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Scientists' warning against the society of waste

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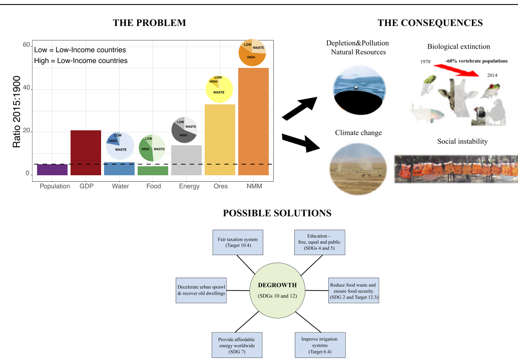
HIGHLIGHTS

- We present a holistic analysis of anthropogenic waste production and its impacts.
- Each year humans waste more than 30% of most natural resources.
- Resource consumption is decoupled from population growth and unevenly distributed.
- Consequences of the Society of Waste include major environmental and social impacts.
- Degrowth and circular strategies are proposed to reduce the human footprint.

GRAPHICAL ABSTRACT



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ABSTRACT

The metabolism of contemporary industrialized societies, that is their energy and material flows, leads to the overconsumption and waste of natural resources, two factors often disregarded in the global ecological equation. In this Discussion article, we examine the amount of natural resources that is increasingly being consumed and wasted by humanity, and propose solutions to reverse this pattern. Since the beginning of the 20th century, societies, especially from industrialized countries, have been wasting resources in different ways. On one hand, the metabolism of industrial societies relies on non-renewable resources. On the other hand, yearly, we directly waste or mismanage around 78% of the total water withdrawn, 49% of the food produced, 31% of the energy produced, 85% of ores and 26% of non-metallic minerals extracted, respectively. As a consequence, natural resources are getting depleted and ecosystems polluted, leading to irreversible environmental changes, biological loss and social conflicts. To reduce the anthropogenic footprint in the planet, and live in harmony with other species and ourselves, we suggest to shift the current economic model based on infinite growth and reduce inequality between and within countries, following a degrowth strategy in industrialized countries. Public education to

Abbreviations: FAO, Food and Agriculture Organization of the United Nations; Gt, Gigatonnes; IEA, International Energy Agency; IRP, International Resource Panel; EJAtlas, Environmental Justice Atlas; NMM, Non-metallic minerals; TPES, TotalPrimary Energy Supply; SDGs, Sustainable Development Goals; UNEP, United Nations Environment Programme.

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Waste
Environmental justice
Sustainability
Degrowth

reduce superfluous consumption is also necessary. In addition, we propose a set of technological strategies to improve the management of natural resources towards circular economies that, like ecosystems, rely only upon renewable resources.

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1. Introduction

The first "Warning to Humanity", made by the Union of Concerned Scientists (1992), stated that developed nations are the largest polluters in the world today, and that they must greatly reduce their overconsumption to reduce pressures on resources and the global environment. Almost three decades later, high-income countries, and especially the richest sector of the population, continue to be the main consumers of natural resources and the main polluters (Dorling, 2010; Kenner, 2015; IRP, 2019; Wiedmann et al., 2020). Although there is a general trend to reduce the use of resources in high-income countries, the rate of this decline is outpaced by far by the increasing use of resources from upper-middle income countries (IRP, 2019; Ritchie and Roser, 2017a, 2020), which are shifting their economies towards more industrialized systems (Haas et al., 2020; Krausmann et al., 2018; IRP, 2019). Consequently, as outlined by a recent second scientists' warning to humanity (Ripple et al., 2017), the depletion of natural resources and pollution released into the environment continues at an even faster pace today. Several authors have acknowledged economic growth as the major driver of environmental change (Pacheco et al., 2018; Victor, 2010; Trainer, 2019; Wiedmann et al., 2020). Despite relative dematerialization due to efficiency improvements in some cases, absolute dematerialization has not happened and it is unlikely to do so (Giljum et al., 2014; Krausmann et al., 2018; Parrique et al., 2019; Wiedmann et al., 2015).

We identify the society of the 20th and 21st centuries as the "Society of Waste", as profligate consumers of high amounts of water, materials and energy due to an ecologically unsustainable social metabolism based on non-renewable resources. The concept of social metabolism refers to the manner in which human societies organize their exchanges of energy and materials with the environment, and within the economy (Demaria, 2022). Thermodynamics establishes that whatever mass and/or energy conversion is constrained by physical limits. From this point of view, waste is seen as an unavoidable by-product in the industrial production of desired goods and services. The quantity of waste generated, however, depends upon the degree of (in)efficiency with which these processes are operated (although there is a thermodynamic minimum required). If our society intends to operate within sustainable levels of metabolism, Baumgartner (2002) suggests that the following rules should apply: 1) Do not use material fuels as a source of exergy, but only sunlight; 2) Keep matter in closed cycles, i.e. heat should be the only waste; 3) Carry out all transformations with thermodynamic efficiency.

In this paper, we include under the term "social metabolism" the consumption of natural resources employed to cover basic needs, as well as the increasing proportion of resources consumed to acquire positional goods, not needed to satisfy basic needs (i.e. overconsumption), as part of the current industrial model based on infinite growth. Under the term "waste" we include all the water, solid material and energy that is lost either as a consequence of social metabolism (i.e. the exploitation of non-renewable resources that once have been consumed, cannot be recycled, and are wasted forever, e.g. fossil fuels; together with the use of renewable resources faster than they can regenerate, e.g. biomass or freshwater) or due to mismanagement (i.e. resources not used for the purpose they were extracted for and returned into the environment in spoiled conditions). The manuscript is thus focused on wasteful practices at the very source of the consumption chain, rather than on the final disposal of products. In the first part of the article ("The Problem"), we highlight the main ways through which humanity is wasting natural resources, and the related environmental and social impacts. In "The Solution" section, we propose a holistic approach to reduce the human ecological footprint, focusing on wasteful practices in industrialized countries.

2. The problem: industrial social metabolism and mismanagement of natural resources

From 1900 to 2015, humanity extracted a total of 3400 gigatonnes (Gt) of biomass, fossil fuels, ores, and non-metallic minerals (Krausmann et al., 2018). Of this amount, 73% was returned to the environment as solid, liquid or gaseous waste — mostly as carbon compounds (Krausmann et al., 2018). Although resource efficiency has improved over recent decades (IRP, 2019), the absolute amount of resources extracted and used keeps rising globally (Krausmann et al., 2018; Ritchie and Roser, 2017a; IRP, 2019; Schandl et al., 2018). The International Resource Panel (IRP) reported that, from 2000 onwards, increasing affluence replaced population as the largest driver of growth in material extraction globally (IRP, 2019). While human population grew by a factor of 5 between 1900 and 2015, world GDP (Gross Domestic Product) at constant prices increased over 21 times corresponding to an average annual rate of growth of 3% (estimated from Bradford De Long, 1998) (Fig. 1). During the same period, water withdrawal increased by a factor of 6; food production by a factor of 5; the extraction of fossil fuels and energy supply by a factor of 15 and 14, respectively; metal extraction by a factor of 33, and the extraction of other, non-metallic, minerals by a factor of 50. As shown in Fig. 1, all the increase in material extraction that exceeds the increase in human population must be attributed to social metabolism and resource mismanagement. Through this section we attempt to assess the losses of natural resources derived from these two sources of waste.

2.1. How we are wasting freshwater

Although 71% of the Earth's surface is covered by water, only 2.5% of that is fresh water, and about 69% of that is locked up in ice or deep underground. In 2014, human diverted ca. 4 trillion m^3 – a volume greater than that of the Mediterranean Sea (3.75 trillion m^3) – or 3918 Gt for agriculture (70%), industry (19%) and domestic (11%) uses (Albert et al., 2020; Ritchie and Roser, 2017a). Fig. 2 shows global water withdrawal and material extracted in 2015, as well as the amounts of these materials that were wasted (in pale colours) – according to our definition of waste (see Introduction).

