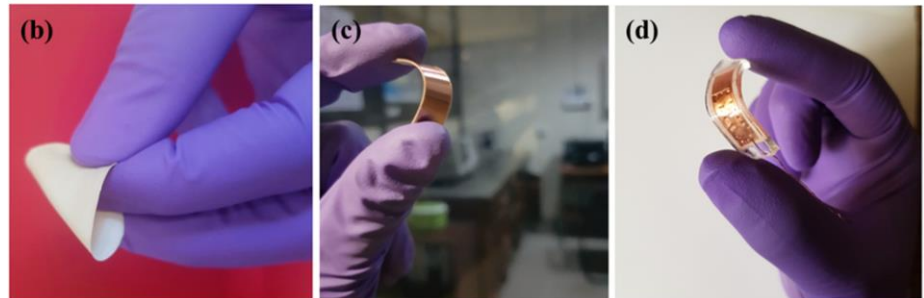
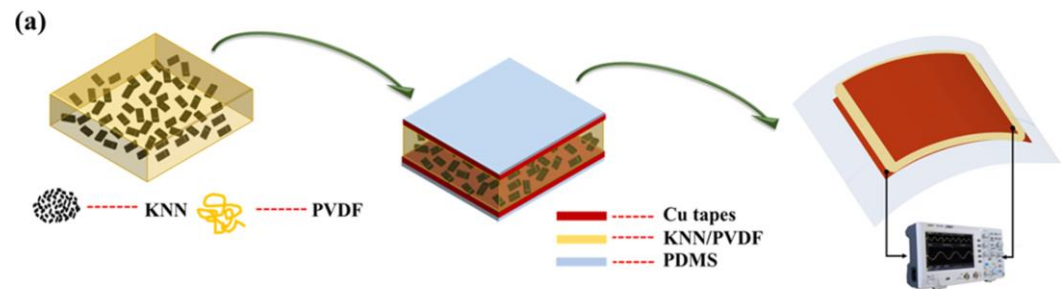
Comparison between the properties of Piezoelectrics with and without lead



Reference: (B. Fontaine, 2022)

Study of the environmental impact of sensors and electromechanical energy harvesters used as IOT sensors;

(a) Schematic of the fabrication procedure of KNN/PVDF-based nanogenerator, (b & c) KNN/PVDF nanocomposite film with high flexibility and (d) fabricated flexible nanogenerator wrapped with PDMS.



Reference: (K.S. Nair, 2022)

Manufacturing process : electrospinning

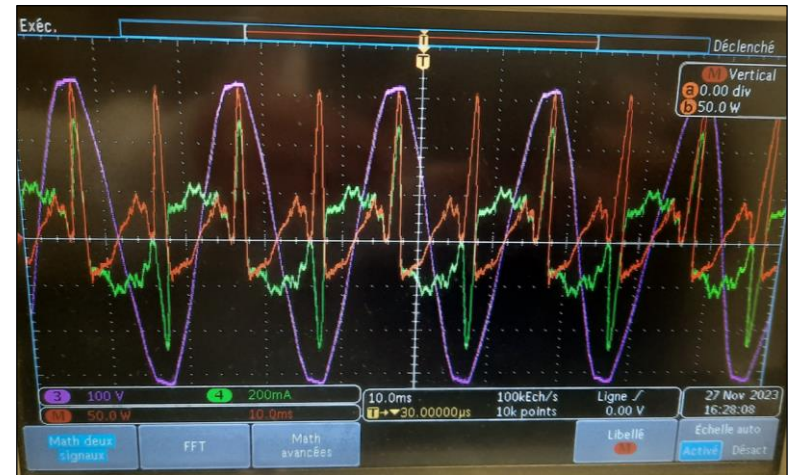
- Deposition of a thin layer of PVDF by centrifugation
- Power measurements made at the UTC Research Center

Power → sum of two periodic signals:

- A sinusoidal signal with zero mean
- A signal composed of a power peak at 150 W over 2ms

$$P = \frac{1}{T} \int_t^{t+T} p(t) dt = \frac{2 \times 150}{10} = 30 \text{ W}$$

