

Article

Changes Toward Sustainability: A Review of Countries' Performances

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Abstract

Here, changes in sustainability are assessed using statistical data for all countries between 1990 and 2015, with a focus on the fifteen most populous countries. The indicators used cover GDP for the economy; poverty, education, and health for human capabilities; as well as environmental impacts on water, climate, air, and bioresources. An authoritative model is used to describe the environmental impacts, resulting from pressures driven by population and affluence; and responses, through decreasing resource intensity, measured by the resource use per GDP, and improving environmental efficiency, defined as emissions per resource use. Resource intensity decreases in most countries. Environmental efficiency improves for wastewater and NO_x, hardly changes for CO₂, and increases in nature protection areas, but this rarely compensates for deforestation. The combination of pressures and responses reduced water pollution and air pollution, and mitigated climate change in high-income countries, but did not reduce the degradation of biodiversity. While the pressures, responses, and environmental impacts of economic growth vary across all countries, twenty-five growing economies have reduced those environmental impacts. Changes toward sustainability are discussed with regard to the growing share of services in economies in the 'EKC hypothesis', innovation for achieving higher value at lower impact in the 'green growth' idea, and regulations that lead to profitable environmental investments in the 'Porter hypothesis'. Combined, they only partially explain the changes because they ignore the low prices of natural resources and high shareholder consumption. Additionally, regulations are needed that increase the price of environmental impacts relative to the price of man-made resources and enforce high-quality performance standards.

Keywords: economy; human capabilities; environmental impacts; sustainable innovations; competition



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1. Introduction

We address the issue of whether economies worsen environmental qualities or evolve toward sustainable development, defined as changes that meet the needs of the present generation without compromising the ability of future generations to meet their needs [1]. In this paper, the author's previous sustainability assessment is revisited, purposed for a new interpretation of the data on environmental impacts and an explanation of changes toward sustainability [2]. Before elaborating on that issue, a few definitions will help to avoid misunderstandings. Sustainability is defined as a process of economic changes that

reduce environmental impacts [3]. In this process, exhaustible natural resources are used together with non-exhaustive man-made labour, capital, and knowledge. This use aims to add value, but it can degrade the quality of natural resources, sinks, and organisms; this is called environmental impact. Resource-intensive use means heavy use of a resource relative to income. A value addition is income minus purchases, and a profit is income minus all costs. Innovation is a major qualitative change for the cost-saving or value-adding use of resources. A value-adding innovation that reduces environmental impacts is called a sustainable innovation. The sum of value additions in a country is measured by the gross domestic product (GDP), equivalent to the national income minus exports. Economic growth is determined as increasing GDP.

1.1. Changes in Environmental Impacts

Environmental impacts are described here, aiming to answer the question about how environmental impacts have been reduced across countries. Therefore, a conventional environmental model is used, called IPAT [4]. In this model, affluence and technology are integrated into the original environmental impact function of population [5]. Regarding disputed causalities, the impact function is simplified into an equation [6]. Environmental impacts are assumed to be the result of population, P , affluence, A , and technology, T . Formally, this is

$$I = P \cdot A \cdot T. \quad (1)$$

This equation can be decomposed into environmental impacts, which are the result of population, P , affluence per person, a/p , resource intensity, m/a , and environmental efficiency, i/m , which is, formally,

$$I = P \cdot a/p \cdot m/a \cdot i/m \quad (2)$$

This IPAT model, known as the Kaya identity, is utilised in this paper [7]. Pressures on environmental qualities are indicated by population and affluence per person $P \cdot a/p$. These are measured as the number of people in a country and GDP per capita, respectively. Their multiplication equals GDP. Responses are estimated by the resource intensity, m/a , and environmental efficiency, i/m . The resource intensity in this model is measured by the use of a natural resource, in physical units, per GDP, in monetary units, which can be MJ of energy per USD. It indicates the effect of consumption on environmental impact. Environmental efficiency is measured by the discharge, in physical units, per use of a natural resource, in physical terms, such as kg CO₂ per MJ of energy. This indicates the effect of technology on the environmental impact. Responses to the pressures are shown by their multiplication: $m/a \cdot i/m$. Environmental impacts are estimated by multiplying the pressures and responses.

Insofar as data is available, all pressures and responses are assessed in the period 1990–2015, which enables comparisons across indicators and countries. It is expected that the pressures increased while the responses improved during that period of time, which is expressed as decreasing environmental impacts across countries. The described environmental impacts are followed by explanations of the changes in pressures and responses.

1.2. Explanation of the Changes

A commonly accepted idea is that environmental impacts are regulated by a country's policies. In this paper, we address the main drivers of decreasing environmental impact, in addition to examining policy-driven regulations. The additional drivers can be defined through focusing on the impacts during the period 1990–2015, when environmental policies were disseminated in nearly all countries, while regulations were often replaced by voluntary agreements with private interests [8]. These arrangements were typically

backed by subsidies [9]. Hence, the changes during that period were largely driven by market forces and policy agreements with subsidies. Given this relaxation in regulations, three hypotheses are used that address the economy as a whole, businesses within an economy, and firms within businesses. These hypotheses are considered in addition to another one solely for discussing changes in performance. As these hypotheses have been tested by numerous scholars, these ideas are used without additional tests in this paper.

The hypothesis that addresses the economy, called the ‘Environmental Kuznets Curve’ (EKC), assumes that the environmental impact of higher incomes is represented by an inverted-U curve. In this idea, growing economies are driven by the shift from land-intensive agriculture and material-intensive industries, which are polluting, to low-polluting labour-intensive services. Herewith, services are comprehended as sales of intangibles [10]. Empirical assessments of the EKC hypothesis across countries, natural resources, and pollutants are inconclusive [11]. Along with the inverse-U curves, continuous increases and decreases have been shown [12–15]. These are assumed to be driven by services, as well as combinations of technologies, policies, and income disparities [16–20]. This paper does not verify this, but considers the EKC hypothesis as a possible driver of changes toward sustainability.

Across businesses, innovation can increase value while reducing environmental impact, mainly due to lower material intensity in economic activities. Such sustainable innovation is observed at the levels of countries [21], businesses [22], firms [23], and products [24]. That there is a spur from sustainable innovation constitutes the ‘green growth’ hypothesis. In support of this idea, a decoupling of economic growth from environmental impacts is observed [25]. This is also pursued in international policies [26]. The main counterargument is that the decreasing impact driven by lower material intensity in production is nullified by growing consumption generated by economic growth; this is called the rebound effect [27]. The idea of rebound effects became popular in sustainability assessments [28]. Other scholars observe decoupling after the correction for rebound effects in several countries [29], and in global energy consumption [30]. Rather than addressing a particular opinion, in this paper it is assessed whether businesses generate sustainable innovations, or largely fail.

The ‘Porter hypothesis’ addresses an efficiency increase triggered by demand for environmental qualities. The assumption is that stringent demands through environmental regulations increase profits by drawing managerial attention to inefficient operations [31]. Stringent demands would improve firms’ quality performance [32], lead to innovation in production technologies [33], and improve life cycle management of products [34]. However, the idea that regulations can improve profitability is emphatically opposed by businesses and mainstream economists on the argument that markets generate optimal solutions because more efficient entrants replace incumbents [35]. Attempts to verify the Porter hypothesis show ambivalent results [36,37]. This paper does not aim to resolve this debate that touches a foundation of the mainstream, neo-classic economic theory. It solely shows the increasing demand for environmental quality and firms’ responses through investment.

It is expected that the above-mentioned hypotheses, which are considered cumulatively, will only partly explain the changes toward sustainability. Additional conditions that require regulatory interventions in economic activities in order to reduce environmental impacts need to be considered.

Several new features are presented in this paper. One novelty is the description of pressures and responses across countries beyond policy interventions, with indications of trends that evolve under competition. Another novelty is the analysis of this description with those hypotheses and regulations. The main limitation of the paper is that the environ-

mental assessment focuses on water, energy, and bioresources at the country level, whereas divisions across businesses, incomes, and social interests need further studies. Furthermore, the data is far from perfect and limited in time, and links to the United Nations Sustainable Development Goals need further research. Following the Introduction, Section 2 outlines the assessment methodology. Section 3 covers the pressures caused by population and affluence. Section 4 displays responses to the pressures and environmental impacts on water, climate, air pollution, and bioresources. Explanations of the observed changes are presented in Section 5. Conclusions are drawn in Section 6.

