Supplementary Material

for

2002-2022: 20 years of e-waste regulation in the European Union and the Worldwide trends in legislation and innovation technologies for circular economy.

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Content:

S1. Industrial technologies and out-puts.

Table S1. Average mechanical pre-treatment output from industrial plants by e-waste category in Italy in 2016.[1,2]

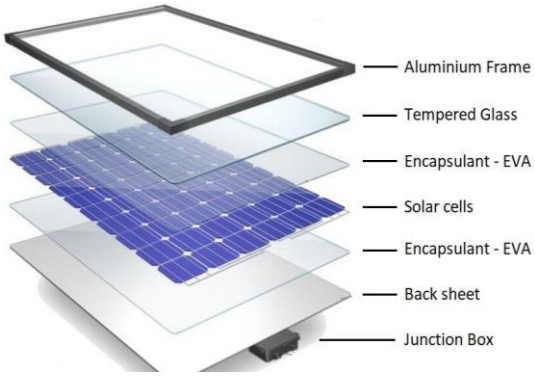
Output mechanical pre-treatment plant	**Cold and climate (R1)**	**Large appliances (R2)**	**Electronic devices (R3)**	**Small appliances (R4)**	**Light sources (R5)**
Power supplies	-	-	-	0.4%	-
Battery	-	-	-	0.1%	-
Lead-acid batteries	-	-	-	0.5%	-
Mixed Cables	0.5%	0.6%	1.8%	2.8%	-
Cement	-	5.0%	-	-	-
Components	-	-	-	0.8%	-
Compressors	13.4%	-	-	-	-
Phosphorus	-	-	0.5%	-	-
Copper yokes	-	-	2.7%	-	-
HDDs and other drives	-	-	-	1.2%	-
Wood	-	0.3%	1.5%	0.8%	-
Quenched and tempered material	0.2%	73.1%	0.0%	33.9%	-
Ferrous	49.9%	14.3%	14,5%	28.3%	1.0%
Non-ferrous metals	4.4%	-	0.4%	2.7%	3.0%
Engines	0.1%	2.1%	0.2%	6.5%	-
Packaging	-	-	-	0.1%	3.0%
Plastics	16.1%	1.1%	15.0%	15.4%	10.0%
BFR Plastics	-	-	-	2.1%	-
Shredder residues	1.1%	3.0%	1.0%	1.5%	-
Hazardous waste	0.7%	0.1%	0.6%	1.7%	2.0%
Residual waste	-	-	0.4%	-	-
PCBs	-	-	8.2%	0.9%	-
High-level PCBs	-	-	-	0.1%	-
Low-level PCBs	-	-	1.8%	0.1%	-
Polyurethane foam	12.6%	-	-	-	-
Toner	-	-	-	-	-
Mixed CRT glass	-	-	21.2%	-	-
Front glass	-	-	30.0%	-	-
Non-CRT glass	0.8%	0.5%	-	-	81.0%
Grand total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

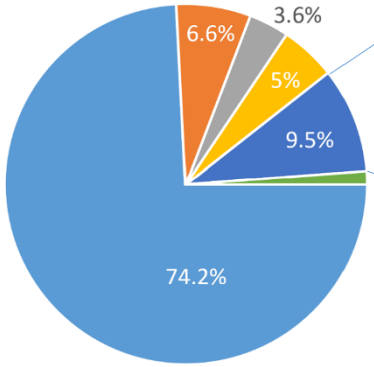
Table S2. PV technologies approaching the market.

PV technology	Brief description
HIT solar cells	*Heterojunction with Intrinsic Thin Layer* technology combines amorphous silicon and crystalline silicon to achieve high efficiency and better performance in high-temperature conditions.
Multijunction solar cells	Typically used in *Concentrated Photovoltaic* (CPV) systems and space applications. They consist of multiple semiconductor materials stacked on top of each other to capture different parts of the solar spectrum, thus achieving very high efficiency.

