TYPE Original Research
PUBLISHED 01 March 2024
DOI 10.3389/frsus.2024.1351841

OPEN ACCESS

EDITED BY
Carlo Ingrao,
University of Bari Aldo Moro, Italy

REVIEWED BY
Kiara Winans,
Oregon Department of Environmental Quality (DEQ), United States
Maksims Feofilovs,
Riga Technical University, Latvia
Rebecca Hanes,
National Renewable Energy Laboratory (DOE), United States

*CORRESPONDENCE
Fabio Zagonari
fabio.zagonari@unibo.it

RECEIVED 07 December 2023
ACCEPTED 12 February 2024
PUBLISHED 01 March 2024

CITATION
Zagonari F (2024) Both de-growth and a-growth to achieve strong and weak sustainability: a theoretical model, empirical results, and some ethical insights.
Front. Sustain. 5:1351841.
doi: 10.3389/frsus.2024.1351841

Both de-growth and a-growth to achieve strong and weak sustainability: a theoretical model, empirical results, and some ethical insights

Fabio Zagonari*

Dipartimento di Scienze per la Qualità della Vita, Università di Bologna, Bologna, Italy

This study *conceptually* characterizes and *theoretically* represents the four main sustainability paradigms (strong sustainability, weak sustainability, de-growth, and a-growth) in terms of equality and inequality. It then applies these conditions to developed and less-developed countries (OECD and non-OECD countries) and *empirically* shows that the change in production technology ($\Delta\theta$) required by a-growth is impossible and the change in consumption preferences ($\Delta\alpha$) required by de-growth is unfeasible. Finally, it combines a-growth and de-growth in a *theoretical* solution for the relationship between $\Delta\alpha$ and $\Delta\theta$ that meets the conditions required by both strong and weak sustainability (parameters are the world's population, consumption preferences, and production technologies or concerns for nature and future generations in developed and less-developed countries) and *empirically* demonstrates that this solution is feasible. In particular, sustainability turns out to be an ethical issue more than a technological issue, and the ethical concern for nature turns out to be more favorable than the ethical concern for future generations. Ethical assumptions and implications of the four main sustainability paradigms are highlighted and ethical assumptions and implications of the combined theoretical model are discussed. In particular, intergenerational efficiency is achieved in terms of welfare, and intergenerational equity is achieved in terms of environmental status.

KEYWORDS
ethics, strong sustainability, weak sustainability, de-growth, a-growth, technological change, value change, OECD countries

1 Introduction

Ecological economists have vigorously debated the concept and consequences of de-growth since the first publication by Kallis et al. (2010) and a-growth since the first publication by Van den Bergh (2010), as well as their value as alternative sustainability paradigms. In particular, an *ideological* debate by these authors (i.e., Kallis, 2011; Van den Bergh, 2011) in *Ecological Economics* has led to a conceptual debate by (mainly) these authors and (some) other authors in (mainly) this journal and (some) other journals (e.g., Haapanen and Tapio, 2016; Cosme et al., 2017).

However, environmental sustainability is a *practical* issue. Indeed, the observed failures of international pacts on climate change (e.g., the Kyoto Protocol and the Paris Agreement) suggest that it is not enough for a technological improvement to be possible or a cultural change to be intended to move the world away from unsustainable practices; new technologies and values must also be feasible (i.e., both effective and practical) to achieve realistic equilibrium sustainability conditions.

The primary purpose of this study is to test whether there can be synergies between a-growth and de-growth to support the *practical* debate over how to achieve weak sustainability and strong sustainability as two theoretically distinct sustainability paradigms. To do so, I will conceptually characterize the four sustainability paradigms (section 2.1) by developing a single theoretical framework that depicts all these sustainability paradigms (section 2.2). I will then apply real-world data to this theoretical framework to test whether the conditions required only by a-growth (based on improvements in production technology), only by de-growth (based on changes in consumption preferences), and the combined requirements under a-growth and de-growth are unable to meet the conditions required by weak and strong sustainability (section 3). I discuss the previous results in the literature and the novel insights of my study, as well as the methodological weaknesses and strengths of my approach in section 4, and I summarize my conclusion in section 5.