2. Method

Impact assessment is based on parallel accounts of economic, social, and environmental indicators next to each other, which is in line with international policy recommendations [38]. Net national income [39], the genuine progress indicator [40], and similar GDP proxies are neglected because of disputed concepts and data. Registered natural resources and discharges are used for the impact assessment instead of per-area entropy [41], solar intake by bioresources [42], environmental sink boundaries [43], or other assumptions about environmental boundaries. Statistical data is used, but opinions are largely neglected. Opinions have been reviewed in other publications [44,45].

The World Bank database is the main source of data used [46]. It is supported by the databases of the OECD [47], the Eurostat [48], the IMF [49], the IEA [50], and a few business-specific databases. When relevant, these data sources are mentioned. All of them are authoritative databases that provide data in the public domain. When a few data points are missing, the missing points are interpolated between two data points in a time series, or extrapolated from the two previous data points. These approximations do not cover more than 5% of all the data in this study. If too much data is missing, the assessment period is shortened, or missing data is noted, as in the cases of poverty, education, and wastewater treatment. Insofar as data is available, all of these are assessed for the period 1990 to 2015 for each country. A minimum of ten years is considered for assessing trends, meaning continuous changes during long periods of time, shown italic in tables. The integrated datasets used for this study is obtainable on personal request for scholarly purposes.

2.1. Data on Pressures

The pressures on environmental quality studied are population and GDP per capita worldwide. The data cover all 207 countries and institutional entities that are considered part of a country. This uses the World Bank accounts of population and constant (real) GDP per capita, meaning GDP in constant USD prices of the year 2015 (USD₂₀₁₅). The focus is on 15 countries with a population of more than 100 million in 2015, including the Arab Republic of Egypt (Egypt), that reached that threshold one year later. The main reason for this selection is that large populations are assumed to generate large pressures on the environment, *ceteris paribus*. These fifteen countries are decisive in shaping global pressures, as they account for more than two-thirds of the global population and GDP. These focus countries are divided into high-, middle-, and low-income countries in line with the World Bank lending criteria [51]. Among the focus countries, the USA, Japan, and the European Union of 28 member states (EU), which includes the United Kingdom, are high-income countries. Their GDP per capita in 2015 exceeded USD₂₀₁₅ 12,000 a year. The other high-income countries are Iceland, Norway, Switzerland, United Arab Emirates (UAE), Saudi Arabia, Oman, Kuwait, Qatar, and Bahrain, called Gulf countries, as well as Israel, Korea Republic (Korea), Singapore, Canada, Australia, New Zealand, and several small-scale economies. All other countries are called lower-income countries. Among these, the middle-income, focus countries are Mexico, the Russian Federation (Russia),

Brazil, and the Republic of China (China), with GDPs per capita of USD₂₀₁₅ 5000–12,000 a year. The low-income, focus countries are Egypt, the Philippines, Nigeria, India, Pakistan, Bangladesh, and Ethiopia, with a GDP per capita below USD₂₀₁₅ 4000 in 2015. Deviations from the focus countries are observed and specific countries are mentioned when relevant.

It is assumed that human capabilities can reduce environmental pressures. Herewith, human capabilities are understood as individual access to resources, which enable value addition that is needed for economic growth [52]. This idea was converted into the Human Development Index of the United Nations Development Program based on indicators for education and health [53,54]. Policies that reduce poverty and finance education and health are assumed to expand human capabilities to mitigate environmental pressures. Poverty reduction and expenditure on education and health are employed as indicators.

2.2. Data on Responses

Responses are indicated by resource intensity and environmental efficiency, including water use and wastewater treatment, fuel use and CO₂ and NO_x emissions, and forest areas and nature protection areas. Environmental impacts are considered to be the results of those responses, given the pressures. They cover water pollution, climate change, air pollution, and the degradation of bioresources. Countries that reduced all the environmental impacts are identified as high performers.

Trends aid in evaluating past changes and anticipating future changes, though trends in the past do not determine the future. An acceleration of a trend indicates presumable expansion in the near future, whereas deceleration indicates possible saturation and a decline in changes; these are measured by higher, or lower average rates of change in the period 2005–2015 compared to the period 1990–2004. Differences across countries are indicated by the standard deviation. Diminishing differences across countries indicate similarity in the countries' patterns, which facilitates international policy coordination. Continuation in such policies can be expected. Growing differences between countries indicate an uncertain continuation of policies. Diminishing and growing differences across countries during a minimum period of ten years are considered converging and diverging trends, respectively. Convergence and divergence are shown by decreasing and increasing standard deviations of the annual data across the focus countries during the observed period. These standard deviations are indexed from 1990 onward (1990 = 100). In formal terms, a standard deviation of N observations is

$$s = \sqrt{\left[1/(N-1)\right] \cdot \sum_{i=1}^N (x_i - \bar{x})^2} \quad (3)$$

3. Pressures on the Environment

Here, it is assessed whether pressures on environmental qualities have increasing or decreasing trends, and if trends of the past can be expected to continue in the near future, meaning within a few decades. The scale and annual changes in population, affluence, and human capabilities are presented.

3.1. Population

The global population has increased from 5.3 billion in 1990 to 7.3 billion in 2015 and is now above 8 billion. Given this increase, we assess whether continuation of the past trend in the global population can be expected in the coming decades. We also explore whether human capabilities can generate economic growth. Human capabilities are indicated by education and health, measured by the percentage of the population that enrolls in higher education and under-five mortality per 1000 births for health, respectively. Table 1 presents these metrics globally and for the selected countries.

Table 1. Populations and their capabilities indicators for education and health.

Annual Average Growth 1990–2015, Italics: Period 2005–2015	Population in Million People		Percent Population That Enrolled in Higher Education		Under-Five Mortality per 1000 Births	
	2015	Growth	2015	Growth	2015	Growth
World	7348	1.3%	37	4%	43	−3%
USA	321	1.0%	89	1%	7	−2%
Japan	127	0.1%	N.A.	N.A.	3	−3%
EU	445	0.2%	67	3%	4	−4%
Mexico	122	1.5%	32	3%	16	−4%
Russia	144	−0.1%	80	2%	8	−4%
Brazil	204	1.3%	51	7%	16	−5%
China	1380	0.8%	46	12%	11	−6%
Egypt	92	2.0%	35	2%	23	−5%
Indonesia	258	1.4%	33	6%	28	−4%
Philippines	102	2.0%	38	3%	30	−3%
Nigeria	181	2.6%	11	1%	126	−2%
India	1310	1.6%	27	9%	44	−4%
Pakistan	199	2.5%	9	10%	76	−2%
Bangladesh	156	1.7%	14	8%	38	−5%
Ethiopia	101	3.0%	10	14%	62	−5%
Standard deviation 1990 = 100	130		80		50	

Population varies across the focus countries. They diverged from 1990 to 2015 due to 30-fold differences in annual average growth rates. While the Russian population declined, the Ethiopian population doubled during that period. Decelerations in the trend of population growth are observed in most countries, except in Africa. Diverging trends across countries imply uncertainty about the continuation of past trends in the coming decades. A United Nations (UN) projection shows a broad range for the global population in 2050, from fewer than the current 8 billion to more than 10 billion [55]. A lower global population may be possible due to faster declines in birth rates than death rates in nearly all countries, which is a trend that converges across the focus countries. Indeed, the global population growth decelerates after 2015. A linear extrapolation of annual average population growth from 2015 to 2022 shows a decline in global population within a decade after 2030, though policies in several countries aim to reverse this trend.

The human capabilities of countries' populations increased. Global literacy increased from 83% in 1990 to 91% in 2015. While nearly 100% enrolment in primary and secondary education is observed in most high-income and middle-income countries, the enrolments in this basic education are lower in low-income countries and for females. Given high enrolment in basic education, and since more skills are needed for jobs, the enrolment in tertiary education is considered, meaning entry into colleges. Enrolment in tertiary education varies from close to nil in Malawi to nearly all youngsters in Puerto Rico. Among the focus countries, this enrolment ranges from 9% in Pakistan to 89% in the USA. It grew in most countries, though growth rates varied from close to nil in the USA and Nigeria to double-digit rates in Ethiopia and China. Based on the converging trends across the focus countries, it can be expected that human capabilities will increase in the future, but any acceleration cannot be assessed because of insufficient data.