Jägermeyr et al. (2015) calculated that, on average, only 26% of the water globally withdrawn for irrigation systems is beneficially consumed. The remainder is lost, either due to non-beneficially consumption (e.g. soil evaporation) or as return-flow. An unknown percentage of the latter is recovered and flows back into aquifers, drains and rivers. However, this discharged water is very often polluted with fertilizers and other chemicals that may alter the biogeochemistry of the receiving waters (Foley et al., 2005; IRP, 2019; Stevenson, 2017). Hence, we consider that fraction as waste (Fig. 2; see Supp. Mat. for waste estimations). Increasing inputs of phosphate, nitrogen and organic matter from agriculture results in eutrophication and deoxygenation in rivers and coastal areas across the world (Breitburg et al., 2018; Foley et al., 2005; Steffen et al., 2015), with consequent negative impacts along the aquatic food chain. The domestic and industrial sectors are even more wasteful. According to data from 1995 and projections for 2025

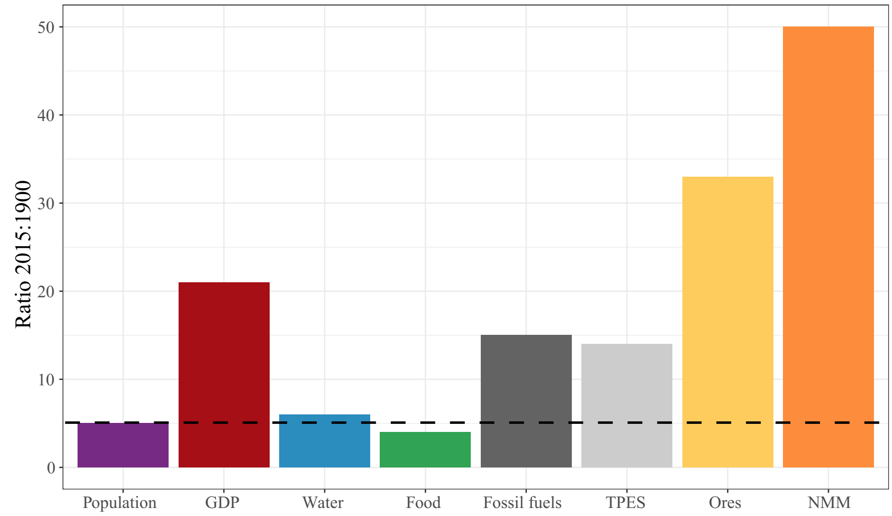

Fig. 1. Increase in human population growth, Gross Domestic Product (GDP) and the extraction of natural resources in 2015, relative to values reported in 1900. The black dashed line delimits the level above which the increase in production of a given material is above the increase in human population growth. Data of human population, food, fossil fuels, ores and non-metallic minerals (NMM) were retrieved from Krausmann et al. (2018) and Haas et al. (2020). Data of GDP were recalculated from estimations from Bradford De Long (1998). Data of freshwater withdrawal were retrieved from Ritchie and Roser (2017a), and total primary energy supply (TPES) data were retrieved from Ritchie and Roser (2020) and the IEA website (https://www.iea.org) (see Supp. Mat.).

(Hamdy et al., 2003), we estimated that the industry and domestic sectors lose 88% and 87% of water each year (Supp. Mat.), respectively, before consumption. Considering the losses from the three sectors, the total amount of water wasted in 2015 was 3040 Gt, or 77.6% of the total water drawdown that year (Fig. 2).

The water footprint of consumers is distributed unevenly across the globe. Table 1 shows noticeable differences in terms of resource use by the top 25 most populated countries. As an example, within these countries, the water footprint varies from 548 $m^3\ y^{-1}$ per capita in the Democratic Republic of the Congo to 2847 $m^3\ y^{-1}$ per capita in the USA. The water footprint depends basically on the quantity of the products consumed and their related water footprint (Mekonnen and Hoekstra, 2011). Overall, animal-based products demand more water per tonne of product and per joule than plant-based products (Ritchie and Roser, 2017a; Mekonnen and Hoekstra, 2012). With increasing water withdrawn, used and discharged back into rivers, river flows become depleted or degraded, yielding to water stress (IRP, 2019). Today, per capita freshwater availability is less than half the level seen in the early 1960s (Ritchie and Roser, 2017a). Albert et al. (2020) reported that around two-thirds of the global population are already experiencing severe water scarcity, during at least part of the year. The Global Atlas of Environmental Justice (EJAtlas: https://www.ejatlas.org; Temper et al., 2015) reports social conflicts around environmental issues. As of September 2021, 892 cases have been reported regarding water access, distribution, and treatment, since the site was launched in 2011. The main environmental and social consequences of freshwater withdrawal and material extraction, driven by the prevailing linear socioeconomic model, are summarized in Box 1 and Fig. 3.

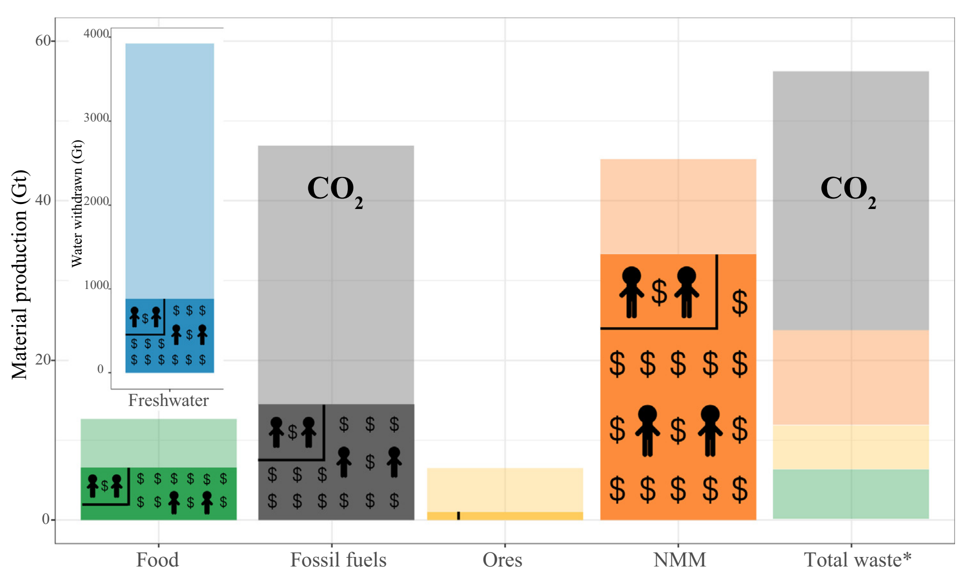

Fig. 2. Global water withdrawn (Ritchie and Roser, 2017a) and material extraction (Haas et al., 2020; Krausmann et al., 2018) in 2015. Dark colours indicate use of resources while pale colours indicate waste (see definition in the text). Sub-areas within the bars indicate the proportion of resources that is consumed by high- and upper-middle income countries (large areas) and low- and lower-middle income countries (small areas). The human icons indicate that each group represents about 50% of the human population (IRP, 2019), while dollar icons stand for the unequal richness distribution between these two groups. *Total waste includes the 23.5 Gt estimated of solid waste from food and mineral (ores and NMM) wastes, plus the 32.4 Gt of CO_2 emitted from the combustion of fossil fuels (Kaza et al., 2018; Ritchie and Roser, 2020; IEA, www.iea.org). NMM = non-metallic minerals. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 1
Selected socioeconomic and resource use (and possible savings) features for the 25 most populated countries. Countries are sorted in alphabetical order. NA = data not available. Blue, green, orange and yellow rows stand for low-, lower-middle, upper-middle and high-income countries, respectively, as assigned by the World Bank in the year 2020 (https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups).

Country	Population (millions)[1]	WF (m^3 y^{-1} cap^{-1})[2]	WF savings (%)[3]	Share of people undernourished (%)[4]	Obesity (% of adults)[5]	Kcal saved from over-consumption (%)[6]	Energy consumption (KWh y^{-1} cap^{-1})[7]	Homeless population (thousands)[8]	CO_2 emissions (kg y^{-1} cap^{-1})[9]	CO_2 savings (%)[10]	Meat consumption (kcal day^{-1} cap^{-1})[11]	Gini index (%)[12]	Total tax revenue (% GDP)[13]	Expenditure on health and education (% GDP)[14]	Land area for irrigation (main system)[15]
Bangladesh	165	767	NA	12.67	4	9	2,995	NA (> 600,000 street children)	630	NA	51	32.4 (2016)	8.2	4.3	5050 (surface)
Brazil	213	2044	57	2.84*	22	41	16,325	222 (2020)	2210	87	466	53.40	33.7	15.7	2619 (surface)
China	1439	1059	34	1.61*	6	36	27,452	2,579 (2011)	7100	63	533	38.5 (2016)	23.8	NA	59338 (surface)
Dem. Rep. Congo (DRC)	90	548	NA	40.40	7	NA	489	1,500 (2017)	30	NA	NA	42.1 (2012)	7.1	4.8	10 (surface)
Egypt	102	1351	45	4.51	32	45	10,753	12,000 (2013)	2460	68	163	31.5 (2017)	NA	NA	3029 (surface)
Ethiopia	115	1168	-24	18.70	5	2	777	NA	150	75	37	35 (2015)	NA	8.0	283.2 (surface)
France	65	1789	47	<2.5	22	55	41,281	142 (2012)	4970	76	527	32.4	45.3	NA	1417 (mixed: surface-sprinkler-drip)
Germany	84	1424	43	<2.5	22	53	43,703	650 (2017)	8400	74	390	31.9 (2016)	37.4	16.2	11 (sprinkler)
India	1380	1095	-18	13.71	4	10	6,924	1,770 (2011)	1910	73	24	35.7 (2011)	17.6	7.3	61938 (surface)
Indonesia	273	1132	5	8.83	7	22	9,147	3,000 (2004)	2280	59	128	38.2	10.4	6.5	6722 (surface)
Iran	84	1862	28	4.64	26	33	41,354	NA	9400	56	149	42.0	8.0	12.7	7970 (surface)
Italy	60	2300	45	<2.5	20	53	29,239	48 (2014)	5800	77	415	35.9 (2017)	42.4	12.5	2399 (surface)
Japan	126	1387	33	2.71*	4	17	40,889	5 (2019)	9048	67	318	32.9 (2013)	32.0	14.2	2010 (surface)
México	129	1971	36	6.98	29	36	16,811	41 (2010)	3530	77	325	45.4	NA	10.3	5168 (surface)
Nigeria	206	1241	NA	11.94	9	10	2,726	24,400 (2007)	700	NA	68	35.1	7.2	NA	238.1 (surface)
Pakistan	221	1314	14	11.81	9	8	4,567	NA	1150	87	75	31.6	10.0	6.1	19270 (surface)
Philippines	110	1387	10	14.00	6	14	5,200	NA (1,500 street children)	1330	69	291	42.3	13.7	NA	1864 (surface)
Russia	146	1862	47	3.57*	23	47	56,756	64 (2010)	11510	77	372	37.5	29.1	9.0	1953 (sprinkler)
South Africa	59	1241	41	5.59	28	26	25,620	200 (2015)	8170	79	345	63 (2014)	29.3	14.5	385 (sprinkler)
Tanzania	60	1022	0	23.50	8	19	1,299	NA	200	81	60	40.5 (2017)	11.4	7.3	184 (surface)
Thailand	70	1424	17	9.29	10	2	22,399	NA	4140	63	241	34.9	17.8	7.9	6415 (surface)
Turkey	84	1643	52	<2.5	32	54	21,609	NA	4860	60	145	41.9	25.3	NA	4690 (surface)
United Kingdom	68	1241	45	<2.5	28	49	32,250	307 (2016)	5590	71	476	35.1 (2017)	32.7	15.5	117 (mixed:surface-sprinkler)
United States	331	2847	50	<2.5	36	64	79,897	568 (2019)	16375	85	459	41.4	25.8	21.9	12696 (mixed: surface-sprinkler-drip)
Vietnam	97	1059	NA	6.29	2	28	11,862	NA	2183	NA	472	35.7	17.9	10.1	4584 (surface)