Note that the public opinion on the growth versus environment dilemma has been properly evaluated (i.e., multi-level and cross-country models) by three recent articles: Gugushvili (2021) in 33 European countries by applying logistic regressions to data from the 2017 European Values Study; Lou et al. (2022) in 58 countries by applying random forest models to the World Values Survey data collected from 2010 to 2014; and Paulson and Büchs (2022) in 34 European countries by applying logistic regressions to data from the 2017 European Values Study. Indeed, other articles are limited to a single country (e.g., Drews et al., 2019; Savin et al., 2021; Böhmelt and Zhang, 2023) or they apply single-level models (e.g., Nadeau et al., 2022). In those three articles, the idea of sacrificing a certain level of growth for the sake of the environment turns out to have predictors at the country level (i.e., Gross Domestic Product growth rate, Gross Domestic Product *per capita*, and carbon dioxide productivity) and the individual level. In particular, post-materialists, politically left-leaning, better-off, and higher educated people with a larger sense of responsibility, self-expansion identity, concern for the environment, and a more favorable attitude toward science and technology prioritize environmental protection over growth; materialists, politically right-wing, and disadvantaged people prioritize growth over environmental protection.

However, combining economic perspectives with ecological perspectives means adopting an interdisciplinary approach.

The secondary purpose of this study is to highlight the main linkages and interactions between ethical assumptions and implications in alternative perspectives. In particular, ethical assumptions and implications of the four main sustainability paradigms are highlighted in section 2.1, whereas ethical assumptions and implications of the combined theoretical model are discussed in section 5.

Note that many articles have characterized de-growth and a-growth in terms of values (e.g., Gunderson, 2018; Hankammer and Kleer, 2018; Strunz and Bartkowski, 2018; Sandberg et al., 2019) and policies (e.g., Khmara and Kronenberg, 2020; Fitzpatrick et al., 2022). Moreover, some articles have compared de-growth and a-growth from the experts' and researchers' perspectives (e.g., D'Amato et al., 2019; Lehmann et al., 2022). Finally, few articles have characterized de-growth and a-growth with a theoretical approach (e.g., Heikkinen, 2020) or an empirical approach (e.g., O'Neill, 2015). However, to the best of my knowledge, no articles have characterized *and* compared de-growth and a-growth with a theoretical *and* empirical approach.

2 Methods

2.1 Conceptual characterization of sustainability paradigms

Four main sustainability paradigms can be identified between a purely economic framework (e.g., Ramsey, 1928) and a purely ecological framework (e.g., Holling, 1973) under the definition of environmental sustainability by Salas-Zapata et al. (2017) (i.e., maximization of social and ecological continuity *and/or* minimization of social and ecological impacts): weak sustainability, a-growth, de-growth, and strong sustainability (Zagonari, 2022).

Table 1 summarizes the main ethical assumptions and implications of the four sustainability paradigms by including a purely social perspective and a purely ecological perspective, whereas Supplementary Materials and Zagonari (2022) provide the definitions of concepts used in the two main economic models and the three main ecological models. In particular, social efficiency in Ramsey (1928) and Arrow and Debreu's (1954) economic models, Holling (1973) ecological resilience, and Yi and Jackson (2021) and Li et al. (2020) ecological models.

Some remarks in Table 1 are worthy here. Social sustainability (in Economy) comes from the maximization of the discounted value of welfare from $t = 0$ to $t = \infty$; ecological sustainability (in Ecology) is based on the environmental status being equal to a resilient equilibrium from $t = 0$ to $t = \infty$. Weak sustainability maximizes total welfare by implementing the inter-generational constraint in terms of the average welfare. Strong sustainability minimizes environmental impacts by implementing the inter-generational constraint in terms of each individual's environmental status. Even if individuals are identified as having a fixed set of preferences (in weak sustainability and a-growth), well-informed preferences together with complete and perfect information are likely to be crucial for environmental issues. Imperfect competition (in de-growth) might be due to the lack of complete and perfect information. The lack of a monetary evaluation in terms of an equilibrium market price due to incomplete information, imperfect information, or imperfect competition implies the relevance of top-down vs. bottom-up decisions in de-growth and the adoption of a top-down approach in strong sustainability. The correct evaluation of externalities in a-growth requires perfect information about future generations' (well-informed) preferences. The correct evaluation of capital reductions in de-growth requires complete and perfect information on the current generation's (well-informed) preferences.

2.1.1 Weak sustainability

Weak sustainability can be defined as a development that meets the needs of (representative individuals of) the present generation without compromising the ability of (representative individuals of) future generations to meet their own needs (Dietz and Neumayer, 2007). Its main features can be summarized as follows: the objective units are the average human needs in at least three incommensurable

TABLE 1 Ethical assumptions and ethical implications.