Health conditions are also improving. Lifespan has increased globally from 64 to 73 years, while the under-five mortality rate has declined from 93 to 43 deaths per 1000 births during the twenty-five year period. Large differences remain across countries. For example, this rate in Nigeria is 30 times higher than in the EU, where people live nearly 30 years longer. These improvements will presumably continue as the trends converge across countries and accelerate in lower-income countries, though decelerate in high-income ones. While global population growth is saturating, human capabilities in terms of mitigating environmental pressures are increasing due to declining poverty, greater participation in higher education, and improving health conditions.

3.2. Affluence

More affluence, as measured by a higher constant GDP per capita, is widely believed to increase pressure on the environment. This idea is based on the assumption that the growth of agriculture and industry consumes many natural resources per unit of value. This idea has been underpinned by correlations of energy use and GDP across countries [56], and over time [57], as well as based on engineering theories [58], and a history of energy use [59]. However, the causalities are dubious. A meta-review of 686 studies on the relationship between energy use and economic growth identifies four alternatives: no direct relationship, incomes generate energy, energy generates income, and feedback loops [60]. Global estimates for the period from 1800 to 2000, which are acquired using the databases on countries' GDP and populations [61], and on energy use [62], show that the global economy grew by 2.1% annually on average, compared to 1.5% for energy and 1.4% for population. While GDP grew faster than energy use in North America and Europe, it was slower on other continents. Meanwhile, fossil fuel use shows even larger differences across continents. Furthermore, fuel-exporting economies grew slower than fuel-importing ones during the last century [63]. Apparently, the pressure on the environment caused by affluence depends on the composition of the economy and other factors.

If GDP growth is driven by man-made resources of capital, labour, and knowledge, as is usually assumed in economic theories, more affluence can reduce pressures on environmental qualities when man-made resources replace the use of natural resources. This possibility is observed as the share of labour-intensive services in GDP increases. Policies can also expand human capabilities that mitigate pressures on the environment through reducing poverty and improving education and health care. These are indicated by the percentage of people whose income is below USD₂₀₁₅ 6.85 per person per day, as well as by governmental expenditure on education and on health. Table 2 shows countries' affluence, measured by GDP per capita, with the share of services, as well as policies on those human capabilities.

Global average affluence exceeded USD₂₀₁₅ 10,000 in 2015, but the average across the 197 countries with sufficient data ranged from USD₂₀₁₅ 306 per capita in Burundi to nearly 550 times more in Lichtenstein. While average affluence grew 1.7% annually from 1990 to 2015, growth varied, from small decreases in 17 countries to 9.1% growth in China, and even higher in Bosnia-Herzegovina and Equatorial Guinea, though the data for these countries can be disputed. As affluence grew, the share of services in GDP increased to more than 50% in most countries. Affluence and the share of services are often linked across countries. The increasing share of services is a trend that converges across the focus countries and accelerates in most of them, which suggests a continuation in the future. As labour-intensive services grow faster than agriculture and industry in most countries, pressures on the environment per income decrease, but total environmental impacts can increase as polluting agriculture and industry also grow, though slower than services.

Table 2. Countries' GDP, share of services in it, and expenditure on capabilities.

Annual Average Growth 1990–2015, Italics: Period 2005–2015	Real GDP in USD ₂₀₁₁ , per Capita		Share of Services in GDP in Percentages		Poverty: Population Below USD ₂₀₁₁ 6.85 a Day per Person		Government Spending on Education as % of GDP		Government Spending on Health as % of GDP	
	2015	Growth	2015	Growth	2015	Growth	2015	Growth	2015	Growth
World	10,232	1.7%	64%	0.3%	51%	−2.2%	4.4%	1.0%	10%	0.4%
USA	56,763	1.5%	77%	0.7%	2%	1.9%	5.0%	−2.6%	16%	1.2%
Japan	34,961	0.9%	70%	0.4%	2%	−1.9%	3.3%	−0.4%	11%	3.4%
EU28	30,485	1.4%	65%	0.3%	0.2%	0.0%	4.9%	0.0%	10%	0.9%
Mexico	9617	1.1%	61%	0.4%	36%	−1.3%	5.2%	1.0%	6%	−0.3%
Russia	9313	0.9%	56%	0.5%	5%	−12.3%	3.8%	1.1%	5%	1.2%
Brazil	8814	1.5%	62%	−0.1%	25%	−5.5%	6.2%	4.2%	9%	0.9%
China	8016	9.1%	51%	0.3%	38%	−6.7%	3.8%	5.1%	5%	1.4%
Egypt	3563	2.2%	53%	0.5%	64%	−1.6%	3.9%	−1.1%	5%	1.0%
Indonesia	3332	3.4%	43%	0.7%	73%	−2.0%	3.6%	3.0%	3%	3.2%
Philippines	3001	2.3%	59%	0.7%	60%	−1.3%	3.5%	3.6%	4%	2.6%
Nigeria	2687	2.2%	58%	2.1%	89%	−0.2%	0.5%	8.2%	4%	−2.2%
India	1606	4.5%	48%	1.3%	89%	−0.5%	4.1%	2.0%	4%	−0.8%
Pakistan	1357	1.6%	52%	0.7%	84%	−0.9%	2.7%	4.2%	2%	1.1%
Bangladesh	1248	3.6%	54%	−0.2%	87%	−0.3%	1.9%	−0.1%	3%	1.3%
Ethiopia	641	3.6%	40%	1.6%	91%	−0.5%	4.7%	−0.9%	4%	−0.5%
Standard deviation 1990 = 100	92		84		83		80		136	

As the data on poverty from 1990 to 2004 are deficient, data from 2005 to 2015 are used. It is observed that more than half of the global population lives in poverty and that poverty often decreases when affluence grows, but not in all countries. For example, poverty increased by a few percent in the growing economy of the USA, while it decreased in the EU where the poverty percentage is much lower, though it increased in a few EU member countries. Poverty was much higher in lower-income countries, decreasing more slowly than the growth of affluence, though it decreased faster in middle-income Brazil and Russia. Up to 90% of the population in low-income countries lives in poverty, though this is lower in Egypt and the Philippines. Large differences remain across the focus countries. Jobs reduce poverty. Globally, nearly half of the global population is considered a labour force in the sense of people with a job, but the labour force is only 30% of the population in most low-income countries, while it is about 70% in the high-income Gulf region, where immigration is high. Meanwhile, governmental support of education and health is also mixed. While the share of governmental expenditure on education and health in GDP is high in high-income and middle-income countries, the growth rate saturates or even declines, whereas the share is low but increasing in most low-income countries. Given that governmental expenditure on education converges across the focus countries, but diverges in health, and the changes in many countries do not accelerate, such policies generate uncertainties about human capabilities in the future. More services in an economy reduces the pressure of affluence on environmental quality, but capabilities vary a lot.

4. Impacts: Water, Energy, Nature

It is assessed whether the pressures are mitigated by responses through decreases in resource intensity and increases in environmental efficiency. These indicate the effects of consumption and technology, respectively, on environmental impacts. GDP multiplied by resource intensity and environmental efficiency equals the impact on environmental quali-

ties. Decreases in resource-use intensity that exceed increases in environmental efficiency imply that the changes in impact are driven by changing consumption.

4.1. Impacts of Water Use

While water resources are abundant globally, they are scarce locally. They are abundant as 1338 million km³ of water is available on earth while only 0.0001% of it is used. Freshwater withdrawal, excluding water in plants, is approximately 4100 km³, equivalent to 2% of the freshwater stock. An additional 30 km³ of seawater and 16 km³ of wastewater are withdrawn for freshwater through desalination technologies [64]. Local water scarcity is mainly caused by agriculture, which withdraws about 69% of the total global freshwater withdrawn [65]. Used water is discharged into the environment. This wastewater contains pollutants that need treatment to prevent water pollution. Table 3 shows the focus countries, their resource intensities, measured in m³ of freshwater withdrawal per USD₂₀₁₅ of GDP, and their environmental efficiency, measured in m³ of untreated wastewater per m³ of that withdrawal. The treated volume of wastewater, without the specification of treatments or reduction of pollutants, is an imperfect indicator of environmental efficiency, but other databases do not provide sufficient data across countries over a period of a few decades. The period 2000–2015 is presented because earlier data from the World Bank database on wastewater treatment is unavailable or insufficiently reliable for extrapolations. Regarding those deficiencies in data, untreated discharges are considered only as rough approximations of environmental impacts that indicate water pollution.