Voltage (purple), current (green) and power (red) signals for operation at 500 rpm



1. Modeling and Hypotheses

Raw materials :

- Quantity
- Origin → location of suppliers (US, India and China)

Transportation : Road and Maritime

Two scenarios:

- Manufacturing in India
- Manufacturing in France



Scenario 1: Manufacturing in India



Scenario 2: Manufacturing in France

Comparison of the life cycle for manufacturing

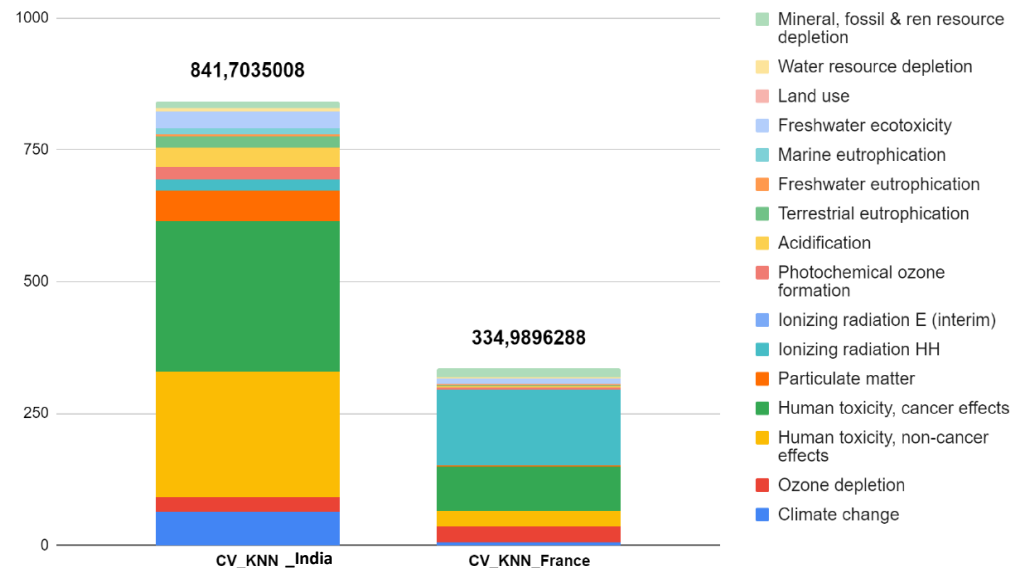
in India VS in France:

- different energy mix
- different transport

→ Manufacturing in India : life cycle 2.5 times

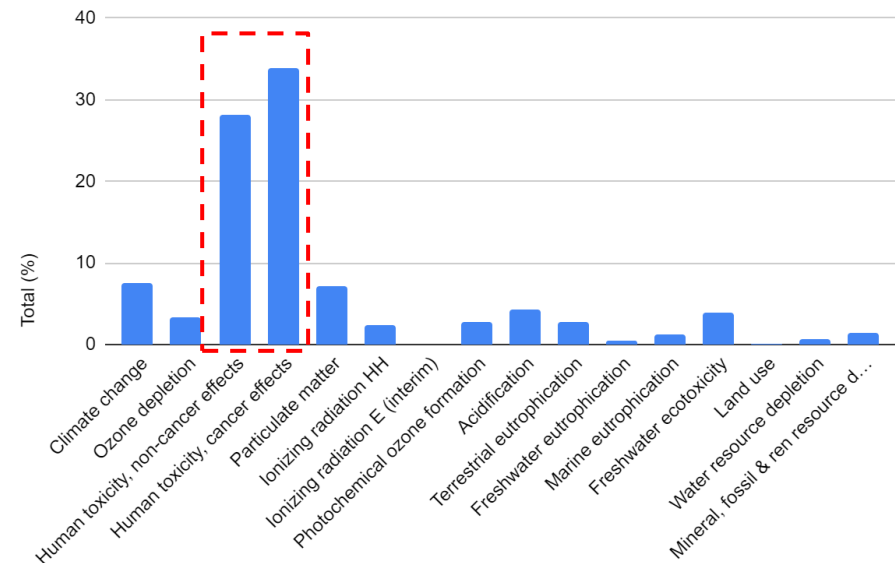
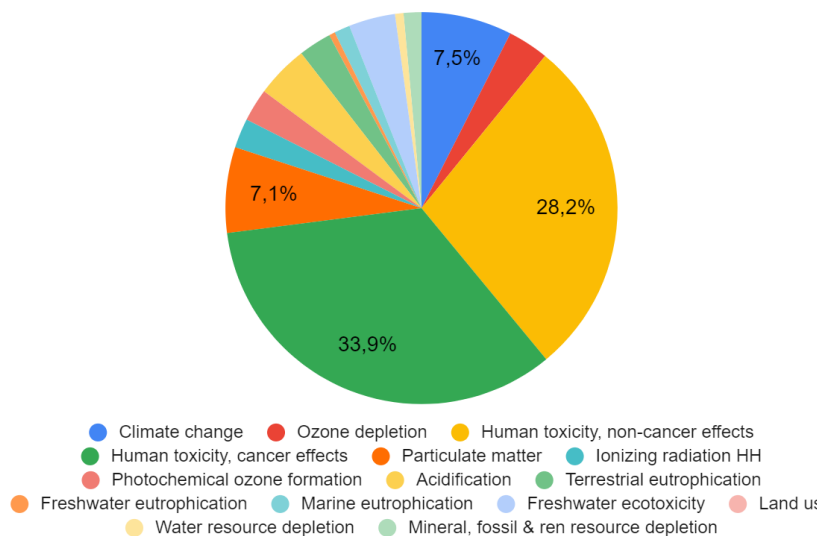
more impactful

Comparison in unique score (μPt) of the life cycle of KNN nanoblocks according to their place of production (India VS France)



Major environmental impacts

Distribution of environmental impacts over the entire life cycle of the KNN nano-blocks manufactured in India

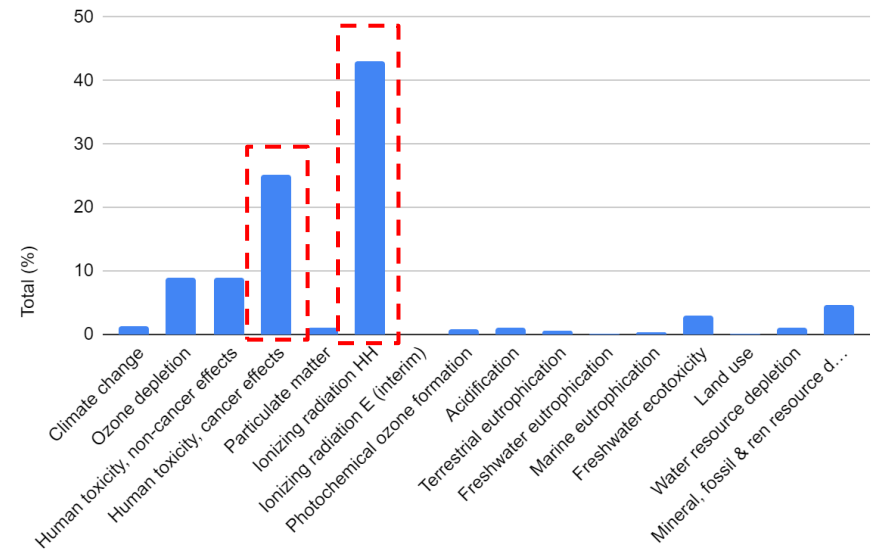
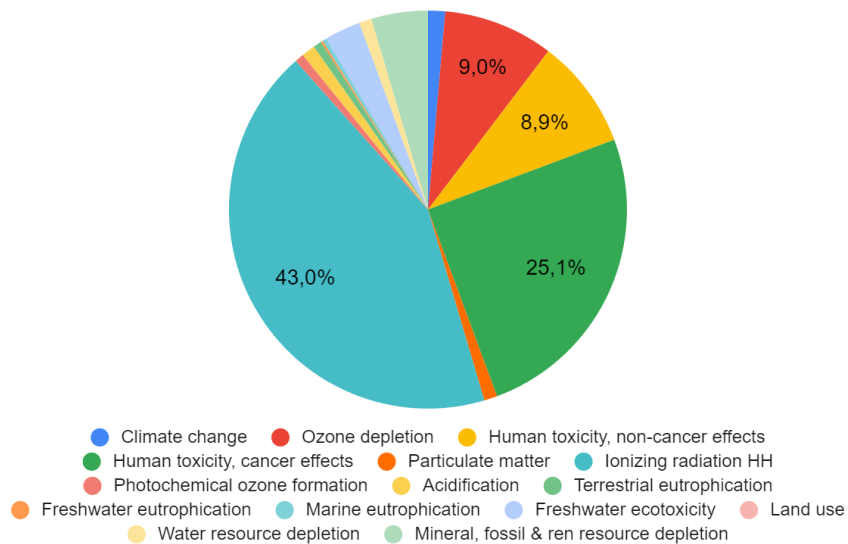