	Economy	Weak sustainability	A-growth	De-growth	Strong sustainability	Ecology
Main goal	Social Efficiency	Inter-generational Efficiency	Inter-generational efficiency by Δθ	Inter-generational equity by Δα	Inter-generational Equity	Ecological Resilience
Main ethics	Utilitarian	Utilitarian	Utilitarian	Utilitarian	Duty to future generations	Duty to non-human beings
Ethical assumptions						
a) Consequentialism					No	No
b) Welfarism (1)				No	No	No
c) Individualism	(2)	(2)	(2)			No
d) Rationality (3)					No	No
e) Efficiency	Pareto	Pareto	Pareto	No	No	No
f) Equity	Same value to individual welfare	Same value to individual welfare	Same value to individual welfare	Minimum individual welfare	Same individual environmental status	No
A Complete information				No	No	No
B Perfect information				No	No	No
C No externalities			No	No	No	No
D Perfect competition				No	No	No
E FG ≥ CG	No (4)			(5)	(6)	No
F Perfect substitution of capitals				No	No	No
Ethical implications						
Environmental sustainability	(From F)	(From F)	Internalized ΔE in P* (7)	No	No	No
Evaluation of environmental status	Monetary (From D)	Monetary (From D)	Monetary (From D)	Physical	Physical	Physical (8)
Ecological sustainability if	Absolute Decoupling	Absolute Decoupling	Absolute Decoupling	Relative Decoupling (9)	Resilient E(0)	
Ecological sustainability in	E(W) = E*	E(W) = E*	E(W) = E*	E (W) = E*	E(0) = E*	E*

Δθ = technological changes, Δα = value changes, Blank = presence, No = absence, E = environmental status, ΔE = a change in environmental status, W = individual welfare; CG = current generation; FG = future generations, P* = equilibrium market prices, E* = a resilient ecological equilibrium, E(0) = a stable ecological equilibrium. (1) W is defined as the satisfaction of preferences, where nature has an instrumental value, (2) an individual is defined as a set of fixed preferences, (3) rationality includes maximization of W, (4) FG ≥ CG is met in the socially stable equilibrium if the social discount rate is 0, (5) FG ≥ CG is met if WCG (E) < WCG (E(0)) ≤ WFG (E(0)), (6) the reference to a specified environmental status E(0) is an ethical assumption, (7) Δα > 0 amounts to the internalization of E in equilibrium market prices P* as suggested by a-growth, (8) the reference to a given definition of ecological resilience is an ethical assumption, (9) Δθ > 0 favors the relative decoupling as assumed by de-growth. Gray cells highlight the main ethical assumptions of the combined theoretical model developed in the present study: there is a technological change Δθ from a-growth and value changes Δα from de-growth such that E = E(0) (i.e., the intergenerational goal of strong sustainability in terms of environmental status E) and WFG ≥ WCG (i.e., the intergenerational constraint of weak sustainability in terms of welfare W), where equity from de-growth is combined with complete and perfect information from a-growth.

dimensions (i.e., economic, social, and environmental); equity as each individual's needs in current and future generations have the same importance, but because the analysis is based on representative individuals, the comparison is only inter-generational (not intra-generational); efficiency as intra-generational Pareto efficiency based on equilibrium prices and inter-generational Pareto efficiency based on constraints for current and future needs; and the constraint unit is the comprehensive amount of capitals (i.e., perfect substitution is possible among natural, manufactured, human, and social capitals).

Note that weak sustainability relies on unlikely absolute decoupling since there are no constraints on population growth (Biely et al., 2018). Moreover, it aims to maximize welfare and is based on instrumental rationality (i.e., on average). Finally, introducing ecological constraints under the weak sustainability paradigm (e.g., tipping points, uncertainties, and resilience), because the results are disliked in terms of environmental status, is an *ad hoc* modification of its logical framework that hides the ethical approach behind the weak sustainability paradigm (Irwin et al., 2016).

The main ethical assumptions behind weak sustainability (i.e., intergenerational efficiency in terms of welfare) are (a) consequentialism, (b) welfarism, (c) individualism, (d) rationality, (e) efficiency, (f) equity as the same value attached to each individual's welfare and (A) complete information, (B) perfect information, (C) no externalities, (D) perfect competition, (E) welfare of future generations at least equal to welfare of current generation, and (F) perfect substitution of different types of capitals. Note that weak sustainability amounts to the Ramsey (1928) model, where the social discount rate is 0.

The main ethical implications of weak sustainability are environmental sustainability (i.e., the environmental status is consistent with social values and dynamics) and monetary evaluation of the environmental status (i.e., an equilibrium price is attached to each natural item from which human beings obtain some welfare). Note that environmental sustainability is distinguished from ecological sustainability here, where the environmental status is consistent with ecological functioning and dynamics.