Table 3. Water pollution in 2015 and annual average growth 2000–2015 (*).

Growth Shown in Italics Is During 2000–2015	Resource Intensity: Freshwater Withdrawal m ³ /USD ₂₀₁₅		Environmental Efficiency: Untreated Wastewater per Withdrawal in m ³ /m ³		Water Pollution: Annual Untreated Discharges in m ³ /Capita	
	2015	Growth	2015	Growth	2015	Growth
World	0.05	−2.1%	0.53	−2.0%	292	−1.3%
USA	0.02	−2.7%	0.02	−2.6%	23	−2.4%
Japan	0.02	−1.5%	0.21	−1.8%	129	−2.3%
EU	0.01	−2.9%	0.11	−1.8%	51	−3.5%
Mexico	0.07	−1.2%	0.55	−2.7%	385	−1.7%
Russia	0.05	−2.3%	0.40	−0.7%	180	−1.0%
Brazil	0.04	−1.0%	0.56	−0.9%	185	−0.2%
China	0.05	−8.5%	0.48	−3.9%	205	−4.3%
Egypt	0.23	−2.8%	0.37	−1.4%	303	−0.2%
Indonesia	0.25	−0.6%	N.A.	N.A.	N.A.	N.A.
Philippines	0.29	−4.2%	0.45	−1.5%	396	−0.8%
Nigeria	0.03	−2.3%	0.72	−0.6%	50	0.5%
India	0.31	−5.0%	0.64	−2.5%	318	−2.3%
Pakistan	0.72	−3.0%	1.00	0.0%	978	0.6%
Bangladesh	0.18	−5.5%	0.66	−1.4%	152	−1.5%
Ethiopia	0.16	−3.7%	0.94	−0.2%	95	3.4%
Standard deviation 1990 = 100	40		96		79	

(*) Missing data on environmental efficiency for the period 1990–1999 could influence changes in water pollution in countries with low growth rates of freshwater withdrawal, such as Japan, Mexico, and Indonesia.

The water resource intensity, measured in m³ per USD₂₀₁₅, varies across countries. For example, the water intensity in Pakistan is nearly 50 times higher than in the EU.

Water is inefficiently used in many lower-income countries. This inefficiency is hardly influenced by local water scarcity caused by climate. For example, the water intensity in arid Egypt is higher than in humid Indonesia and the Philippines, with similar income per capita. Agricultural performance has a limited influence as high water intensity does not correlate with large cereal production in tons per hectare in many of the focus countries. Obsolete installations and wasteful practices caused by the low price of water due to large subsidies are considered to be the main causes of high water use per value, as well as per capita [66]. An encouraging trend is that water intensity in lower-income countries has decreased; this happened particularly fast during periods of high fuel prices. Environmental efficiency in wastewater treatment varies across countries even more than the water intensity. While global discharges exceed 2000 km³ of untreated wastewater, these discharges are usually treated in high-income countries but rarely in low-income ones. For example, 98% of people in the USA are connected to wastewater treatment, compared to 6% in Ethiopia. Environmental efficiency, measured by coverage of discharged wastewater, increases with affluence, but data on Indonesia are unavailable. Regarding more advanced wastewater treatment technologies in high-income countries, the correlation could be even higher when measured by the reduction in pollutants. As a result, water pollution per capita in low-income Pakistan is nearly fifty times higher than in the high-income USA when the discharge coverage is accounted for. An encouraging trend is that water pollution has decreased in most countries. Possibly, the decreasing trend will continue in the future regarding the converging trend in water intensity across the focus countries and the acceleration in wastewater treatment in many lower-income countries. Changes in water pollution are driven by water consumption and wastewater treatment technologies.

4.2. Impacts of Fuel Use

Energy on earth is abundant, but fossil fuels are scarce. While 2.6 YJ, which is 2.6×10^{12} GJ, and 1 GJ equals 1000 MJ, of solar energy hits the earth surface, hardly 0.04% of it is used [67]. Meanwhile, about 80% of global energy use is covered by the combustion of fossil fuels, which causes emissions with severe impacts on the life cycles of products [68]. Among the impacts, CO₂ emissions cause climate change, and NO_x emissions are toxic and acidifying. Fuel use and emissions are considered for the estimates of environmental impacts. Emissions from shifting cultivation [69] and capture in impervious infrastructure [70] are neglected. Table 4 shows the resource intensity of fossil fuels in GJ per USD₂₀₁₅, and environmental efficiency in kg CO₂ and kg NO_x emissions per MJ of fuel use. Their multiplication by GDP with correction for the units yields the impacts of fuel use on climate change and air pollution, respectively.

The resource intensity of fuels, measured in GJ/USD₂₀₁₅, is high in a few countries. For example, Russian fuel intensity is twice that of China, which is twice that of Brazil, despite similar affluence, but that of Brazil grows while the others decrease. While the fuel intensity decreases in many countries and globally, it increases in many lower-income countries. Increasing fuel intensity indicates an inefficient generation of economic growth, as observed in Bangladesh, Indonesia, and Brazil among the focus countries. Environmental efficiency, measured in kg CO₂ per MJ of fuel, declines in most countries, which reflects shifts to lower-carbon fuels, such as a shift from coal to natural gas in power generation. It does not vary much across countries, nor change much per year, nor can it be linked to affluence. High fuel prices could be more important for the shifts. The impact of climate change based on the multiplication of resource intensities, environmental efficiencies, and GDP varies a lot. Across the focus countries, this impact per capita in the USA is a hundredfold greater than in Ethiopia, but it decreases in the USA and the EU, while it increases fast in China, Bangladesh, and Ethiopia among the focus countries, as well as in Mozambique,

Benin, Tanzania, Cambodia, and Vietnam. It is encouraging that the trends across the focus countries are converging towards lower impact. The converging trend facilitates international coordination. The growth rate of climate change impact also decelerates in many countries, which indicates that the growth is saturating, which may generate a slowdown in the climate change impact. The drivers of these changes are found mainly in the consumption of fossil fuels.

Table 4. Environmental impacts related to fuel use in 2015 and annual average growth 1990–2015.

Growth During 1990–2015	Resource Intensity of Fuel Use in GJ/USD ₂₀₁₅		Environmental Efficiency of CO ₂ in kg/MJ		Climate Change Impact in CO ₂ kg/Capita		Environmental Efficiency of NO _x in kg/MJ		Air Pollution in NO _x kg/Capita	
	2015	Growth	2015	Growth	2015	Growth	2015	Growth	2015	Growth
World	6.57	−1.0%	0.07	−0.04%	4.5	1.1%	0.005	−1.0%	0.32	−0.1%
USA	4.57	−2.1%	0.06	−0.2%	15.6	−1.8%	0.003	−0.2%	0.74	−0.8%
Japan	3.85	−1.0%	0.07	0.5%	9.3	0.02%	0.001	−1.3%	0.14	−2.0%
EU	3.71	−2.0%	0.06	−0.4%	6.5	−1.2%	0.004	−1.7%	0.41	−2.3%
Mexico	6.08	−0.5%	0.07	0.4%	3.9	0.1%	0.005	−1.4%	0.29	−0.9%
Russia	20.59	−1.5%	0.06	−0.3%	11.1	0.3%	0.002	−1.4%	0.38	0.9%
Brazil	4.10	1.0%	0.07	−0.1%	2.4	2.0%	0.013	−1.2%	0.47	1.2%
China	10.29	−3.1%	0.09	−0.2%	7.1	7.0%	0.004	−2.5%	0.35	3.5%
Egypt	8.96	−0.6%	0.08	0.3%	2.4	2.7%	0.007	−0.9%	0.23	−0.5%
Indonesia	8.33	1.2%	0.07	−0.8%	1.9	2.5%	0.009	−1.8%	0.25	2.6%
Philippines	4.79	−0.4%	0.08	0.4%	1.1	1.2%	0.006	−0.7%	0.09	−0.5%
Nigeria	2.08	0.4%	0.11	−2.5%	0.6	−1.6%	0.006	−0.5%	0.04	2.0%
India	11.59	0.1%	0.09	−0.7%	1.6	4.2%	0.007	−1.9%	0.13	2.4%
Pakistan	7.62	0.03%	0.08	0.1%	0.8	1.3%	0.015	0.005%	0.16	1.0%
Bangladesh	5.40	2.7%	0.07	−0.4%	0.5	7.0%	0.018	−2.0%	0.12	4.1%
Ethiopia	2.73	0.9%	0.07	0.1%	0.1	6.2%	0.021	−0.4%	0.04	5.9%
Standard deviation 1990 = 100	59		34		78		74		67	