- Major environmental impacts

Human toxicity, cancer effects	Human toxicity, non-cancer effects	Climate change	Particulate matter
33,9%	28,2%	7,5%	7,1%
<ul style="list-style-type: none"> - Human health hazards - Cancer effects 	<ul style="list-style-type: none"> - Human health hazards - Non-cancer effects - Substances released from electricity production 	<ul style="list-style-type: none"> - Climate change - Greenhouse gas emissions 	<ul style="list-style-type: none"> - Ingestion of fine particles - Consequences on human health

Major environmental impacts

Distribution of environmental impacts over the entire life cycle of the KNN nano-blocks **manufactured in France**

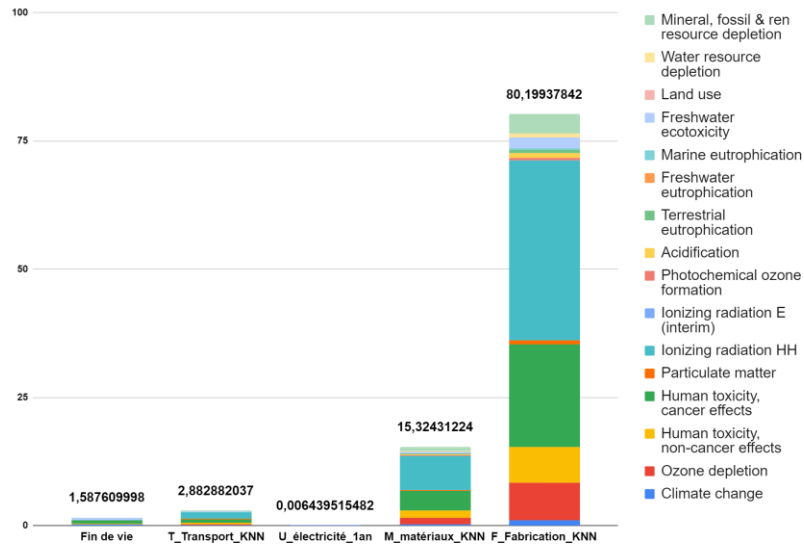


- Major environmental impacts

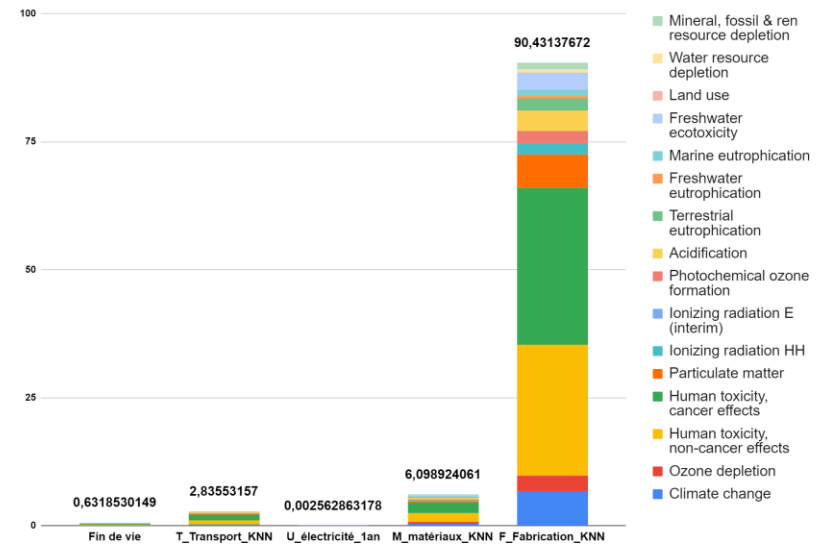
Human toxicity, cancer effects	Human toxicity, non-cancer effects	Climate change	Particulate matter
33,9%	28,2%	9%	8,9%
- Ionic radiation due to the radioactivity of uranium	- Human health hazards - Cancer effects Emissions from thermal power plants, waste management.	- Depletion of the ozone layer - Exposure to harmful ultraviolet rays	- Human health hazards - Non-cancer effects Oxides of sulfur, nitrogen, etc.