2.1.2 A-growth

A-growth can be defined as an ecological and economic strategy that focuses on indifference to or neutrality about the economic (GDP) growth as a non-robust and unreliable indicator of social welfare and progress due to the many neglected non-market transactions (e.g., informal activities and relationships) and the many unpriced environmental effects (e.g., long-term impacts of nuclear power or plastic production; Van den Bergh, 2010). Its main features can be summarized as follows: the objective unit is the average human welfare; equity as each individual's welfare in current and future generations has the same importance, but because the analysis is based on representative individuals, the comparison is only inter-generational (not intra-generational); efficiency as intra-generational Pareto efficiency based on equilibrium prices that include environmental externalities and inter-generational Pareto efficiency based on constraints for current and future welfare; and the constraint unit is the comprehensive amount of capitals (i.e., there is a perfect substitution among natural, produced, human, and social capitals).

Note that both rich and poor people will oppose policies that threaten their real incomes via an increase in prices (Shao, 2020). Moreover, different increases in prices, which result from different levels of internalization of environmental impacts, will produce different changes in production sectors and rich and poor members of society. Finally, information campaigns to educate the adult population or environmental education to inform the young population can produce only long run behavioral and structural changes, together with technological and scale changes, based on relative and absolute decoupling, respectively (Kallis, 2011).

The main ethical assumptions behind a-growth (i.e., intergenerational efficiency pursued by technological changes) are the weak sustainability assumptions *plus* the absence of C (i.e., the presence of externalities). The main ethical implications of a-growth are the weak sustainability implications *plus* internalized prices (i.e., equilibrium prices include the non-compensated impacts of pollution production and resource use on current and future generations' welfare).

2.1.3 De-growth

De-growth can be defined as an ecological and economic perspective based on a socially sustainable and equitable reduction (and eventually stabilization) of the quantities of materials and energy that a society extracts, processes, transports, distributes, consumes, and returns back to the environment as waste (Kallis et al., 2010). Its main features can be summarized as follows: the objective unit is the individual human welfare; equity as each individual achieves the same minimum welfare level so that both intra- and inter-generational equities are achieved; efficiency is unimportant since the focus is on the possible inequitable costs of the transition toward smaller quantities; and the constraint units are some alternative amounts of capitals (i.e., there is only a partial substitution among natural, produced, human, and social capitals).

Note that the reduced investment in cleaner technologies in the short run due to smaller production and profits will lead to a larger production of pollution in the long run at a reduced economic scale (Hanaček et al., 2020). Moreover, the selection of produced capital to be reduced cannot be based on market forces or on voluntary choices by consumers or producers, so many private goods must be replaced by public goods. Finally, de-growth requires institutional changes toward eco-villages, co-housing, consumer–producer cooperatives, and non-monetary exchange systems (Cosme et al., 2017).

The main ethical assumptions behind de-growth (i.e., intergenerational equity pursued by value changes) are the a-growth assumptions *plus* absence of (e) (i.e., efficiency), equity (f) as a minimum of each individual's welfare, absence of (A) complete information, (B) perfect information, (D) perfect competition, and (F) perfect substitution of different types of capitals. The main ethical implications of de-growth are the absence of environmental sustainability and physical evaluation of the environmental status.

2.1.4 Strong sustainability

Strong sustainability can be defined as a development that allows (each individual in) future generations to access the same amount of natural resources and the same status of the environment as (each individual in) the current generation, where natural and physical or social capitals are complementary but not interchangeable (Jain and Jain, 2013). Its main features can be summarized as follows: the objective units are capitals in at least three main incommensurable dimensions (i.e., economic, social, and environmental); efficiency is disregarded because the environmental goals are considered more important than all other goals; equity as each individual has access to the same amount of natural and other types of capital, so both intra- and inter-generational equity are achieved; and the constraint units are many alternative amounts of capitals (i.e., no substitution is allowed between natural capital and the produced, human, or social capitals due to the intrinsic value of nature).

It is difficult to distinguish the critical capital that must be preserved from non-critical natural capital (Hickel, 2020). Moreover, technological progress is disregarded, although this could imply a smaller sustainability burden. Finally, strong sustainability must be combined with measures to reduce inequality since redistribution of rights to use resources will be required (Haskell et al., 2021).

The main ethical assumptions behind strong sustainability (i.e., intergenerational equity in terms of the environmental status) are the de-growth assumptions *plus* equity (e) as each individual's access to the same environmental status and an intergenerational constraint in terms of the environmental status. The main ethical implications of strong sustainability are the de-growth implications *plus* a specified environmental status as the reference level to minimize ecological impacts. Note that this amounts to the maximization of ecological continuity in Holling (1973), Yi and Jackson (2021) and Li et al. (2020) models if the specified environmental status is an ecologically resilient equilibrium.