The resource intensity of fossil fuels also applies to NO_x emissions. The environmental efficiency of NO_x reduction in kg NO_x per MJ fuel use varies a lot across the focus countries. It is influenced by affluence. For instance, it is 20 times more efficient in Japan than in Ethiopia. Although nearly all countries have improved the environmental efficiency of NO_x emissions, de-NO_x technologies are insufficient to counter the pressures of growing GDP. In effect, global air pollution hardly decreases. Air pollution decreases in high-income countries, but increases in several lower-income countries. Encouraging trends include the convergence of air pollution across countries, which facilitates international policies, and the decelerating growth rate in many countries, which could decline in the coming decades. Based on these trends, a global decline can be expected in the near future, though air pollution continues to increase in several countries. Changes in air pollution are driven by technology.

4.3. Impacts of Bioresource Use

Although the global economy uses less than one in 1000 of the global 550 billion-ton biomass stock in carbon equivalent, the use of bioresources is constrained by there being 130 million km² of global land area, with 9.9% of it used for agricultural production and 2.8% for urban uses. Given limited land, the impacts on bioresources are based on land area. The focus is on forest areas, that cover 31% of the land area in the world but are decreasing through legal and illegal logging and shifting cultivation [71]. Forestry is the

largest bioresource use. Responses to the pressures include decreasing forest use and compensation for this use through nature protection areas. Policies aim to increase the coverage of nature protection areas from 18% of global land area in 2020 to 30% by 2030 [72]. On the assumption that nature protection areas can provide novel uses of bioresources that compensate for forest use, their balance is estimated instead of using the multiplication of resource intensity by environmental efficiency. It should be noted that this balance is an imperfect indicator of the impacts because non-forest bioresources are also used and nature protection areas are often dedicated to the protection of biodiversity rather than bioresource uses.

The resource intensity of bioresources is expressed as forest area, which is measured in m^2 per USD_{2015} , and environmental efficiency is defined as nature protection areas, measured in m^2 per m^2 of forest. Impacts on bioresources are estimated by subtracting forest areas from nature protection areas, all measured in m^2 per capita. It is also assessed whether the impacts on bioresources are driven by changes in forest use and compensations through the nature protection areas. The World Bank database is used for the forest areas, and the OECD database is sourced for the nature protection areas, but the latter misses several lower-income countries. Table 5 shows the estimates of resource intensities, environmental efficiency, and impacts on bioresources. Regarding the imperfect indicator and missing data on nature protection areas, the findings should be treated with caution.

Table 5. Environmental impacts of bioresource uses in 2015 and annual average growth 1990–2015.

Negative Means Decrease in the Bioresource Loss	Resource Intensity of Forest Use in $\text{m}^2/\text{USD}_{2015}$		Environmental Efficiency of Nature Protection per Forest Use in m^2/m^2		Impacts on Bioresources: Nature Protection—Forest Area in m^2/Capita (**)	
	2015	Growth	2015	Growth	2015	Growth *
World	5443	−1.4%	0.48	3.2%	−2824	−2.8
USA	9668	−0.9%	0.38	0.6%	−6000	−0.7
Japan	1962	−0.1%	0.29	0.5%	−1396	−0.2
EU	3560	0.6%	0.69	4.0%	−1094	−2.9
Mexico	5443	−1.7%	0.40	7.9%	−3279	−3.2
Russia	56,554	0.1%	0.20	3.0%	−45,286	0.1
Brazil	24,643	−1.9%	0.49	6.8%	−12,499	−4.0
China	1524	0.4%	0.04	7.0%	−1459	0.2
Egypt	5	−1.5%	N.A.	N.A.	−5	−3.4
Indonesia	3678	−2.3%	0.23	1.3%	−2815	−1.9
Philippines	687	−2.4%	N.A.	N.A.	−687	−1.8
Nigeria	1239	−3.2%	N.A.	N.A.	−1239	−3.3
India	541	−1.2%	0.26	0.1%	−401	−1.1
Pakistan	197	125.4% (1)	N.A.	N.A.	−197	−3.1
Bangladesh	121	−1.7%	N.A.	N.A.	−121	−1.4
Ethiopia	1729	−3.5%	N.A.	N.A.	−1729	−3.1
Standard deviation 1990 = 100	93		215		80	

(*) The declining forest areas along with lacking data on the nature protection areas in low-income countries indicate worrisome losses of bioresources. (**) These results are based on annual differences between nature protection areas and forest areas, not the multiplication of resource intensities and environmental efficiencies, as shown in Tables 3 and 4. (1) Unreliable data because of spiked increases.

The resource intensity of forests ranges from only 5 m² per USD₂₀₁₅ in Egypt to 10,000 times higher in Russia, which can be explained by their arid and temperate climates, respectively. Meanwhile, the resource intensity of forest use in Indonesia is five times that of the Philippines, with a similar humid climate, island-rich geography, population density, and affluence. Policies could cause this difference, but no sound explanation has been found. The resource intensity of forests decreased in most countries, except in the EU, Russia, and China. It hardly converges across the focus countries, which means that introducing international policies on deforestation would be laborious. Insofar as data is available, the environmental efficiency of the nature protection areas insufficiently compensates for forest losses across all the focus countries, particularly in China. The lack of statistical data about the nature protection areas in many low-income countries, along with ongoing deforestation, indicates a worrisome degradation of bioresources. Nearly all countries lose bioresources, though the size of these losses decreases in most of them. Based on the trends in the focus countries with sufficient data, it can be expected that loss of bioresources will continue in the near future, while the decreasing size of these losses suggest some improvements. These losses are driven by the consumption of forests and insufficient compensation through nature protection areas.

4.4. Improving Performance

Performance in the period 1990–2015 showed mixed results. Water pollution decreased globally and in most countries. The impacts of climate change decreased in most high-income countries, but increased globally and in many lower-income countries. Air pollution decreased globally and in high-income countries, contrary to increases in many lower-income countries. Impacts on bioresources increased globally and in nearly all countries despite more nature protection areas. Apparently, the policies that emerged in the 1970s, with enforced regulations on water and air pollution, could reduce global impacts, whereas more recent policies using voluntary agreements on climate change and biodiversity could not attain much improvement.

Furthermore, larger impact reduction is attained in high-income countries than in lower-income ones. So, the share of high-income countries in the global impacts has declined. While high-income countries' share of global GDP declined from 98% in 1990 to 81% in 2015, their share in global water pollution decreased from 5% to 4%, in climate change from 76% to 51%, in air pollution from nearly 50% to 34%, and in bioresource degradation from 39% to 33% during those twenty-five years. The decreasing environmental impact in high-income countries is often explained by the migration of industries to lower-income countries, along with imports of ready-made products for consumption in high-income countries. This observation during the second half of the 1900s paved the way for the argument that high-income countries shift polluting production to lower-income countries [73]. This is often labelled as the 'externalisation of pollution'. However, this observation is not valid in the period 1990–2015 based on material flows across countries, though this indicator does not indicate all emissions that cause pollution. The material flows are assessed with the OECD data on domestic material consumption and material footprint that includes imports minus exports of materials, while the OECD data is derived from trade statistics. Though the domestic material consumption per person in 2015 in high-income countries was nearly twice as high as the 11 tons in lower-income ones, it grew faster in lower-income countries than in high-income ones during that period. Meanwhile, the material footprint of high-income countries did not increase. Growing GDP and domestic material consumption in low-income countries indicate larger domestic consumption of high-value products. In effect, the material intensity in lower-income countries has decreased from 40 tons per USD₂₀₁₅ in 1990 to 5 tons per USD₂₀₁₅ in 2015, compared to a small decrease from 0.6 to

0.5 tons per USD₂₀₁₅ in high-income countries. This environmental performance is driven by changes in consumption and technology, though the decreasing material intensity does not necessarily match the reduction in environmental impact.