[1]Data from Worldometers for the year 2021 (https://www.worldometers.info/world-population/population-by-country/).
[2]Water footprint (including blue, green and grey) per capita, as reported by Mekonnen and Hoekstra (2011).
[3]Water footprint (blue and green) savings, considering the shift from baseline-adjusted values to a vegan diet, or a plant-based diet that included small amounts of low-food chain animals (as reported by Kim et al., 2019; who considered data for the period 2011–2013). Negative values (in red) mean that the change of diet suppose an increase in the WF.
[4]Estimated from undernourishment data per country retrieved from FAOSTAT (http://www.fao.org/faostat/en/#data/FS), as the average for the period 2017–2019, and the total population of the given country in 2018. For France, Germany, Italy, Turkey, United Kingdom and the USA, a fixed value of <2.5% is estimated. *Most updated data from Brazil (2007), China (2010), Japan (2010) and Russia (2003) were retrieved from Roser and Ritchie (2019) at OurWorldInData.org.
[5]Share of adults that were obese in the year 2016. Data retrieved from: 'https://ourworldindata.org/obesit (Ritchie and Roser, 2017b).
[6]Calculated from subtracting the dietary energy supply of a given country (as kcal per person per day, retrieved from FAOSTAT) the 2300 kcal per person per day determined by Springmann et al. (2016) as the upper bound of average per capita energy required.
[7]Ritchie, H. and Roser, M. 2020. Data retrieved from 'https://ourworldindata.org/energy/country' for the year 2019 (for DRC, Ethiopia, Nigeria and Tanzania the most updated data are for 2016).
[8]Data reported as homeless population present on any given night. More recent estimation (year) is shown. Data retrieved from Wikipedia (https://en.wikipedia.org/wiki/List_of_countries_by_homeless_population).
[9]Ritchie, H. and Roser, M. 2020. Data retrieved from 'https://ourworldindata.org/co2-emissions' for the year 2019.
[10]Savings in CO_2 emissions from shifting to baseline-adjusted values to a vegan diet, or a plant-based diet that included small amounts of low-food chain animals (as reported by Kim et al., 2019; who considered data for the period 2011–2013).
[11]Per capita meat consumption in the year 2013, according to the FAO Food Balance Sheets (FBS). Data retrieved from FAOSTAT (http://www.fao.org/faostat/en/#data/FBS).
[12]Gini index (as %) reported by the World Bank (2020). Data refer to the year 2018, unless specified otherwise.
[13] Tax revenue as percentage of GDP for the year 2016, retrieved from: 'https://ourworldindata.org/taxation' (Ortiz-Ospina and Roser, 2016).
[14]Government expenditure, as percentage of GDP, on health and education during the period 2013–2018 (World Bank, 2020).
[15]Land area equipped for irrigation (in 1000 ha) in the year 2007, and irrigation system predominant in a given country, as reported by Jägermeyr et al. (2015).

2.2. How we are wasting food

In 2015, biomass extracted to fulfil human nutrition and feed livestock was 12.7 Gt (Krausmann et al., 2018) – for comparison, there would be needed 3100 Parliament Palaces of Romania, the heaviest building in the world, to equal this amount of mass. Biomass extracted for other uses (e.g. timber, biofuels) amounted 10 Gt (Krausmann et al., 2018). For simplicity, we focus only on the waste derived from the food sector, which currently has a higher biomass demand. It is commonly stated that global food wastes through different stages of the food production-supply-consumption chain are about one third of the total food produced, as reported by the FAO (2011). However, Alexander et al. (2017) estimated that roughly half of the food (as dry mass) produced annually in the world is lost (Fig. 2). This study included losses from livestock production and over-consumption, which had been previously neglected. Livestock farming generates the greatest losses in

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Box 1
Global consequences of the society of waste.

The main environmental and social consequences of the society of waste are represented in Fig. 3. The increasing extraction of natural resources, in both total and per capita terms (Fig. 1), is leading to the depletion of resources, even of those considered previously as "renewable" (e.g. freshwater, biomass). In addition, the extraction and processing of food, fuels and other minerals make up about half of total global greenhouse gas emissions (excluding climate impacts related to land use) and more than 90% of biodiversity loss and water stress (Giljum et al., 2014; IRP, 2019). The IRP recently reported that the impacts from climate change increased by a factor of 1.4 between 2000 and 2011, following a similar trend to that of total mass of extracted resources (IRP, 2019).

It is becoming increasingly recognized that we are witnessing the 6th mass extinction event, the only one that is being caused by the appropriation of resources by a single species. At least one million species of plants and animals are facing extinction in the coming decades, half of them being insects (IPBES, 2019). Even populations from species considered as "low concern" by the International Union for Conservation of Nature (IUCN) are also decimated all over the globe (WWF, 2018). The Living Planet Index has estimated that vertebrate populations decreased by 60% between 1970 and 2014 (WWF, 2018) (Fig. 3). The loss of species and populations is inherently negative, but, additionally, the destruction of wild habitats and biodiversity loss is acknowledged for the increase of zoonotic diseases, such as the COVID-19 pandemic that sparked at the beginning of 2020 (O'Callaghan-Gordo and Antó, 2020; Vidal, 2020).

Depletion of natural resources has an impact not only on the environment, but also on society. Approximately 26 million premature deaths per year globally are attributed to environmental and infrastructure-related risk factors resulting from industrial social metabolism (Bringezu et al., 2017). On the EJAtlas, a total of 3516 conflicts related to the extraction and management of natural resources have been reported as of September 2021. The Global Witness report documented the killing of 212 environmental defenders in 2019, four per week on average (Global Witness, 2020). Ironically, the richest countries in terms of natural resources are commonly the ones who suffer the most in this regard. These conflicts can escalate from social unrest into open wars, resulting in hundreds or thousands of deaths and forcibly displaced people (Corral et al., 2020) (Fig. 3). Many of these conflicts involve multinational corporations paying large amounts of money or royalties to local or federal governments to extract resources, leaving most of the population behind, as documented at the Environmental Justice Atlas and elsewhere (e.g. Trefon, 2016; Menton and Le Billon, 2021).

terms of dry matter, energy and protein (Alexander et al., 2017). Worldwide, intensive livestock production demands 36% of global cereals (Cassidy et al., 2013) and 98% of the world's soybean production (Goldsmith, 2008). However, the calories returned as food to humans are very low. For example, for every 100 cal fed to animals as cereals, we only get 3% and 40% from beef or milk, respectively (Cassidy et al., 2013). The feeding of crops to livestock instead to humans therefore undermines food security (Ripple et al., 2014; Stevenson, 2017). Intensive agriculture is considered the main driver of water stress and the second most important human activity leading to biodiversity loss (Maxwell et al., 2016; IRP, 2019) (Fig. 3). As a result of the change in land-use, it is also a major driver of deforestation and anthropogenic greenhouse gas emissions (Ripple et al., 2014; Stevenson, 2017).