In summary, social continuity amounts to weak sustainability with efficiency (i.e., it maximizes inter-generational total welfare) *if* the social discount rate is 0; in contrast, ecological continuity amounts to strong sustainability with equity (i.e., it minimizes inter-generational resource inequality) *if* the reference environmental status meets the conditions for resilience. Note that population growth affects both the ecological equilibrium and the economic equilibrium. Indeed, as for the ecological equilibrium, total ecosystems could move from a stable to an unstable level in the short run and toward an insufficient level in the long run. As for the economic equilibrium, *per capita* capital in the long run could be too large in terms of its temporal discount rate and capital decay rate.

2.2 Mathematical representations of the sustainability paradigms

From the perspective of an average individual, weak sustainability can be depicted as follows:

$$U_F = \left(E^* / \theta_F\right)^{\alpha F} \geq U_C = \left(E / \theta\right)^{\alpha} E^{-\beta} U_F^{\gamma}$$

Where U_F and U_C are the *per capita* utility levels of the future and current generations, respectively; E^* and E are the *per capita* sustainable and current use of Earth's resources, respectively, at the current global population; θ_F (i.e., $\theta_F = E^* / X_F$ with X_F the future production of goods and services) and θ (i.e., $\theta = E / X$ with X the current production of goods and services) are production technologies available to future and current generations, respectively; α_F and α are the consumption preferences of the future and current generations, respectively; and β and γ are the concerns for nature and future generations that characterize the current generation, respectively.

Note that β refers to the current environmental status without minimum thresholds since this concern is for nature *per se*, not for an equilibrium environmental status. Moreover, weak and strong sustainability are the baselines for the other equations, and thus, WS and SS are not included in the variable names. Finally, γ refers to the future generation's utility without minimum thresholds since this concern is for the future generation *per se*, not for an equitable future generation utility.

From the perspective of an average individual, a-growth can be depicted as follows:

$$U_{F,AG} = \left(E^* / \theta_{AG}\right)^{\alpha F} \geq U_{C,AG} = \left(E^* / \theta\right)^{\alpha} E^{*-\beta} U_{F,AG}^{\gamma} \quad (1_{fut})$$

Or

$$U_{F,AG} = \left(E^* / \theta_{AG}\right)^{\alpha F} \geq U_{C,AG} = \left(\frac{E^* /}{\theta_{AG}}\right)^{\alpha} E^{*-\beta} U_{F,AG}^{\gamma} \quad (1_{cur})$$

with

$$\theta_{AG} = \left(\theta E^*\right) / E < \theta \quad (2)$$

and

$$E \geq E^*$$

Where θ_{AG} is the improved production technology advocated by a-growth. In other words, the current generation predicts the conditions that will prevail for the future generation in terms of production technologies and bears the transition costs to a more efficient technology (i.e., $\theta_{AG} < \theta$) that allows the future generation to sustainably consume at the same level as the current generation (i.e., $E^*/\theta_{AG} = E/\theta$) by paying higher prices or achieving lower welfare (i.e., $U_{C,AG} < U_C$), where the future welfare is not smaller than the current welfare (i.e., $U_{F,AG} \geq U_{C,AG}$) and where the current consumption is smaller than the future consumption (i.e., $E^*/\theta_{AG} > E^*/\theta$) if the technological transition is not implemented until the future (i.e., inequality 1_{fut}) or the current consumption is the same as the future consumption (i.e., $E^*/\theta_{AG} = E/\theta$) if the technological transition is implemented starting in the current period (i.e., inequality 1_{cur}). That is, two extreme contexts are conceivable and mathematically formalized by numerically analyzing intermediate contexts.

Note that the future generation is not concerned about the environment under a-growth (i.e., $\beta_F = 0$) since the future generation is in an environmentally steady state. Moreover, the maximum transition cost that the current generation is willing to pay amounts to the opportunity cost to achieve sustainability (i.e., $U_C - U_{C,AG}$), where sustainability is pursued for ethical reasons (i.e., a duty to future generations) and nature has instrumental value (i.e., it is evaluated in terms of welfare; Zagonari, 2020a). Finally, the future generation is not concerned about the future generation (i.e., $\gamma_F = 0$) since the future generation is in a socially steady state.