More affluence did not obstruct better environmental performance, as shown by the low correlations between environmental impacts and affluence across 206 countries; the Democratic People's Republic of Korea is excluded because of a lack of data. The estimates cover 75 high-income countries, 51 middle-income countries, and 80 low-income ones. Economic growth is neither a blessing nor a disguise when measured by changes in human capabilities and environmental impacts across all countries per unit of economic growth. Figure 1 shows the annual average changes in human capabilities and environmental qualities estimated per one percent of economic growth, specified for high-, middle-, and low-income countries. These changes cover the period 2005–2015 when sufficient World Bank data is found, but more than tenfold spikes in the annual changes are excluded as unreliable. Human capabilities address poverty and government expenditure on education and health. Environmental performance includes water use and water pollution, fuel use with its associated impacts on climate change and air pollution, as well as forestry and nature protection areas.

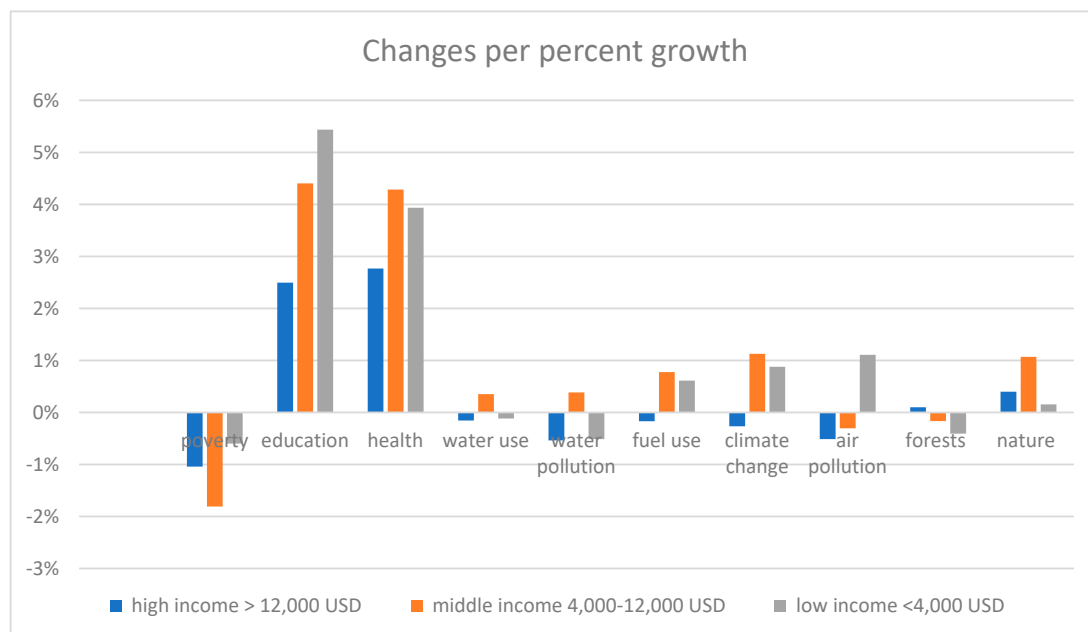


Figure 1. Changes in capabilities and environmental qualities per percent growth.

While high-income economies grew more slowly than middle-income and low-income ones, at 1.1%, 2.8%, and 2.7% annual average, respectively, their social and environmental performances per percentage of economic growth varied. Poverty declined faster in high-income countries and middle-income ones than in low-income countries, which indicates a failure in the eradication of poverty. Despite ideas about privatisation, governmental expenditure on education and health increased faster than economic growth, and was particularly fast in lower-income countries. Per additional USD₂₀₁₅, water use and water pollution decreased in high-income and low-income countries, but increased in middle-income ones. Meanwhile, fuel use and its impact on climate change decreased in high-income countries, but increased in lower-income ones. The impacts on climate change increased a lot in the fast-growing economies of Azerbaijan, Nauru, China, and Turkmenistan, where GDP grew about 9% annually, as well as in Myanmar, Ethiopia, and Mongolia that experienced 8% growth. Air pollution decreased in high- and middle-income

countries, but it increased in low-income countries. Deforestation decreased in high-income countries along with larger nature protection areas, while economic growth increased forestation and hardly enlarged nature protection areas in lower-income countries, insofar as data is available. Across all countries, fast economic growth hardly contributes to human capabilities and environmental qualities. Fast economic growth generates even slower improvements compared to the moderate growth in many countries. Apparently, the effects of economic growth on human capabilities and the environment depend on the allocation of generated income.

Several countries improved all the aforementioned environmental performances from 1990 to 2015, and several human capabilities between 2005 and 2015 when sufficient data were available. These countries, in descending order of economic growth during 1990–2015, are: Ireland, Israel, Slovak Republic, Iceland, Poland, Cyprus, Slovenia, USA, Sweden, Netherlands, United Kingdom, Spain, Czechia, Austria, Romania, Belgium, Hungary, Finland, Denmark, Switzerland, France, Germany, Portugal, Greece, and Italy. Their economies grew while water pollution, climate change impacts, and air pollution decreased, and nature protection areas increased, though this increase did not always compensate for forest losses. Several of these high environmental performers also decreased poverty, but poverty increased in eight of them despite economic growth. Nearly all these countries increased governmental expenditures on education and health. For policymaking aiming at sustainability, it is relevant that these twenty-five high environmental performers share a few features. They are considered democracies that experience peace within their borders. All of them have enforced environmental policies since the 1990s. Except for middle-income Romania, all the other countries are high-income ones whose economies grew moderately, which means below the 5% annual average. Their populations are highly educated, with high female participation. These features enabled changes towards sustainable development within market economies. Several of the high performers reduced environmental impacts by half over those twenty-five years, which is based on a 3% annual average change. Eighteen countries achieved this reduction in water pollution, two countries in climate change, ten in air pollution, and twenty countries doubled their areas for the protection of nature. However, their performances on human capabilities varied. Generally, affluent democracies with high human capabilities and moderate economic growth improve environmental performance, whereas the environmental performance of fast-growing economies worsens while the improvements in human capabilities are limited, or there is even a decline. Possibly, fast economic growth obstructs allocation of income toward sustainable development. This possibility needs further research.

5. Drivers of Higher Performance

Regarding the described mixed effects of economic growth on environmental performance, the issue is about the factors that drive changes toward sustainability. These drivers address the shift from agriculture and industry to services in the EKC hypothesis, sustainable innovation in the ‘Green Growth’ idea, and efficiency-improving regulations in the Porter hypothesis. These hypotheses are used for the interpretation of observations; we are not testing the hypotheses. This is followed by theorising about generic conditions for these drivers.