We are also wasting a high amount of food in the fisheries and aquaculture industries. The FAO reported that 35% of the global catches are wasted (FAO, 2020). About a quarter of these losses are linked to bycatch or discards, mainly from trawling (Pérez-Roda et al., 2019; Stiles et al., 2010). In addition, fishing gear is sometimes lost or abandoned at sea, where it continues catching unintentionally, giving rise to ghost fishing mortality (FAO, 2020). Other practices, such as shark finning, are significantly wasteful and cruel. Between 63 and 273 million of sharks are killed each year by finning, whereby 5% of the shark's weight is consumed and 95% is thrown away (Worm et al., 2013). Industrialized fisheries are also very inefficient, energy inputs exceeding the nutritional energy embodied in the catch by at least an order of magnitude (Tyedmers, 2004). Both the catching and farming of big carnivorous fish is 10 times more energy consuming than catching smaller fish or culturing herbivorous fish, respectively (Friends of the Earth, 2018; Tyedmers, 2004). At the same time, about one third of total world catch (30 million tonnes) of small pelagic fish is reduced into fishmeal or fishoil to feed farmed animals (Friends of the Earth, 2018; Pauly, 2009). Fish farms also lose millions of fish every year in fish spills and due to the spread of diseases (Friends of the Earth, 2018). Intensive aquaculture practices involve the supply of high-quality artificial feed, medication and chemicals, with the consequent production of organic and inorganic waste (Arvanitoyannis and Kassaveti, 2008; Chopin et al., 2001; Dauda et al., 2019), fuelling eutrophication (Chopin et al., 2001; Dauda et al., 2019; Friends of the Earth, 2018) and ultimately hypoxia, as previously described (Fig. 3). This is especially true for the raising of shrimp and carnivorous fish. Together, the intensive farming of both land and aquatic animals is the major contributor to the wasteful use of antibiotics, accounting for more than 50% of all antimicrobial production in some countries (WHO, 2011). Environmental degradation and the widespread use of antibiotics in intensive farming are leading to an increase in human diseases (WHO, 2011; Vidal, 2020).

Human population has grown faster than food production since 1900 (Fig. 1). Thus, the loss of almost half of the total food produced in a year indicates that we have been either producing more food than we need to accomplish our per capita dietary requirements, or a huge fraction of the human population are undernourished. The truth is actually a combination of both. Across the 25 most populated countries, the share of people undernourished reaches values >15% in some countries within the African continent (Table 1). On the other side, the share of obese adults attains values >20% across all regions of the world (Table 1). While in low-income countries food losses occur mainly at early stages of the food chain (from production to retailing), in upper-middle and high-income countries more than 40% of the yearly losses are due to overconsumption and the direct discarding of food (FAO, 2011).

As of September 2021, 184 and 134 conflicts have been reported on the EJAtlas in relation to intensive food production (monoculture and livestock) and aquaculture and fisheries, respectively – there are many more related to land acquisition and deforestation. The onset of industrial fishing at the end of the 19th century has led to the progressive depletion of first onshore, and then offshore fish stocks (Pauly, 2009). Overexploited fish stocks account for 33% of global fisheries (FAO, 2020) and, in coastal regions, fish biomass has been reduced globally by about two-thirds compared to pre-industrial levels (Edgar et al., 2014). The depletion of fishing stock in the northern hemisphere was followed by a southward expansion and the development of industrial fishing in non-industrialized countries, yielding to the reduction of stocks in even remote areas of the world (Pauly, 2009). This expansion has consequently driven international resource conflicts, such as the famous case of the Somali "pirates". Illegal, unreported, and unregulated fishing by foreign vessels in Somalia has been taking place for several decades since the collapse of the Federal government in 1991. Organized groups of fishermen then started to hijack fishing vessels, partly in response to the international community refusal to acknowledge illegal fishing (Glaser et al., 2019).

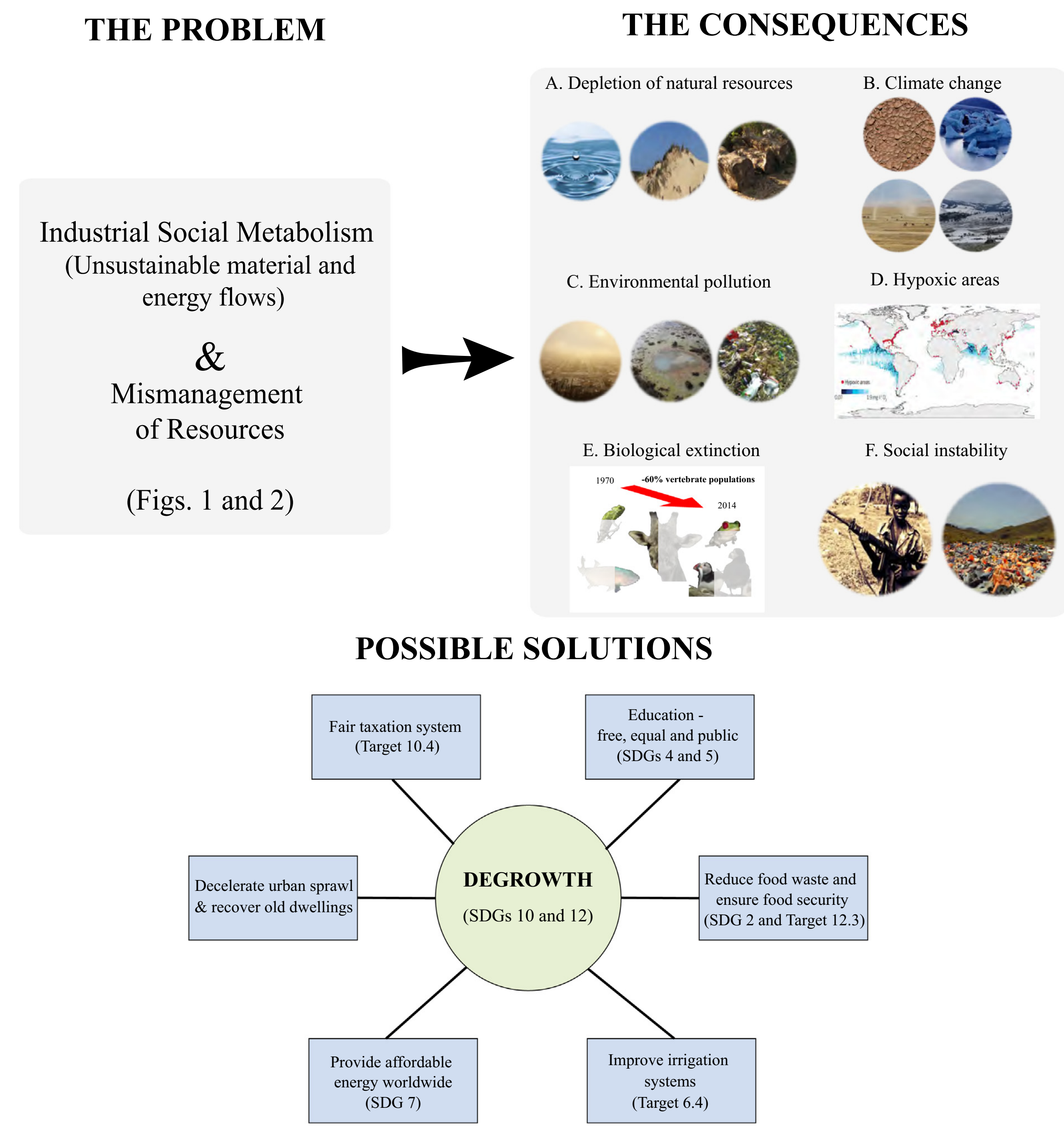

Fig. 3. Industrial social metabolism and the mismanagement of resources demand and waste high amounts of natural resources. As a consequence, natural resources are getting depleted (A). Human societies are also driving global environmental changes, such as the current climate change (B); the pollution of the atmosphere (free picture retrieved from Pexels at https://www.pexels.com), the hydrosphere and the geosphere (C); the increase in hypoxic zones worldwide (D; image from Breitburg et al., 2018); or biological extinction (E). The scarcity and unequal distribution of resources leads to armed conflicts, as represented here by a child soldier (picture retrieved from El País, 2014), and desperate travels, as displayed in this picture of the "lifejacket graveyard" in the island of Lesvos, Greece (F). To ease human impacts on the planet and reach equality among human beings, we advocate for degrowth, accompanied by other socio-economic and technological strategies. In parenthesis is noted the link between these strategies and the SDGs or Targets of the 2030 Agenda.

2.3. How we are wasting mineral resources

As an increasing proportion of the global society is becoming industrialized, the demand for materials has shifted from renewable to non-renewable resources, reflecting the global trend away from agriculture-based to urban and industrial economies (Bringezu et al., 2017; Krausmann et al., 2018; IRP, 2019) (Fig. 1). Since the industrial revolution, this transition from circular to linear economies has generated new waste flows, leading to increasing pollution (IRP, 2019). We have calculated that 23.5 Gt of solid waste are generated annually from the food and mineral industries (Fig. 2). This number does not include other solid waste that is increasingly accumulating in the environment, such as plastic materials (Box 2).

2.3.1. Metals

In 2015, 6.5 Gt of ores were extracted globally, from which 5.5 Gt (85%) were discarded as tailings shortly after processing (Haas et al., 2020; Krausmann et al., 2018) (Fig. 2). The extraction of metals has grown by an average 36% per year since 1900, reflecting the importance of metals for construction, industry, energy and transport infrastructure, manufacturing and many consumer goods (IRP, 2019). This increase is more than 6 times higher than the increase in population growth in the same period (Fig. 1). A great variety of metals are now required in unprecedented quantities for everyday items (e.g. indium in cellular phones; Gulley et al., 2018), low-carbon technologies (e.g. tellurium in solar cells; Nassar et al., 2020; UNEP, 2016), and applications related to national security (e.g. germanium for infrared goggles; Gulley et al.,

Box 2
Single use products, the climax of the society of waste.