From the perspective of each single individual, de-growth can be depicted as follows:

$$U_{F,DG} = \left(E^* / \theta\right)^{\alpha DG} \geq U_{C,DG} = \left(E^* / \theta\right)^{\alpha DG} E^{*-\beta} U_{F,DG}^{\gamma} \quad (3)$$

with

$$\alpha_{DG} = \alpha \left(\ln\left[E / \theta\right] / \ln\left[E^* / \theta\right]\right) - \beta \left(\ln\left[E / E^*\right] / \ln\left[E^* / \theta\right]\right) \quad (4)$$

and

$$E \geq E^*$$

Where α_{DG} is the consumption preference advocated by de-growth. In other words, the current generation predicts the conditions that will prevail for the future generation in terms of consumption preferences and attaches a different value to the current consumption level (i.e., $\alpha_{DG} \neq \alpha$) to achieve the same welfare at a sustainable (smaller) consumption level (i.e., $E/\theta > E^*/\theta$), where the current consumption equals the future consumption (i.e., $E/\theta = E^*/\theta$) and the future welfare is not smaller than the current welfare (i.e., $U_{F,DG} \geq U_{C,DG}$). That is, a single context is conceivable and mathematically formalized.

Note that using $U_C = U_{F,DG}$ instead of $U_{C,DG} = U_C$ to solve for α_{DG} replicates weak sustainability. Moreover, we will focus on changes in consumption preferences by keeping changes in the concern for nature ($\Delta\beta$) and future generations ($\Delta\gamma$) as alternative scenarios. Finally, using $U_{C,DG} = U_{F,DG}$ instead of $U_{C,DG} = U_C$ to solve for α_{DG} replicates a-growth.

From the perspective of each single individual, strong sustainability can be depicted as follows:

$$E^* \leq E$$

Note that θ_{AG} from equality 2 satisfies the condition for weak sustainability, in which the technological transition is implemented in the future if ln [θ] ≥ [1−β/(αγ)] ln [E]. Moreover, weak sustainability, a-growth, and de-growth assume that U_F cannot be smaller than U_C to avoid forcing the future generation to bear the sustainability burden (e.g., technology improvements funded by public debt). Finally, α_{DG} from equality 4 satisfies the condition for strong sustainability by definition since it includes E = E*.

3 Results

In this section, we rely on the following *realistic* assumptions to support the *analytical* results:

1. Production technologies and consumption preferences of the future generation are weighted averages of the production technologies and consumption preferences of current generations in developed and less-developed countries, for which the weights are the current relative populations (i.e., the proportions of the total global population in developed and less-developed countries). This accounts for historical legacies and traditions.
2. The changes in consumption preferences required by de-growth are proportional to the initial level of preferences in developed and less-developed countries [i.e., $(\alpha_{N,t+1} - \alpha_{N,t})/\alpha_{N,t} = (\alpha_{S,t+1} - \alpha_{S,t})/\alpha_{S,t}$ where N and S stand for developed and less-developed countries, respectively]. This depicts an equitable social cost for changes in consumption preferences.
3. Technology improvements required by a-growth are proportional to the initial technology levels in developed and less-developed countries [i.e., $(\theta_{N,t+1} - \theta_{N,t})/\theta_{N,t} = (\theta_{S,t+1} - \theta_{S,t})/\theta_{S,t}$ where N and S stand for developed and less-developed countries, respectively]. This depicts an equitable economic cost for improved technology.
4. The perspective of an average individual is depicted by referring to both developed and less-developed countries properly weighted in terms of their relative populations, whereas the perspective of each single individual is depicted by separately referring to representative individuals in developed and less-developed countries.
5. The environmental transition starts during the current generation (i.e., $E = E^*$) to depict the urgency of environmental sustainability, with a sustainable consumption preference implemented in the current period, but with options for the sustainable production technology: it can be totally implemented in the current period, totally implemented in the future period, or partially implemented in both periods.
6. Sustainability is based on inter-generational equity in terms of welfare in weak sustainability, a-growth, and de-growth (e.g., Aristotle or Harsanyi equity as teleological ethics grounded on duty to future generations, where it is assumed that actions have a goal: Aristotle in eudemonic terms based on flourishing and Harsanyi in utilitarian terms based on welfare, but both focused on human beings from an average person's perspective), but in terms of the environment in strong sustainability (e.g., Kant or Rawls equity as deontological ethics grounded on duty to future generations, where it is assumed that actions are performed for their own sake rather than based on their consequences: Kant in terms of freedom and Rawls in terms of resources, but both focused on human beings from a per-capita perspective).

Note that technology improvements or value changes in current generations in developed and less-developed countries will affect the production technologies and consumption preferences of the future generation (Van den Bergh et al., 2019). Moreover, the equitable distribution of social and economic costs solves the problem created by referring to average representative individuals. Finally, nature has instrumental value in weak sustainability, a-growth, and de-growth, but intrinsic value in strong sustainability (Zagonari, 2021).