5.1. Shift to Services

With regard to the EKC hypothesis, the question is whether labour-intensive services use fewer materials and replace agriculture and industry. A major limitation in answering this question is that the material use across businesses during a minimum period of ten years is rarely found in the statistics. Such data is found in the OECD database on the energy

intensities of businesses in several high-income European countries. Inter alia, a database on materials used in USA businesses is detailed but is a one-time shot [74]. The OECD database shows energy intensities in MJ per Euro and changes cover the period 2008–2018, while the difference between USD and Euro is irrelevant for the assessment. This period covers a period of high fuel prices until 2015, followed by low prices, which reasonably reflect the averages of energy intensity with respect to fuel prices. This database is used for estimation of the annual average energy intensity and changes during that period of time. These are estimated for all businesses, as well as for agriculture, forestry, and fisheries; mining and quarrying; manufacturing; electricity, gas, and air conditioning; water supply and sanitation; construction; information and communication; education; health and care; and arts and entertainment. Sufficient data are found on Belgium, Italy, Portugal, Slovenia, Sweden, Spain, and Switzerland. The averages of their businesses are estimated. Compared to the average energy intensity used in manufacturing in these countries, the average energy intensity in mining and quarrying is 11 times higher, and in electricity, gas, and air conditioning, 7 times higher, while it is similar to the energy intensity in agriculture, forestry, and fishery. Manufacturing is nearly 10 times more energy-intensive than construction, which is 20 to 30 times more energy-intensive than services, while differences between services are negligible. This data shows that the energy intensity in manufacturing is typically a few hundred times higher than in services, and they decline more slowly than in services. The differences across those countries are also large. For example, the energy intensity of all businesses in Belgium is about 30 times higher than in Spain, but it decreased in Belgium while increasing in Spain. These differences in the energy intensity of businesses underpin the low energy intensity of services compared to agriculture and industry. Data on other countries would, presumably, strengthen this finding. The observed low energy intensity of services is consistent with the EKC hypothesis.

However, the value addition of services is disputed. A widespread idea among economists is that services do not add but only distribute the value that is generated by converting natural resources into valuable products in agriculture and industry. This idea persists in classical, liberal economics [75], and in socialist economics [76], as well as in mainstream, neo-classical economics, though services could add value to other businesses when reducing transaction costs in firms [77]. Other scholars assume value addition of services due to the increase in human capabilities for jobs [78], research and development for innovation [79], and information and communication for social and personal development [80]. Changes in ideas about services reflect the growth of services. While global GDP grew fivefold during the 1900s, the share of services increased from 50% to more than 63%, whereas the shares of industry decreased from 37% to 31% and of agriculture from 13% to 5% [81]. The share of services continues to grow in most countries, even in a manufacturing powerhouse like China. However, the replacement of material conversions is dubious as the value of agriculture and industry is growing in most countries, though the value of services is growing faster. So, services are usually added to agriculture and industry rather than replacing them. Although growth in services decreases the resource intensity of economies, the environmental impacts increase as long as agriculture and industry remain polluting.

5.2. Sustainable Innovation

In the idea of ‘Green Growth’, businesses would generate sustainable innovation, meaning innovation that increases value along with having a lower environmental impact. Sustainable innovation would expand due to the growth of knowledge work. Knowledge work, in the narrow sense of research and development (R&D), has increased. R&D expenditure increased to 2–3% of GDP in 2015 in high-income countries. Though it was below 2% in most other countries, it grew faster. Aside from R&D, definitions of knowledge work are

disputable [82]. An estimate based on technical, intellectual, artistic, and communicative businesses in statistics is that knowledge work in the USA grew from a few percent to one-fifth of the labour force during the second half of the 1900s, when the total labour force doubled [83]. The growth of knowledge work is also underpinned by assessing consumer expenditure. This expenditure is divided into three categories with regard to resource use. These categories cover the material-intensive ‘products’ in food, beverages, clothing, housing, and furniture; the labour-intensive ‘physical services’ in health, transport, restaurants, hotels, and miscellaneous; and the knowledge-intensive ‘upgradation services’ in education, communication, recreation, and culture. Estimates with the OECD data between 1990 and 2015 show that the ‘upgradation services’ have grown faster than ‘products’ and ‘physical services’, toward 15% of all consumer expenditure in high-income countries. Inter alia, Japan consumes many ‘products’ and the USA many ‘physical services’, while the share of ‘upgradation services’ is somewhat lower. The Eurostat data on Europe, including several middle-income countries and low-income Albania, show larger ‘upgradation services’ in high-income countries, up to 20% of consumer expenditure in Norway, and faster growth in lower-income countries. Considering knowledge work in all categories of consumer expenditure, knowledge work increased toward 20% of all the labour force in high-income countries and middle-income ones, but this was lower in low-income countries.

The growth in knowledge work led to more innovation, when measured by the number of intellectual property rights and new firms in the World Bank database. Whether this innovation increased value while reducing environmental impacts or failed to achieve this is assessed using the business data. Therefore, the global production value of businesses in money and the use of natural resources in physical terms is estimated. Larger production value indicates contributions to GDP, while lower use of materials and energy is an approximation of decreasing environmental impact, based on the assumption that the environmental efficiency of businesses increases with increases in knowledge work. Both indicators are indexed. Global agriculture, industry, and transport are covered. These data sources are specified in another publication [84]. In agriculture, indices from 1990 to 2020 (1990 = 100) cover the production of cereals in current USD per hectare and in tons per hectare, as well as the use of fertilisers in tons per hectare. Compared to 1990, the production value had increased by nearly 100% in 2020, the production mass of cereals by 60%, while fertiliser use had decreased by about 15%, which indicates sustainable innovation for ‘green growth’ in agriculture. In industry, indexes from 1990 to 2019 (1990 = 100) cover production value in current USD per MJ energy using the World Bank data, and deliveries of kg products per MJ energy, and kg products per kg of material resources used, using data on materials in physical terms. The mass of products and mass of resources are compiled in the UNEP database based on trade statistics [85]. It is estimated that the value of energy use grew by 20%, in line with the mass indicators in physical terms from 1990 to 2005, but the value of energy use declined by nearly 10% during the period of high fuel prices from 2005 to 2015, and then grew by 25% in the four years to 2019. Meanwhile, the mass of products and of material resources in physical terms steadily increased. Throughout those thirty years, global industry hardly improved the value of energy use. Global industry did not reduce its material use in products, nor its material resources, nor its energy use during periods of high fuel prices. Presumably, labour costs are lowered for the production of cheaper products. In transport, indices from 1990 to 2019 (1990 = 100) cover the value per MJ energy and the number of travellers per MJ energy for air, rail, and road transport. The value of energy use tripled in aviation, but the energy per passenger also increased, which indicates larger earnings without energy savings. In rail transport, the value increased by 50%, with a similar increase in energy use per passenger, but its energy use per passenger

is a small fraction—below one hundred—of the use in aviation. Meanwhile, energy use per passenger increased in road transport. Global industry and transport have not reduced their environmental impacts. The value addition of global industry grew more slowly than the impacts, which generated a cul-de-sac of cheap, polluting activities. Sustainable innovations are lacking, particularly in industry.

5.3. Porter Hypothesis

The main assumption in the Porter hypothesis is that demands for environmental qualities posed by regulators lead to investments that generate profitable activities. The issue is whether stricter environmental demands are posed by consumers in businesses and households. These demands align with observations during the period of relaxation in environmental regulations from 1990 to 2015.

During the last century, consumer demand for environmental qualities emerged as leisure time increased due to a halving of work time and doubling of lifespan [62]. Increases in knowledge work have added to the demand. Leisure time increased globally by 20% during the period 1990–2015. This increase will presumably continue in the future given the acceleration in the growth in lifespan in lower-income countries and convergence across countries. Due to increased leisure time and affluence, businesses in tourism, wellness, hospitality, sports, and other services that cater to the consumption of environmental qualities have expanded. For instance, international tourism grew 3% above the growth rate of global GDP. In addition, increases in knowledge work demand tranquillity, beauty, and other amenities of a good environment for high performance. These interests are served by increasing expenditure on mitigating environmental impacts. Indications of the environmental demands of services for knowledge work are high, with increasing correlations between R&D and environmental expenditure from 1990 to 2015 across 22 high-income countries in the OECD database. While regulations were relaxed, consumer demands were strengthened during this period of time.

Whether this shift from regulations to consumer demand has added value and reduced environmental impact warrants another study. In this study, investments in environmental protection are considered indicators of improved environmental performance in businesses. Global investments from 2000 to 2019 are estimated. These estimates cover investments in renewable energy, based on the UNEP data [86]; as well as investments in sanitation, with the World Bank data; and investments in nature protection areas, with the OECD data. The former are largely voluntary because regulations on renewable energy are rare, whereas sanitation is regulated and nature protection is a mix of regulated and voluntary activities. During those two decades, the average annual investment in renewable energy was 6 times larger than in sanitation, which attracted 37 times more investment than nature protection areas. While all global investments increased by 3% as an annual average, those in renewable energy increased by 12%, whereas global investments in sanitation hardly increased, and those in nature protection decreased. Meanwhile, EU investment in air pollution, waste, safety, soil, noise, radiation, environmental R&D, and others put together was lower than in sanitation, and increased more slowly. Regulations and consumer demand led to investments that could generate profitable activities. This is consistent with the Porter hypotheses insofar as private interests in renewable energy are considered, but environmental regulations hardly led to investments during that period.