Solid waste is becoming a major footprint of the environmental degradation caused during the Anthropocene. According to our estimations (based mostly on data retrieved from Krausmann et al., 2018 and Haas et al., 2020; see Sup. Mat.), the world generates at least 23.5 Gt of solid waste (including both industrial and municipal) annually (Fig. 2). This value is 10 times higher than reported by the The World Bank (Kaza et al., 2018) – which only includes municipal solid waste, and does not consider e.g. losses from minerals other than metals –, but it is as the 20 Gt reported by Krausmann et al. (2018). While municipal waste generated in lower income countries is mostly composed by food and greens, 51% of the waste generated by wealthy countries is dry waste, including plastic, paper, metal, and glass (Kaza et al., 2018). The increasing production and misuse of plastics is currently getting notable attention. Plastics are replacing other materials for diverse purposes because, among other advantages, they are durable and resistant to degradation (Gago et al., 2018). Ironically, around 40% of all plastic produced yearly is destined to produce single use or short-lived products (Napper and Thompson, 2019). In a planet close to ecological collapse, we simply cannot afford the profligacy of intentionally designing items aimed to be dumped after extremely short usage – unless for specific healthcare products.

2018). The design of products to have an artificially limited useful life (planned obsolescence) increases the demand for metals and other materials even more. Once products containing metals reach their end of lives, recycling is economically and technologically challenging (Prior et al., 2012; UNEP, 2016), since most waste products are a complex mixture of metals and other materials.

The continuous rising demand of metal ores is leading to their depletion. Three groups of metals widely used may become critical in the coming years: the rare-earth elements, the platinum-group (platinum, palladium, iridium, ruthenium, rhodium and osmium), and indium (Hayes and McCullough, 2018; Nassar et al., 2020). Aluminium, copper, iron, manganese and zinc, five out of the six most produced metals, are estimated to reach their maximum production peaks before the end of the 21st century (Calvo et al., 2017). In addition, a declining trend in ore grade has been observed for copper, gold, lead, nickel, silver and zinc (Calvo et al., 2017, and references therein). This implies that more water, energy, and capital will be needed to extract and process this low ore grade mines to obtain the same amount of ore than before, generating more waste rock (Calvo et al., 2017). Prior et al. (2012) reported that "while reliable mineral availability and supply is a concern for critical and scarce metals, production limitations resulting from social and environmental constraints and impacts are likely to arise well before physical depletion". Environmental damage related to the extraction of ores has increased in parallel with rising demand. It includes high energy intensity and greenhouse gas emissions, the release of smog-forming substances, drinking water drawdown, and mine waste that ultimately yields water pollution, acidification and aquatic ecotoxicity (Bringezu et al., 2017; Prior et al., 2012; Trefon, 2016). There are also social impacts. On the EJAtlas, there have been reported 734 conflicts related to the extraction and processing of mineral ores, as well as disposal of tailing, as of September 2021. It is noteworthy to mention the case of "E-waste". While the African continent generates the less amount of E-waste by far (0.002 Gt out of a global value of 0.45 Gt in 2016; Balde et al., 2017; Kuehr, 2019), a significant part of this waste is increasingly being imported to Western Africa from industrialized countries. Other importing countries are in Latin America, Eastern Europe and Asia (Kuehr, 2019). Electronic devices entering these countries have already been used extensively. Hence, once imported, they may be used for a few weeks, months or years, and are burned afterwards or end up in dumpsites, endangering the environment and human health (Balde et al., 2017).

2.3.2. Fossil energy carriers

Human dependence on fossil fuels inaugurated the Anthropocene. Because of the interdependence that exists between water, food and energy (the so called nexus), the increasing demand of the first two also means an increase in the energy demand. Fossil fuel consumption, however, has increased by 15 times since 1900, an increase much higher than that observed for human population, water and food consumption (Fig. 1). Consumption of fossil fuels per capita has triplicated since 1900, reflecting the increase in the consumption of commodities (especially in wealthier countries, where energy consumption is higher, as shown in Table 1). At an individual level, demand for energy is remarkably the highest for the production of personal items (25%), followed by car trips, heating and cooling, and jet flights (MacKay, 2008).

In 2015, the global extraction of fossil fuels amounted to over 14.5 Gt (Krausmann et al., 2018), accounting for 82% of the total energy produced globally (estimated from data available at the International Energy Agency – IEA – website; https://www.iea.org). Total primary energy supply in 2015 was 570 EJ, of which 394 EJ correspond to final energy consumption. Thus, there is a gap of 177 EJ that is attributed to i) inefficient energy conversion of the technology that humankind is currently using and to ii) useless usage and direct waste of energy. In respect to the inefficiency of energy conversion, there is some level of energy inefficiency that is physically unavoidable, as 2nd Law of Thermodynamics establishes. Nevertheless, commercial technology currently available presents a very ample margin of improvement. In fact, already existing technological solutions could significantly increase energy efficiency. There are already as well regulations oriented to exploit this potential of energy efficiency improvement, as it is the case of the European Union that has established an energy efficiency target increase for the year 2030 of at least 32.5%, with a clause of a possible upwards revision by 2023 (European Parliament, 2018). Therefore, as a first thermodynamic approach, the previously referred gap of 177 EJ (31% of the energy produced) could be mainly considered energy wasted that can be significantly reduced.

Increasing energy demand driven by industrialization has led to perhaps one of the main environmental problems our society is facing, climate change (Fig. 3). Anthropogenic CO_2 emissions, released from the combustion of fossil fuels, amounted for 32.5 Gt in 2015 (Kaza et al., 2018; Ritchie and Roser, 2020; https://www.iea.org) (Fig. 2). Concentration of CO_2 recorded in the atmosphere at the Mauna Loa station, Hawai'i, shows a continued and steep positive slope since the mid-twenty century, reaching ca. 415 ppm as of August 2021 (ESRL's Global Monitoring Laboratory of the NOAA). While fossil fuels still account for most of the energy supply, the availability to extract them globally is decreasing, since it is becoming technologically and economically challenging. According to the IEA, the peak of conventional oil production took place in 2006, while the peak of all liquid hydrocarbons (conventional and non-conventional) is likely to have taken place in December 2018 (IEA, 2010). Some authors (and the data so far) suggest that coal production peaked in 2014, although others expect its peak to occur by the year 2050 (Mediavilla et al., 2013, and references therein). Likewise, gas extraction peaks are expected by 2030 (Mediavilla et al., 2013). Since fossil fuel resources are not evenly distributed globally, and countries have different capacities to extract them, national and international conflicts for their appropriation are increasingly being observed worldwide. On the EJAtlas, 539 conflicts related to fossil fuel extraction and processing have been recorded as of September 2021. It is not a secret that the most powerful military and industrial countries have been fighting for the control over the world's oil producing areas since World War I, especially in the Persian Gulf area and the Caucasus (Klare, 2015). USA President Donald Trump openly admitted in October 2019 that the USA "has taken and secured" oil fields from northeastern Syria (The New York Times, 2019).

2.3.3. Non-metallic minerals (excluding fossil fuels)

Non-metallic minerals are materials such as sand and gravel, mainly used in construction. They comprised over 50% of global material use in 2010 (Miatto et al., 2017), and their extraction has accelerated since 2002 (Krausmann et al., 2018). The extraction of these materials in 2015 was 50 times higher than in 1900 (Fig. 1), while per capita consumption increased by 11 times during that period. From 45 Gt of non-metallic minerals extracted in 2015 (Haas et al., 2020; Krausmann et al., 2018), approximately 26% were returned to the environment as domestic processed output (Haas et al., 2020) (Fig. 2). As cities worldwide expand (Seto et al., 2012), the demand of these materials keeps increasing. Sand is often taken for granted, and its extraction is unregulated or subjected to illegal extraction and trade in most countries (Bendixen et al., 2019; Torres et al., 2017). Astonishingly, a significant amount of buildings and infrastructures around the world are either empty or have no particular use whatsoever. Although data on vacant dwellings are scarce, the OECD has recently shown that, among its members, there are countries with approximately 20% of their dwellings empty (OECD, 2020). Morgan (2017) analysed the top 20 ranking countries from Mercer's 2017 Quality of Living Rankings, and found that 32.5 million houses were empty across them. This number almost equals the number of homeless people in Nigeria and Egypt, the two countries where homelessness is the highest, summing 36.4 million people (Table 1).

Rates of recycling and down-cycling of construction materials are unknown for most of the world. In Europe and Latin America and the Caribbean region, demolition estimates show large quantities of construction waste ending up in landfills (Miatto et al., 2017; Moreno, 2020). Although data from sand extraction are scarce and unreliable, Bendixen et al. (2019) estimated that sand is reaching a maximum yearly extraction, and three-quarters of the world's beaches are already in decline. As a consequence of the increasing scarcity of sand, illegal sand mining is rife in around 70 countries, and hundreds of people have been killed in battles over sand (Bendixen et al., 2019). On the EJAtlas, there have been reported 115 conflicts related to the extraction of building materials as of September 2021.