Some teleological ethics are based on duty to future generations (e.g., Aristotle and Harsanyi); some deontological ethics are based on duty to future generations (e.g., Kant and Rawls);

In this section, we rely on the following *real* parameter values for the *numerical* results (Footprint Network, 2023; World Bank, 2023):

1. $Q_N = E_N/\theta_N$ is the production function in developed countries (N for northern hemisphere countries, for simplicity), with θ_N representing the technology that transforms the environmental status into goods and services (i.e., $\theta_N = 5.74/36.727 = 0.156$ ha ecological footprint [*EF*]/thousand US$ [GDP]). Similarly, for less-developed countries (S for southern hemisphere countries, for simplicity): $Q_S = E_S/\theta_S$ (i.e., $\theta_S = 2.14/8.216 = 0.260$ ha ecological footprint [*EF*]/thousand US$ [GDP]).
2. $U_N = (Q_N^{\alpha N})\,(E_N^{-\beta N})(U_F^{\gamma N})$ is the utility function for developed countries, with α_N the utility from consumption of goods and services, β_N the concern for the environmental status, and γ_N the concern for future generations, where parameters of Cobb–Douglas utility functions represent the proportion of the individual's income spent on a given life aspect (i.e., its relative importance). Let $\alpha_N = 0.6$, $\beta_N = 0.1$, and $\gamma_N = 0.1$, by referring to the individual average expenditure on consumption as a percentage of GDP (i.e., the household final consumption expenditures (% of GDP) in the World Bank dataset is used as the *per-capita* importance attached to consumption by assuming that this percentage is shared by all household members), the individual average expenditure on environmental protection as a percentage of GDP (i.e., the national expenditures on environmental protection (% of GDP) in the World Bank dataset is used as the *per-capita* concern for the environmental status by assuming that this percentage is supported by all country citizens), and the individual average expenditure on research and development as percentages of GDP (i.e., the domestic expenditures on research and development (% of GDP) in the World Bank dataset is used as the *per-capita* concern for future generations by assuming that this percentage is shared by all country citizens) in OECD countries, respectively (i.e., the average values based on the World Bank dataset from 2000 to 2020). Similarly, for less-developed countries: $U_S = (Q_S^{\alpha S})\,(E_S^{-\beta S})(U_F^{\gamma S})$. Let $\alpha_S = 0.75$, $\beta_S = 0.05$, and $\gamma_S = 0.05$.
3. $Q_F = E^*/\theta_F$ and $U_F = Q_F^{\alpha F}$ are the production and utility functions for future generations, with $\theta_F = p_N\,\theta_N + p_S\,\theta_S$, $E^* = 1.7$ ha, and $\alpha_F = p_N\,\alpha_N + p_S\,\alpha_S$, with $p_N = 0.18$ and $p_S = 0.82$ representing the proportions of the world population in developed and less-developed countries, respectively.

Note that I have assumed perfect inter-generational equity for all sustainability paradigms and no intra-generational equity for weak sustainability and a-growth (i.e., these sustainability paradigms adopt the perspective of an average individual). Next, the subscript N (northern hemisphere) is used to label parameters for OECD countries, and the subscript S (southern hemisphere) is used for non-OECD countries, with full recognition that this approach ignores some exceptions.

In summary, strong sustainability refers to sustainability in terms of an individual's use of Earth's resources (i.e., $E_N \leq E_F$, $E_S \leq E_F$); de-growth refers to sustainability in terms of both individual welfare and use of Earth's resources (i.e., $E_N \leq E_F$, $E_S \leq E_F$, $U_N \leq U_F$, $U_S \leq U_F$); a-growth refers to sustainability in terms of both average welfare and use of Earth's resources (i.e., $p_N\ E_N + p_S\ E_S = E_C \leq E_F$, $p_N\ U_N + p_S\ U_S = U_C \leq U_F$); and weak sustainability refers to sustainability in terms of average welfare (i.e., $U_C \leq U_F$). In other words, weak and strong sustainability differ to the greatest extent among the four paradigms.

Using these assumptions and data, sustainability is not achieved under a-growth, since $U_F = 4.444 < U_C = 6.251$ and $E^* = 1.7 < E_C = 2.788$. A technology improvement in both developed and less-developed countries should be achieved to meet $E^*/\theta_{AG} = E_C/\theta$ and $U_{F,AG} \geq U_{C,AG}$ (i.e., $E = E^*$ is included in this condition).