5.4. Drivers of Sustainability

Given partial confirmation of the hypotheses alongside insufficient changes toward sustainability in the market economy, necessary additional conditions are assessed. This assessment refers to the mainstream economic idea about competition driven by product

quality at a given price [87]. Such quality competition is considered as if it is a natural experiment in sustainability [88]. However, it is commonplace in markets whenever designs of products instead of bulky commodities are involved. The main conditions for changes toward sustainability are discussed in theory, followed by a real-life example.

In theory, all producers in quality competition are price-takers, who use natural and man-made resources to sell their specific products' qualities. As lower use of a resource generates cost savings that contribute to profits, high prices of natural resources relative to man-made ones decrease the use of energy and materials because more cost savings can be generated. These cost savings increase when know-how about lower use of energy and materials is cheaply available and technologies can be changed flexibly. Such know-how and technologies require innovation. Realised cost-savings add to profits that are allocated to consumption or production. Consumption refers to dividends paid to shareholders and bonuses paid to employees, which increase their wealth and savings for future investment. Profits allocated to production are used for expansion of activities, as well as for know-how about cost-saving and R&D that generates innovation, which contribute to future profits. In theory, this allocation mechanism reduces the use of natural resources when their prices are high-, and a large share of profits is allocated to innovations dedicated to cost-saving uses of natural resources. In mainstream economic theory, such an allocation mechanism in quality competition would generate changes toward sustainability.

In practice, the prices of natural resources accounted in current USD are low and tend to decrease compared to man-made resources. In effect, the allocation mechanism in quality competition does not encourage changes to sustainability. This is illustrated by the cost savings and profit allocation in the USA during the 2020s, with annual average cost-savings on energy of USD 0.10 trillion [89], while energy is the costliest natural resource in economies. These cost-savings were hardly 0.3% of USD 3.4 trillion total profits that were allocated in dividends for shareholders (24%) and in bonuses for employees (1.5%) [90], while the payouts of dividends vary from nil to above 100% of profit across businesses [91]. The profit allocation to production covered 21% for R&D [92], while the remaining 54% addressed expansion of existing activities and taxes. This illustration of profit generation and allocation in the largest economy indicates that lower use of natural resources hardly contributes to profits and that 80% of all profits are allocated to non-innovative activities. Although competition for product quality could reduce the use of natural resources in theory, actual cost savings on natural resources are negligible for profits that are mainly allocated to non-innovative activities. Within whole economies, the cost-savings on natural resources could provide a larger contribution to profits in agriculture and industry, but this data is missing.

The present incentives in product competition are insufficient to enhance changes toward sustainability. Higher costs of natural resources in economic activities and encouragement of innovation in quality competition would provide these incentives. They would require regulations that raise the price of environmental impacts. This can be reached through a shift in taxes from man-made resources to natural ones and putting high prices on emissions. In addition, the enforcement of high-quality products is needed to spur sustainable innovation.

6. Conclusions

Herein, questions are answered about what environmental impacts are reduced in growing economies and what drives these changes toward sustainability. Ongoing changes are described with statistical data based on authoritative, though imperfect, data sources. Possibilities for enhancing changes toward sustainability are explained by theories.

The descriptive assessment with statistical data encompasses pressures on the environment, measured by number of people and affluence in terms of GDP per capita; as well as human capabilities, indicated by poverty, education, and health. The assessed responses cover resource intensities in consumption and environmental efficiencies of technologies. Multiplication of the pressures and responses delivers the environmental impacts of water pollution, climate change, and air pollution, but bioresource degradation is based on a comparison of nature protection areas to deforestation areas. These environmental impacts are estimated for all countries, with the focus on the fifteen largest populations in the period 1990–2015. During this period, environmental policies were adopted by nearly all countries, but regulations were relaxed in favour of voluntary agreements with businesses. This implies that the observed changes were driven by market and societal demands rather than by stricter regulations. The expectations are that the pressures have been reduced and responses to consumption and technologies have been improve.

The pressures of population and affluence on the environment continue to grow globally, but the growth rates are declining. Population growth has declined globally and in most countries outside Africa. A global slowdown during the coming decades can be expected, as declining birth rates are being driven by more people pursuing education and jobs, particularly women. Affluence has also grown, particularly in lower-income countries. Meanwhile, growing economies in nearly all countries have shifted from land-intensive agriculture and material-intensive industry towards labour-intensive services, thereby reducing environmental pressure per unit of income. Human capabilities to resolve problems also expand as poverty declines, along with increasing government expenditure on education and health in most countries. Regarding trends in the past decades, decreasing pressures on the environment can be expected in the coming decades. This expectation is based on the slowdown in population growth and shift in economies towards services, along with growing human capabilities to resolve environmental issues in most countries.

Observed responses to these pressures and their results, measured by environmental impacts, vary. Most countries have reduced their resource intensities in terms of water use, which converged across countries, but technologies for wastewater treatment are rarely used in lower-income countries. As a result, water pollution has decreased in high-income countries but increased in many lower-income ones. The resource intensity of fossil fuels has decreased in many countries, but increased in several low-income ones. While the effects of changing fuel technologies on global CO₂ are negligible, more use of NO_x-reducing technologies has been effective. As a result, the impacts on climate change have decreased in high-income countries, but increased in lower-income countries. Air pollution has decreased slowly across all countries, mainly due to the use of technologies keeping pace with the pressures. The use of forests has hardly declined while nature protection areas are insufficient to compensate for deforestation in most countries. As a result, bioresources have degraded in nearly all countries.

The global trends show a slow reduction in water and air quality, a slowdown in growth of CO₂ emissions that cause climate change, and fast degradation of bioresources. As these responses converge across countries, these trends, presumably, will continue unless shifts in consumption and technologies are enforced. High-income countries have reduced their share of global impacts due to a larger consumption of services and greater use of environmental technologies, while the externalisation of environmental impacts is hardly observed. In lower-income countries, increases in production are used mainly for domestic consumption, without sufficient use of environmental technologies. Given that, arguments for shared financing of international burdens fade away. Economic growth is neither a blessing nor a disguise for environmental impact and human capabilities given that additional affluence does not reduce environmental impacts nor improve human

capabilities across countries. Positive results depend on the allocation of additional income. Meanwhile, twenty-five countries with economies that grew moderately reduced all the environmental impacts, some of them by as much as half compared to 1990, and many of these high performers also improved most of the human capabilities. All these countries are considered democracies that experience peaceful economic development that generates affluent, well-educated, and healthy societies. Good living with environmental quality can be reached.

The observed environmental impacts and possibilities for changes to sustainability are explained with the use of three popular theories. They focus on the shift to services in economies in the ‘Environmental Kuznets Curve’ hypothesis, on sustainable innovations in the idea of ‘Green Growth’, and on regulatory demands for environmental performance in the so-called ‘Porter hypothesis’. These hypotheses are considered cumulatively as they address the changes on the level of the whole economy, in businesses, and in firms, respectively. The share of services in economies increases with income, but services complement growing polluting agriculture and industry rather than replacing them. Innovation increases but instead of sustainable innovation, industries and transport innovate to achieve the lowest costs for low-value products. Firms face consumer demand for environmental qualities thanks to longer leisure time and more knowledge, but environmental regulations hardly invoke environmental investment. Combined, these hypothesised factors contribute to the observed changes toward sustainability, albeit conditional. In theory, this condition emerges when lower use of natural resources provides large cost savings for profits that are dedicated to sustainable innovations. Presently, lower use of natural resources hardly contributes to cost-savings because prices of natural resources are low, while profits are mainly dedicated to shareholder consumption and the scaling up of existing activities instead of sustainable innovations. Conditions for change toward sustainability can be created in practice through putting high prices on environmental impacts, shifting taxes from labour to natural resources, and enforcing high-quality performance in production. Shifts toward sustainability within market competition are a realistic prospect if policies are enacted decisively.

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