Tandem solar cells	Tandem solar cells stack multiple layers of solar cell materials with varying bandgaps to capture a wider range of the solar spectrum and improve efficiency.
OPV solar cells	*Organic Photovoltaics* use organic materials to convert sunlight into electricity. They are lightweight and flexible but generally have lower efficiency than traditional PV technologies.
Perovskite solar cells	Emerging technology known for the potential to achieve high efficiency at a lower cost than others. Still in the research and development stage, this technology hold promises for future PV applications.

a)





Metals	wt. %[a]	wt. %[b]
Al	87.0	8.26
Cu	10.5	1.0
Ag	0.5	0.05
Sn	1.3	0.12
Pb	0.7	0.07
Tot.	**100**	**9.5**

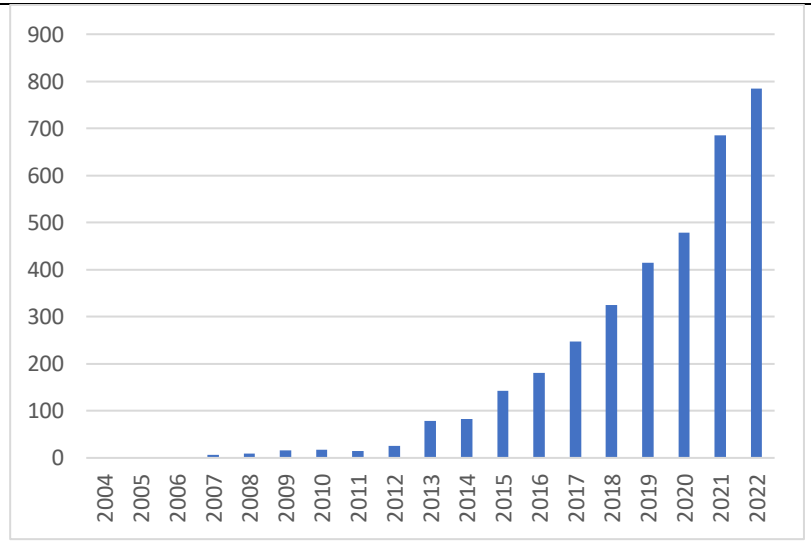
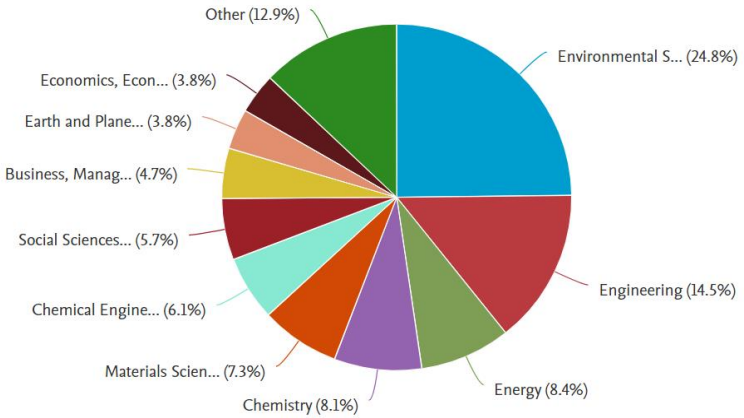
b)

Figure S1. a) Typical multilayer structure configuration for a Si-technology-based photovoltaic panel and b) its composition. ● Glass, ● EVA, ● Tedlar, ● Si, ● Metals, ● Other. [a] Metal fraction composition; [b] Percentage concerning the whole PVP. Adapted from [3].

S2. Trends in research and innovation products concerning e-waste valorization

In this section the distribution of publications and patents by year, subject, and geography related to *urban mining*, *ecodesign*, and *e-waste*, is detailed. The study covers data spanning from 2002 until 2022 and exploited the Scopus database[4] for publications and Orbit database[5] for patents.

Table S3. Trends in research and innovation products concerning e-waste valorization (data sourcing on 29/01/24).

Topic	Query	Trend of publications (n.) over time	Rate of papers by subject area
Urban mining	**"Urban mining" OR "Urban mine"**		