2.4. Who is wasting the most?

The use of natural resources and material footprint is not distributed evenly among the human population. The material footprint in high-income countries is two times higher than in upper-middle income countries, 5 times higher than in lower-middle income countries, and 13.5 times that of low-income countries (estimated from IRP, 2019). If high- and upper-middle income countries are grouped together on one side, and low- and lower-middle income countries on the other, we find that each group accounts for around 50% of the total population. However, the former accounts for approximately 80% of total material consumption and footprint (IRP, 2019), as illustrated in Fig. 2.

Table 1 provides data on resource use (and potential savings) per capita in the 25 most populated countries. It has to be considered, though, that per capita values reported are usually estimated from a net variable output divided by the total population of a country. However, the distribution of resource use is also unequal within countries. Although detailed data on consumption by the richest sector of the population is scarce (Bringezu et al., 2017; Kenner, 2015), it is estimated that the billion richest individuals consume 72% of global resources, while the poorest 1.2 billion consume only 1% (IRP, 2019). The recent Scientists' warning on affluence argues that affluent citizens are responsible for most environmental impacts and are central to any future prospect of retreating to safer environmental conditions (Wiedmann et al., 2020). The world's top 10% wealthiest is responsible for between 25% and 43% of environmental impact, as compared to about 3–5% of environmental damage from the world's bottom 10% income earners (Teixidó-Figueras et al., 2016). The inequality becomes even greater in the case of carbon footprint. The richest 10% accounts for approximately 50% of global CO_2 emissions yearly, while the poorest 10% is responsible for 1% of them (Teixidó-Figueras et al., 2016). Among the 25 most populated countries, CO_2 emissions per capita range from 30 kg y^{-1} in the Democratic Republic of the Congo (DRC) to 16,375 kg y^{-1} in the United States (Table 1).

In the last decade, the rich – both between and within countries – are becoming richer, while the poor are becoming poorer (Corral et al., 2020; Lawson et al., 2019; Mikkelson et al., 2007). While the richest and most powerful sectors of the population benefit the most from the extraction of natural resources, international trade mechanisms allow them to displace its impact to the global poor (Wiedmann et al., 2020). Less wealthy countries or communities are thus the most affected by natural and anthropogenic hazards (e.g. pollution, extreme weather events) (Dorling, 2010; Kenner, 2015). There is a positive correlation between income inequality, environmental degradation and biodiversity loss (Holland et al., 2009; Mikkelson et al., 2007; Teixidó-Figueras et al., 2016). Mikkelson et al. (2007) reported that this relationship was stronger than those found between biodiversity loss and either human population size or affluence. In the Global North, more unequal societies have higher levels of pollution, take more flights, consume more meat, fish and water per person, and dump more household waste (Dorling, 2010). These inequalities lead to social instability and conflicts, some of which have been analysed in previous sections.

3. The solution: sustainable degrowth and minimization of wasteful practices

In the first part of the paper, we have explained how resource consumption and waste production have dramatically increased in the last century, with devastating ecological and social consequences. We have focused our attention on wasteful practices at the beginning of the consumption chain, rather than on the post-consumption management of waste. The latter is well covered in the literature, from waste hierarchy to zero waste policies (see e.g. Demaria, 2022, and references therein). However, since they are end-of-pipes solutions, they can never solve the problem. Hence, the solutions that follow are aimed to avoid waste production, rather than to manage the existing waste. For the purpose of simplicity, we have not provided either country-specific or city-specific data on every resource consumption and waste production. Some of these estimations are available elsewhere (e.g. Galli et al., 2020; Kim et al., 2019; Mekonnen and Hoekstra, 2011; Vanham et al., 2016; Wiedmann et al., 2015), and we acknowledge the importance of this type of studies to provide adequate management strategies at regional and local scale. Still, we have highlighted that most resources are actually consumed in wealthier countries (as evidenced by e.g. higher water footprint and energy consumption in upper-middle and high-income countries, as shown in Table 1), and more particularly by the richest individuals. Thus, the solutions here proposed are mostly focused on reducing consumption and waste in industrialized countries, and more particularly from the richest sector of the population. Nonetheless, we also propose some strategies to increase efficacy on resource management in both high- and low-income countries.

Politicians and some scientists defend the idea that nations can perpetually grow in a "green" or "sustainable" way, assuming that technological improvements will eventually lead to a decouple between economic growth and material extraction. However, thus far, there is no evidence on this decouple (Parrique et al., 2019; Wiedmann et al., 2015). On the contrary, resource extraction and waste production have increased exponentially in the last decades, as shown in this

(Figs. 1 and 2) and previous studies (Haas et al., 2015; IRP, 2019; Krausmann et al., 2018; Schandl et al., 2018). We are not only consuming more that the Earth can provide, but the planet is no longer able to assimilate all the waste we produce (Box 2). While some argue human population growth is the main driver of ecological damage (e.g. Crist et al., 2017; Hardin, 1968), resource extraction, especially from mineral resources, has increased much faster than human population (Fig. 1), and the most populated countries are not necessarily the main polluters (Table 1). Instead, previous studies have shown that wealth and income inequality are the main culprits of environmental degradation and biodiversity loss (Holland et al., 2009; Mikkelson et al., 2007; Wiedmann et al., 2020). Thus, as facts evidence, there is an urgent need for a radical transformation of the current, linear, socio-economic model towards a circular one, more equitable and respectful with the environment and other species and human beings. The problem is that the current linear industrialized economy cannot easily be turned into one that emulates the circularity of ecosystems without radical changes in its structure and functions. This is the central challenge of the sustainability transformation. Due to the urgency of the situation, we propose that industrialized countries should follow a degrowth strategy to face immediate challenges, at least until an eventual decoupling between economic growth and material extraction is achieved. Degrowth is understood as "a democratically led redistributive downscaling of production and consumption in industrialised countries as a mean to achieve environmental sustainability, social justice and well-being" (Demaria et al., 2013), and has been previously proposed by several scholars as an alternative to the current, market-driven economic system (e.g. D'Alisa et al., 2015; Demaria et al., 2013; Kallis et al., 2020; see also https://degrowth.org). It calls for a future where societies live within their ecological means, and resources are distributed more equally through new forms of democratic institutions (D'Alisa et al., 2015). D'Alessandro et al. (2020) showed with a macrosimulation model that following a strategy of degrowth it is indeed possible to reduce greenhouse emissions while increasing economic equality. In opposition, projections of a green growth model predict an increase in inequality (D'Alessandro et al., 2020). Similarly, Keyber and Lenzen (2021) have recently found by means of a quantitative model of the fuel-energy-emissions nexus that degrowth scenarios minimize many key risks for feasibility and sustainability compared to technology-driven pathways. While seems more difficult to advocate for degrowth in low or lower-middle income nations, there is plenty of room in some of these countries for a better distribution of wealth, as indicated by Gini indexes above 40% in countries such as Tanzania, the DRC or the Philippines (Table 1). As an example, in the DRC, GDP has quintuplicated in the last 20 years, but only the elites of the country and multinational corporations have made profit from these earnings (Trefon, 2016). Data from the 25 most populated countries show that the Gini index can actually be similarly high or even higher in upper-middle and high-income countries such as South Africa (63%) or the United States (41%) (Table 1). This means that high GDP values do not necessarily represent the wealth of a country's inhabitants. Thus, we support the idea that GDP should not be used as indicator of progress, but substitute it by other indicators that account for environmental and social wealth of societies (Demaria et al., 2013; Hickel, 2020, and references therein).

Degrowth raises many challenges also for industrialized countries, for instance in terms of employment and debt. How can economies without growth become socially sustainable and economically stable? How can novel economic policies facilitate the transition to such sustainable economic systems? Kallis et al. (2020) explore the politics of degrowth and proposed five 'non-reformist reforms' for high-income economies: 1) Green New Deal without growth ; 2) Universal Care Income and Universal Basic Services; 3) Reduction of working hours ; 4) Support for the commons; 5) An overhaul of taxation and fiscal systems that, for instance, taxes carbon and resource use, instead of work. Kallis et al. (2020) argue that these strategies in synergy can promote a transformation beyond growth. Along these lines, hereafter, we discuss 6 proposals more specific to tackle the problems of the "Society of waste" addressed in this paper. Two of these — a fairer taxation system and public education – have the general purpose to reduce social inequality and superfluous consumption, while the other 4 tackle the main sources of waste for water, food and mineral resources. These proposals have common ambitions with the Sustainable Development Goals (SDGs) established by the United Nations at the 2030 Agenda (UNEP, 2015b), as schematized in Fig. 3. Although we question the call for sustained economic growth, stated at SDG 8, our suggestions are in agreement with SDGs 10 – Reduce inequality – and 12 – Ensure sustainable consumption and production patterns –, among others that are discussed below.