Environmental impacts of the manufacturing process

Breakdown of the environmental impacts of the KNN nanoblock manufactured in France by phase of the life cycle

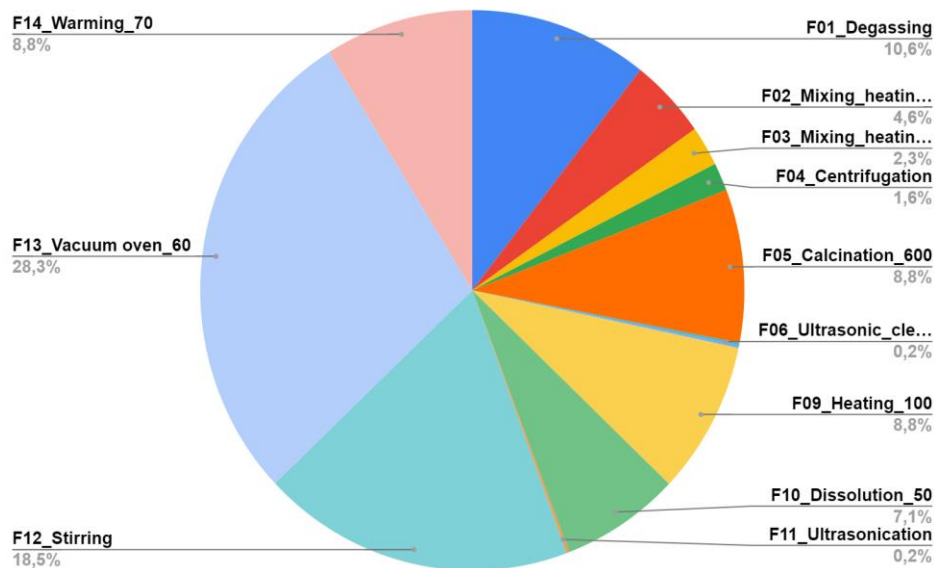


Breakdown of the environmental impacts of the KNN nanoblock manufactured in India by phase of the life cycle



Environmental impacts of the manufacturing process

Breakdown of the total environmental impact of the KNN nanoblocks manufacturing process by manufacturing stage



Most impactful stages of the process:

- Heating empty at 60°C 4h (28.3%)
 - Stirring in the heated mixer 4 h (18.5%)
 - Degassing in the empty oven 1.5 hours (10.6%)
 - Calcination 1 hour (8.8%)
- ➔ It is the longest stages or those requiring heating or maintaining vacuum pressure which consume the most energy.

Conclusions

- The material KNN has been studied as a lead-free piezoelectric material.
- A complete life cycle analysis of this material is carried out with hypotheses using Simapro.
- Manufacturing is the most important phase in the product life cycle, regardless of the manufacturing location, due to the energy-intensive nature of its process.
- PDM is the most important, it is in fact a polymer having strong repercussions on the ozone layer, according to our LCA.

Prospects

- Conduct a similar LCA for a classic PZT using the same analysis method, database, and software.
- Rigorous comparison between the two technologies, thus offering more robust perspectives on their respective environmental impact.

**Thank you for your
attention**