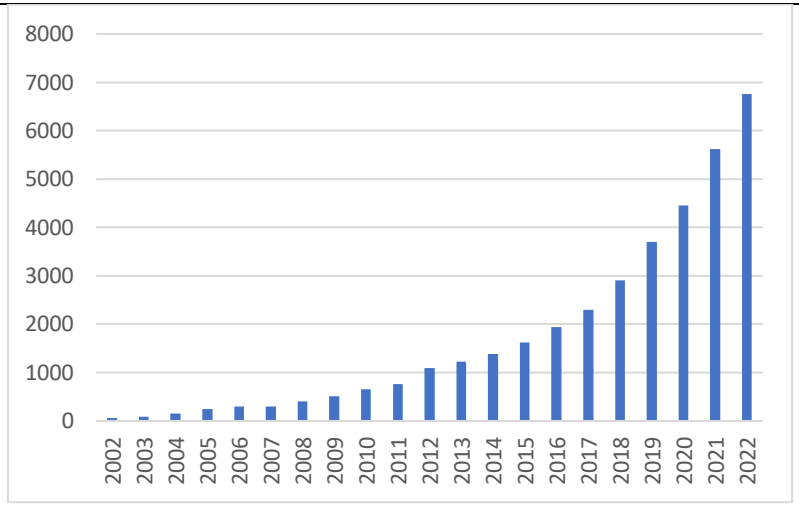
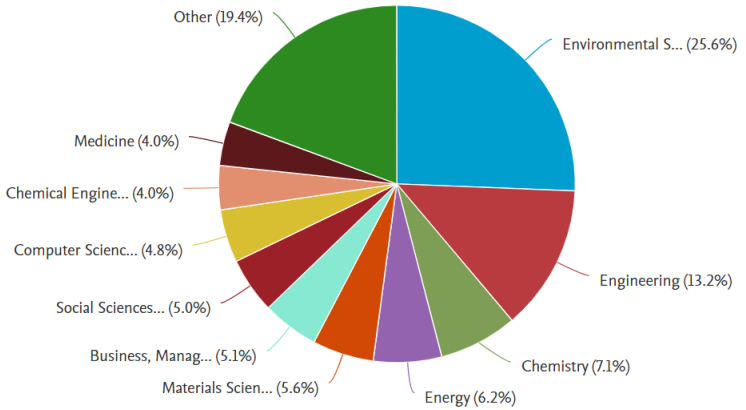
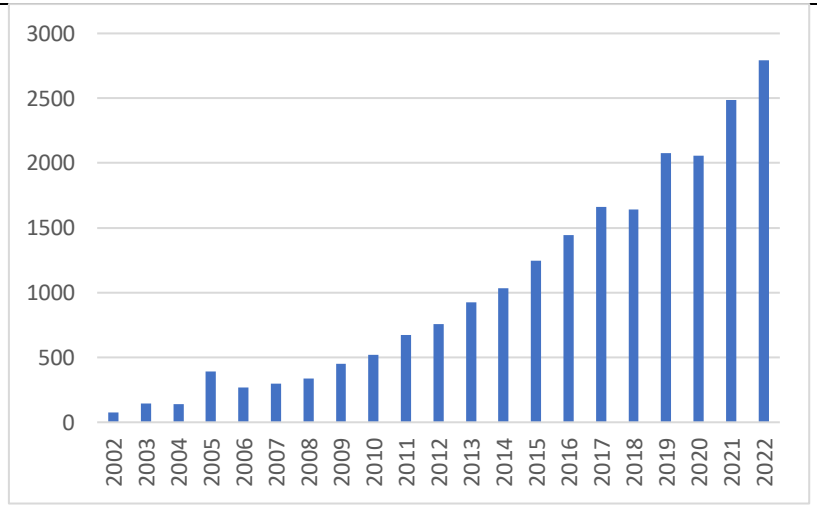
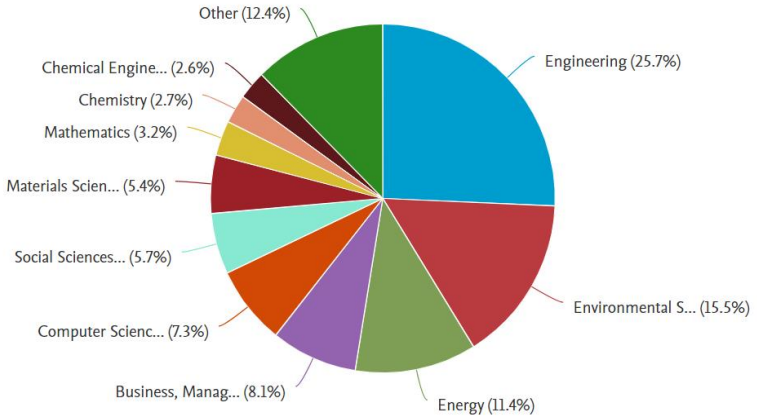
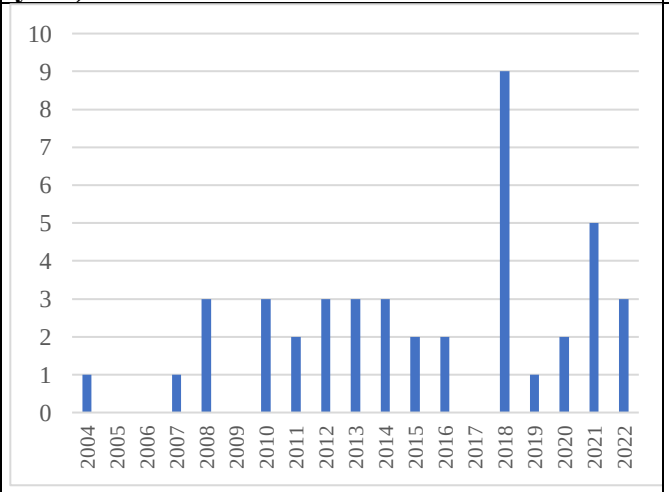
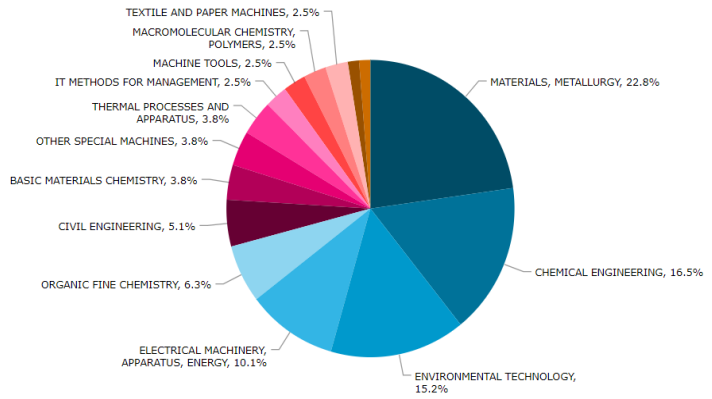
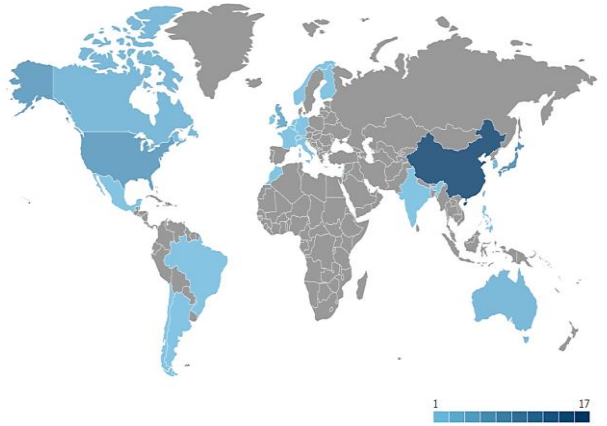