3.1. Strategy 1: build fairer taxation systems and internalize environmental costs

While we encourage the whole society to take part in the shift towards sustainable degrowth, we believe governments worldwide need to provide the adequate tools for this change to happen. As previously discussed, income inequality (as evidenced by the Gini Index; Table 1) is one of the main reasons for ecological degradation, as well as social dissatisfaction. To reduce inequality within countries, governments urgently need to ban tax havens and implement fairer taxation systems (Target 10.4 of the 2030 Agenda) (Fig. 3) that increase progressively with net wealth, ensuring that corporations and the richest individuals are not under-taxed, as recently revealed by Oxfam (Lawson et al., 2019). The implementation of an adequate taxation system of course relies on political willingness, which may be the reason why some politically unstable countries such as the DRC and Nigeria have very low tax revenues (Table 1). On this regard, bottom-up actions from citizens and NGOs may be needed to exert pressure on governments. Whereas to estimate country-specific benefits from undertaxed fortunes remains difficult (since a good part of them are hidden in tax havens), the revenues from these taxes could be allocated to public social services such as education and health, accomplishing with SDGs 4 – Ensure inclusive and equitable quality education –, 5 – Achieve gender equality and empower all women and girls –, and Target 3.8 – Achieve universal health coverage – of the 2030 Agenda. Currently, expenditure on education and health accounts together for less than 15% of GDP in most of the 25 most populated countries (Table 1). In addition, we agree with Wiedmann et al. (2020) that both a basic and a maximum income level need to be set. For example, the international standard Wagemark established that the ratio between the highest and lowest earners should be within a 8:1 ratio.

National governments also need to regulate that corporations internalize the environmental costs derived from the environmental damage they produce. We also advocate for an extended producer responsibility, meaning that manufacturers must take responsibility of their products also at the post-consumer stage (Bringezu et al., 2017). This, jointly with ending with the negligent practice of planned obsolescence, will contribute to circularity, since companies would have an incentive to give a second life to waste. As an example, some phone companies are already reusing minerals from old smartphones in the manufacturing of new ones. Governments should halt the subsidies and investments currently provided to highly polluting activities, such as fossil-fuel (Target 12.c of the 2030 Agenda) and certain types of industrial meat production and fisheries (Target 14.6) (Crist et al., 2017; Fuchs et al., 2016; Pauly, 2009), and instead subsidize economic activities with good environmental and social practices that favour a circular economy. As an example, regenerative organic agriculture systems incorporate permaculture and organic farming with mobile livestock shelters and grazing where the excrements of forage animals are used as fertilizers for crop production, closing the production loop. These systems have been proven to provide greater ecosystem services (e.g. restoring the carbon content of the soil), and profitability for farmers than inputintensive models of crop production in the United States (LaCanne and Lundgren, 2018). Following the "Scaling up Agroecology Initiative" (FAO, 2018), Ethiopia and Mali have reduced hunger from 37 to 20% and from 14 to 5%, respectively, since 2006.

3.2. Strategy 2: promote education for responsible consumption

Education is also a key pillar towards sustainability. Governments should offer a free, equitable and public primary and secondary education to their whole population, accomplishing with the aforementioned SDGs 4 and 5 of the 2030 Agenda (Fig. 3). According to Oxfam (Malouf-Bous, 2019) "transformative public education fights economic and gender inequality, builds active citizens, protects communities and the environment, and forges inclusive and stable societies". More particularly, awareness programs and policies aimed to reduce superfluous consumption (SDG 12) need to be developed, and properly coordinated across various governmental levels. This is especially important for the reduction of mineral extraction and energy production, since, as explained in "The problem" section, personal items constitute the main demand for energy and a variety of metals. The more aware the people are on our impact on the environment, the more they prone to take action. Some examples are the increasing number of individuals and associations working to tackle plastic pollution worldwide, or the global "Youth for Climate" movement. In addition, a free education system can bring other positives consequences such as informed birth decisions, which may follow a reduction in total fertility rate (Kim, 2016), another driver of environmental damage (Hardin, 1968; Crist et al., 2017; Ripple et al., 2017). Free education promoting a reduction in overconsumption presents a big challenge first for the countries that still rely mostly on private education for the elite of the country. On this regard, Oxfam has pointed that the promotion of private schooling in low-income countries by international donors reinforces social inequalities and excludes especially girls (Malouf-Bous, 2019). It is also a challenge for most industrialized countries where a consumption-driven model is being increasingly implemented and promoted by the richest fortunes that benefit from this system, and have the power to control consumption patterns across the population (Fuchs et al., 2016; Wiedmann et al., 2020). That is why the previous strategy (more equal distribution of wealth) is also key towards a sustainable downscaling in consumption.

3.3. Strategy 3: reduce food (water & energy) waste and ensure food security

Because of the nexus that exists between water, energy, and food, to reduce the first two highly depends on the reduction of food waste (Kim et al., 2019; Vanham et al., 2016). This corresponds to target 12.3 of the 2030 Agenda, and it is also tightly linked with SDG 2 to ensure food security worldwide (Fig. 3). According to a recent report from Compassion in World Farming (Stevenson, 2017), an extra 3.55 billion people could be fed with current food production by 2050 if we halved (i) the use of cereals as animal feed – and eat them directly instead –, (ii) the discard of food and (iii) overconsumption. Country-specific variabilities have to be considered here, though, the last two measurements applying only to the wealthiest. To avoid the discard of food in industrialized countries, we suggest – along with strategies 1 and 2 – to follow the advices of the FAO (2011) and (1) promote the cooperation among farmers to reduce the risk of overproduction; as well as (2) incentivate closer sales from producer to the consumer, promoting urban-rural linkages (Galli et al., 2020). Following a circular model, when food is no longer suitable for human consumption, it could be used to feed animals, for food conversion or composting.

Overconsumption drives health issues such as obesity, a problem that is becoming common especially in upper-middle and high-income countries (Table 1). Based on data so far, we believe there is no need to produce more food, but to share it more equally and eat healthier. In this sense, the shift towards plant-based diets can bring positive consequences on the health of the planet and its people. Vegan diets or diets including modest amounts of low-food chain animals (e.g. bivalves, insects) are expected to reduce the water footprint and CO_2 emissions up to 57% and 87% baseline values, respectively, in some of the most populated countries such as Brazil, Egypt, France, Russia, South Africa, Turkey or the United States (Kim et al., 2019) (Table 1). Other studies have reported similar results for different cities from industrialized countries in Europe (Vanham et al., 2016; Galli et al., 2020). Some authors have, however, pointed to the challenges of shifting towards more sustainable diets due to deficiencies in local and national policy implementation (Galli et al., 2020; NASEM, 2019), or through lobbying exerted by transnational corporations (Fuchs et al., 2016). On the other hand, changing to a vegan diet may result in some countries in an increase of the water footprint, as observed for Ethiopia or India (Table 1). This is because inhabitants from these two countries rely mostly on local agriculture and livestock production (Tafere and Worku, 2012; Venkatesha et al., 2016). Therefore, a shift to a plant-based diet also needs to account for the origin of the products and international trade networks. Whenever possible, we recommend the consumption of seasonal and locally grown products. The reduction of overconsumption and moving to healthier diets may in addition revert on economic savings to national health systems.

Managing by-catch and discards from fishing is also urgently needed to reduce both food waste and biological loss. Improvement of fleet communication, scientific monitoring as well as economic incentives for landing by-catch and discards should be applied. In the case of the latter, a better assessment needs to be done to understand which species may survive and which not when they are returned to the sea. We welcome the recent announcement made by the European Commission to increase efforts to control by-catch (European Commission, 2020). However, specific measurements are yet to be implemented by each state member. An international agreement should ban the most damaging fishing methods such as bottom trawling. It is equally important to design gear that increases selectivity and to encourage the removal of the derelict one. In any case, management strategies should focus especially on industrial fisheries, and consider country or region-specific dependency on fish and seafood products and cultural heritage. Aquaculture carried out in ponds, cages and flow through systems needs to be substituted by systems that reduce waste, increase efficiency, and limit the escape of cultured fish. Recirculating Aquaculture Systems, biofloc technology, and integrated multi-trophic aquaculture systems are promising alternatives for a circular economy (Chopin et al., 2001; Dauda et al., 2019; Friends of the Earth, 2018). As an example of circularity, multitrophic aquaculture in Ghana have been proven effective to grow algae that serve to feed omnivorous fish such as the Nile tilapia, whereas the excess cultivated nutrient-rich algae is used as land fertilizers (The Fish Site, 2021).

3.4. Strategy 4: reduce water losses by improving irrigation systems

While the practice of agroecology aforementioned should help to reduce the demand of water (FAO, 2018), we suggest that non-beneficial evaporation in agriculture could be optimized by replacing surface irrigation by sprinklers and drip systems (target 6.4 of the 2030 Agenda; Fig. 3). Globally, this could allow for water drawdown saving by 44% in the case of sprinklers and 68% with drippers (Jägermeyr et al., 2015). The latter are very efficient in water use (Hamdy et al., 2003; Jägermeyr et al., 2015), and thus their implementation could be particularly relevant in water stressed countries such as those in the Mediterranean region, the Middle East or South Asia, most of which still relying on surface systems (Table 1). Natural conditions (type of soil, climate, etc.) and social factors need to be considered before upgrading to sprinkler or drip systems, though. These systems, especially the latter, have high capital investment per hectare, and thus are preferred for high value crops, such as vegetables and fruit trees (FAO, 2012). It also needs to be carefully assessed the impact of the reduction in the return flow on downstream users (Jägermeyr et al., 2015).