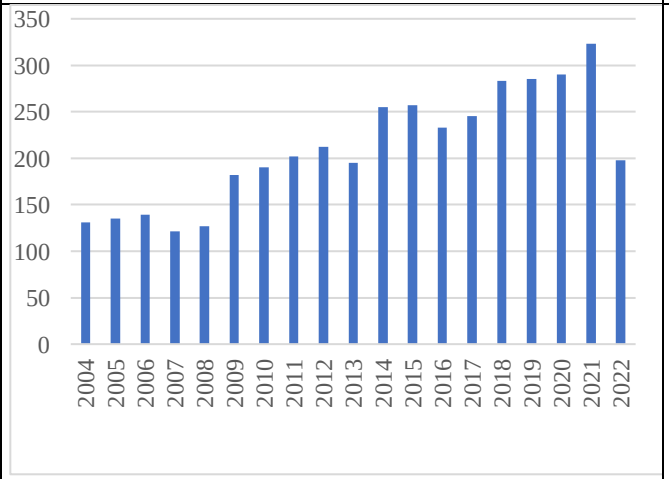
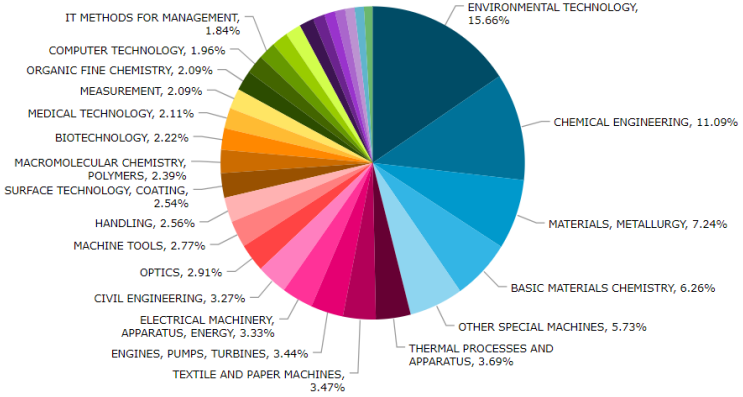
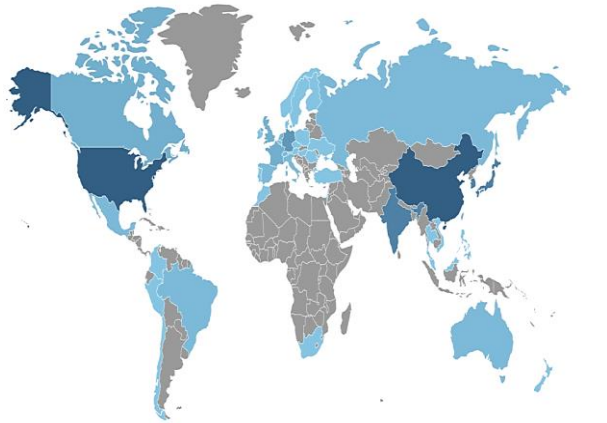
E-waste	**“Ewaste“ OR “e-waste“ OR “WEEE“ OR “Waste Electrical and Electronic Equipment“**		
Ecodesign	**“Ecodesign“ OR “Eco design“ OR “Eco-design“**		

Table S4. Publications by country/territory (data sourcing on 29/01/24)

Territory	***Ecodesign***	***Urban Mining***	***E-waste***
USA	2380	297	4399
CHINA	2271	747	11827
UK	1822	179	2239
FRANCE	1439	115	977
ITALY	1830	262	1476
GERMANY	1432	304	1521
SPAIN	1162	97	985
JAPAN	807	302	1164

Table S5. Patent's statistics (data sourcing on 30/01/24).

topic	Technology investment trend over last 20 years (patents families by first application year)	Patent families by Top technical domain (top 30)	Patent families by market coverage
Urban mining			
E-waste			

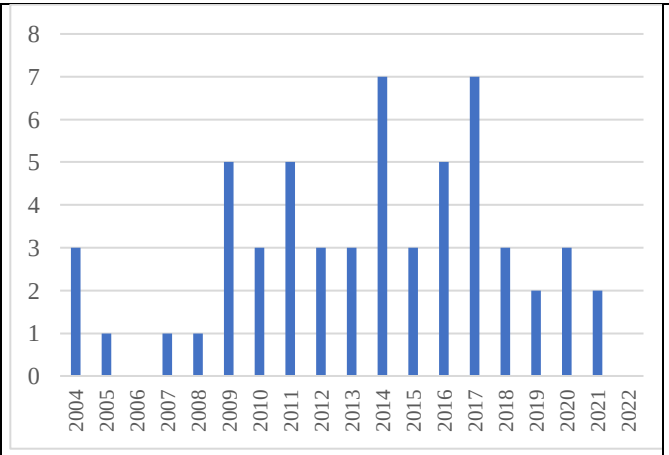
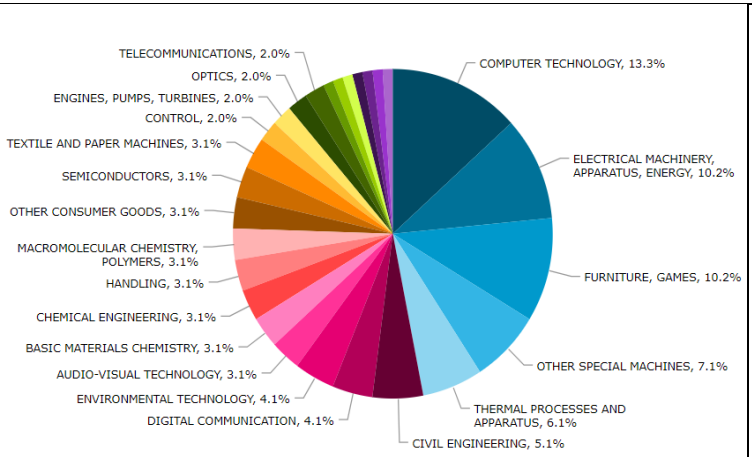
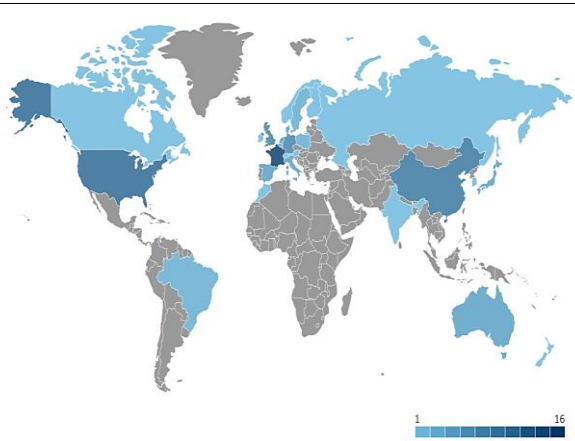
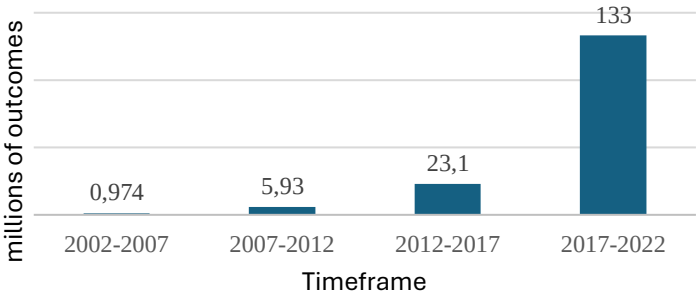
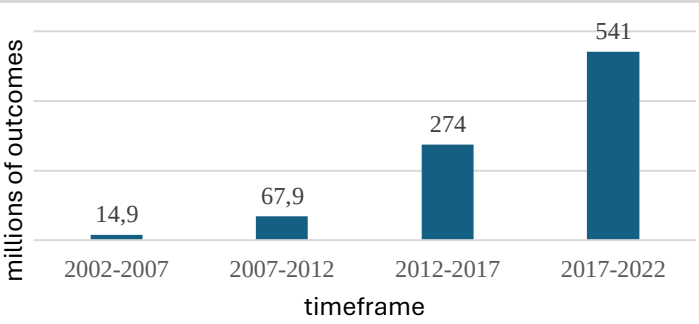
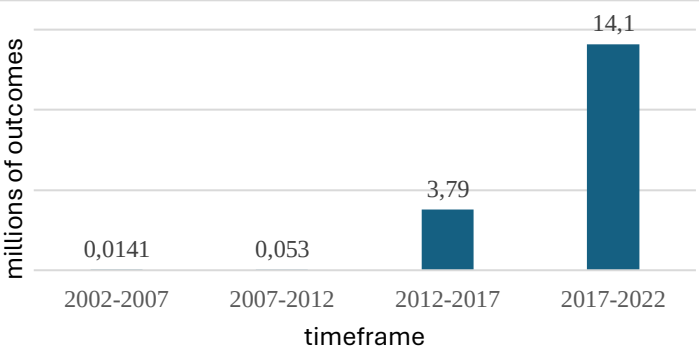
Eco-design	 8 7 6 5 4 3 2 1 0 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022	 TELECOMMUNICATIONS, 2.0% OPTICS, 2.0% ENGINES, PUMPS, TURBINES, 2.0% CONTROL, 2.0% TEXTILE AND PAPER MACHINES, 3.1% SEMICONDUCTORS, 3.1% OTHER CONSUMER GOODS, 3.1% MACROMOLECULAR CHEMISTRY, POLYMERS, 3.1% HANDLING, 3.1% CHEMICAL ENGINEERING, 3.1% BASIC MATERIALS CHEMISTRY, 3.1% AUDIO-VISUAL TECHNOLOGY, 3.1% ENVIRONMENTAL TECHNOLOGY, 4.1% DIGITAL COMMUNICATION, 4.1% CIVIL ENGINEERING, 5.1% THERMAL PROCESSES AND APPARATUS, 6.1% OTHER SPECIAL MACHINES, 7.1% FURNITURE, GAMES, 10.2% ELECTRICAL MACHINERY, APPARATUS, ENERGY, 10.2% COMPUTER TECHNOLOGY, 13.3%	 1 16

Table S6. Results on Google web search engine (data sourcing on 29/01/24).

Urban Mining	
E-waste	
Ecodesign	

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