3.5. Strategy 5: reduce energy consumption to provide affordable energy worldwide

Governments should decarbonize their economies and move towards low-carbon sources of energy. However, in industrialized countries, the replacement should be accompanied by a reduction in consumption. Firstly, because in a business-as-usual scenario, with a 3% economic growth yearly, the demand for energy would be greater than the supply, even with a 8% increase in renewable energies (Mediavilla et al., 2013). Instead, a scenario of economic degrowth of −0.5% yearly shows that the demand for electricity decreases significantly and an annual growth of 10% in renewable energy would be sufficient to cover all the electricity demand in 2050 (Mediavilla et al., 2013). Secondly, because even low-carbon energy sources have other negative impacts on the environment, such as the damming of rivers in the case of hydroelectricity, the high amount of metals required for manufacturing of renewables infrastructure, or the change in land use required for most types of renewables. An important sector where energy consumption could be remarkably reduced at both local and global scale is in the transportation of goods and people. The transport mode that requires the most energy per person is the car, followed closely by sea and air transport; while bus and rail are far more efficient (MacKay, 2008; Trainer, 2019). We thus encourage the expansion of the public transportation systems in cities (as pledged in target 11.2 of the 2030 Agenda), as well as the use of non-motorized transport when possible, what would in addition bring positive health consequences.

Energy savings can be achieved in a context of a circular economy. For instance, at a municipal level, district energy systems can supply heating and cooling energy services taking advantage from the own urban heat, generated from industrial plants, sewage systems, or underground railway tunnels (Lagoeiro et al., 2019). These systems may have limitations depending on the specific urban area, but there are different sources, including local renewable energies, with the potential to provide energy all-year round (Werner, 2017; Buffa et al., 2019). For cooling networks, locally available water sources such as rivers, lakes or the sea can also be used, as it is the case of the district cooling network at Toronto in Canada, Gujarat in India or Port Louis in Mauritius (UNEP, 2015a). If buildings are very inefficient, they require basic efficiency measures, such as insulation, energy efficient lighting and other retrofits. However, as a building's efficiency improves, district energy can provide greater efficiency savings than full retrofits (UNEP, 2015a). A transition to such systems as compared to current prevailing systems of energy supply, could reduce primary energy consumption by 30–50% and CO_2 emissions up to 58% by 2050 (UNEP, 2015a). Because the costs are not very high, and local energy is capitalized, these systems can ensure affordable modern energy worldwide in a sustainable way, achieving Goal 7 of the 2030 Agenda (Fig. 3).

3.6. Strategy 6: decelerate urban sprawl

Apart from demanding 70% of the total energy produced (UNEP, 2015a), urban sprawl is the main culprit for sand appropriation (Torres et al., 2017), and one of the main drivers of land-cover change and biodiversity loss (Foley et al., 2005; Seto et al., 2012). Regarding construction material, it has been recently proven that 100% of the arid materials used in construction could be replaced by recycled aggregates (Betancourt-Quiroga et al., 2019), which could reduce to almost zero the extraction of sand and gravel. We also advocate that, when empty houses are available, it is unreasonable to construct more buildings. The implementation of an empty home tax may alleviate the housing problem existing in most countries worldwide. In Melbourne, the 1% "vacant house tax" has already been implemented, taxing owners when the dwelling is empty for more than 6 months (Morgan, 2017). Bourne (2019) reported that an empty home tax of 1% would generate the equivalent of 11% of the current council tax in England and Wales. In addition, the recovery of old dwellings, some with historical and patrimonial relevance, should be preferred over new construction. Refurbishment works should be sustainable, considering energy efficiency aspects, as mentioned earlier. This not only saves extraction of raw material but also energy by preserving the "embodied energy" already represented in the existing buildings (EPA, 2016). A practical case is the Retro-Tek project, which is bringing empty homes back into use in the UK with 75% energy savings and 67% reduction in annual CO_2 emissions (Ceranic et al., 2017).

4. Conclusions and future perspectives

We have shown that the extraction of natural resources in the last 115 years has increased at a much faster pace than human population has grown. Furthermore, a remarkably percentage (more than 30%) of the resources extracted are not used to cover basic human needs, but directly discarded or mismanaged somehow. On this regard, extracted resources are consumed and wasted mostly by the wealthiest. As a consequence, even resources previously thought to be renewable, are getting depleted. Where resources still stand, they are getting polluted. Competition for increasingly scarce resources is yielding an annihilation of other forms of life, as well as bringing social and economic instability.

We have proposed to follow a degrowth strategy to minimize the depletion of natural resources, the production of waste and ultimately environmental degradation and social conflicts. Degrowth, though, is unlikely to be promoted by the most powerful actors of the current consumption-driven economic model, who benefit from it (e.g. Fuchs et al., 2016; Wiedmann et al., 2020). Therefore, we believe the active participation of citizens is key to change this model, but governmental institutions may need to be involved mainly by providing citizens with the means (i.e. public services) to address the change. For example, we suggest to start by a redistribution of wealth and income and provide citizens with a public education system, in agreement with Sustainable Development Goals 4, 5 and 10 of the 2030 Agenda (UNEP, 2015b). Recent research has shown that resource use could be significantly reduced in many wealthy countries without affecting social outcomes (O'Neill et al., 2018). There are also practical examples within these countries of small communities or eco-villages that have managed to successfully reduce their material and energy footprint, as well as economic costs, and live happier and in harmony with the environment (Trainer, 2019; see also www.thesimplerway.info). Still, more research is needed on how to implement sustainable degrowth strategies at larger spatial levels, and about its short-term implications (see e.g. Kallis et al., 2020).

Degrowth can be accompanied by other social and technological strategies that optimize the management of natural resources, minimizing waste. On this regard, we have proposed to significantly reduce meat consumption and the direct discard of food to ensure food security. Shifting to more plant-based diets could in addition reduce freshwater and CO_2 footprint up to 57% and 87%, respectively (Kim et al., 2019; Vanham et al., 2016). There is increasing research and public campaigns on food waste and its link with freshwater and energy losses, as well as undernutrition and food security (e.g. Alexander et al., 2017; NASEM, 2019; FAO, 2011; Kim et al., 2019; Stevenson, 2017). Still, there is a need to assess real reductions at country level and its socioecological impacts, as well as implementing public policies to reduce food waste (NASEM, 2019) and meat consumption (Fuchs et al., 2016; Galli et al., 2020). We also emphasize the importance of monitoring discards from fisheries and regulating by-catch. We acknowledge the recent report from the European Commission (2020) on the implementation of the Marine Strategy Framework Directive as a step forward in this direction, but global agreements are also urgently needed to control unregulated fisheries and their social impacts.

The other solutions here suggested are more technical and include upgrading irrigation systems to reduce freshwater losses (from 44 to 68%; Jägermeyr et al., 2015) from agriculture; more selective fishing nets (at least 9% of reduction of by-catch and discards if trawling was banned); circular aquaculture systems; district energy systems for reducing primary energy consumption (30–50%) and CO_2 emissions (up to 58%) (UNEP, 2015a); or decelerating urban sprawl and the reconstruction of old dwellings over new construction (~75% energy savings and ~67% reduction in annual CO_2 emissions; Ceranic et al., 2017). Regarding energy production, the ecological impacts of fossil fuel burning are currently well known and low-carbon alternatives are being propelled globally. However, we warn that for supplying sustainable energy worldwide, the shift needs to be accompanied by a downscale in energy consumption, as suggested by other authors (e.g. Mediavilla et al., 2013; Keyber and Lenzen, 2021). As the extraction peak for all liquid hydrocarbons is likely to have taken place already (IEA, 2010), we forecast there will be increasingly more energy, capital, environmental and social costs related to those already existing. The same applies to the extraction of some metals in the near future, which extraction is expected to increase for low-carbon technologies and personal items such as cellular phones or computers. On this regard, we stress that further research is particularly needed on the increasing extraction and waste from metals and other, non-metallic mineral resources, which socioecological impacts remain understudied (Bendixen et al., 2019; Torres et al., 2017). Regarding social conflicts related to resource extraction and waste, open-access tools such as the Environmental Justice Atlas (ejatlas.org) can be very useful to visualize these global problems.

In all, the solutions proposed in this *Discussion* article should help to move from a wasteful to a wasteless society, from linear economies centered around economic growth to circular economies that prioritize well-being, social equity, and ecological sustainability. By no means we attempted to be exhaustive and we acknowledge that other socio-economic and technical strategies may be followed to achieve sustainability and equity. We, though, believe our proposals may incentivate further discussion among the scientific community, policymakers and the whole society to reach an agreement on truly sustainable alternatives to the prevalent, consumption-driven, economic model that is unfair with the planet and its people.

CRediT authorship contribution statement

I.M-B. designed the main idea of this study, prepared the figures and wrote a first draft of the manuscript to which all the other authors contributed. All authors read and approved the last version of the manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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