In particular, from $E^*/\theta_{AG} = E_C/\theta$ (equality 2), the use of resources must decrease (i.e., technological improvement $TI = 1 + \Delta\theta < 1$) if

$$TI = EF\ /\ EC < 1 \qquad (5)$$

Since $E_F = E^* = 1.7$ and $E_C = 2.788$. Thus, environmental efficiency must increase. Numerically, $\Delta\theta = -0.39 = 1.7/2.788 - 1 = 0.61 - 1$. Next, from $U_{F,AG} = U_{C,AG}$ (inequalities 1_{cur} and 1_{fut}), the level of consumption must decrease (i.e., $TI = 1 + \Delta\theta > 1$) if:

$$\ln[TI] = [1 - \beta/(\alpha\,\gamma)]\ln[E_F] - \ln[\theta] > 0 \qquad (6_{cur})$$

or

$$\ln[TI] = \ln[E_F] - \ln[\theta] - \begin{bmatrix} \alpha\ln[\theta] - \\ (\alpha - \beta)\ln[E_F] \end{bmatrix} / [\alpha(1-\gamma)] > 0 \qquad (6_{fut})$$

Thus, if technological improvement occurs in the current period, the current generation must decrease its consumption level to avoid achieving greater welfare than the future generation. In contrast, if technological improvement occurs in the future period, the current generation can increase its consumption level without achieving a larger welfare than the future generation. Numerically, $\Delta\theta = +2.51$ from Equation 6_{cur} and $\Delta\theta = -0.16$ from Equation 6_{fut}.

Note that consumption is more likely to decrease (i.e., $\Delta\theta > 0$) if the concern for nature is small (i.e., small β) and the production technology is environmentally efficient (i.e., small θ), the consumption preference is large (i.e., large α), the concern for the future generation is large (i.e., large γ), and the world's population is small (large E_F). Moreover, $U_{F,AG} = 6.483$, $U_{C,AG}$ (current implementation) = 7.593, $U_{C,AG}$ (future implementation) = 5.204 (i.e., $U_{F,AG} > U_{C,AG}$ only if the technological transition occurs in the future period). Finally, under weak sustainability, sustainability is not achieved since $U_F = 4.444 < U_C = 6.251$. Achieving weak sustainability will require a reduction of the current welfare by 29% since $U_F = 0.71\ U_C$. This is larger than the 24% reduction required under a-growth, in which technological improvement is implemented.

Under de-growth, sustainability is not achieved, since $U_N = 8.265 > U_F = 4.444$, $U_S = 5.808 > U_F = 4.444$, $E_N = 5.74 > E_F = 1.7$, and $E_S = 2.14 > E_F = 1.7$. A change in consumption preferences in both developed and less-developed countries should be espoused to achieve $U_N^* = U_N$ and $U_S^* = U_S$. That is, $E_N = E_N^* = E_F$ and $E_S = E_S^* = E_F$ are included under these conditions. In particular, from equality 4, consumption preferences must decrease in developed countries (i.e., value change of α in developed countries $VCA_N = 1 + \Delta\alpha_N < 1$) and in less-developed countries (i.e., value change of α in less-developed countries $VCA_S = 1 + \Delta\alpha_S < 1$) if:

$$VCA_N < 1 \leftrightarrow \ln[E_N] < \begin{pmatrix} (\alpha_N^2 - \beta_N)\ln[E_F] - \\ (\alpha_N - 1)\alpha_N\ln[\theta_N] \end{pmatrix} / (\alpha_N - \beta_N) \qquad (7_N)$$

$$VCA_S < 1 \leftrightarrow \ln[E_S] < \begin{pmatrix} (\alpha_S^2 - \beta_S)\ln[E_F] - \\ (\alpha_S - 1)\alpha_S\ln[\theta_S] \end{pmatrix} / (\alpha_S - \beta_S) \qquad (7_S)$$

Numerically, $\Delta\alpha_N = -0.66$ and $\Delta\alpha_S = -0.87$. Next, from inequality 3, consumption preferences must decrease in developed countries (i.e., value change of α in developed countries $VCA_N = 1 + \Delta\alpha_N < 1$) and in less-developed countries (i.e., value change of α in less-developed countries $VCA_S = 1 + \Delta\alpha_S < 1$) if:

$$VCA_N = (\beta_N\ VCB_N\ \ln[E_F]) / \begin{pmatrix} \alpha_N\ln[E_F/\theta_N] + \\ \alpha_W(\gamma_N\ VCG_N - 1) \\ \ln[E_F/\theta_W] \end{pmatrix} < 1 \qquad (8_N)$$

$$VCA_S = (\beta_S\ VCB_S\ \ln[E_F]) / \begin{pmatrix} \alpha_S\ln[E_F/\theta_S] + \\ \alpha_W(\gamma_S\ VCG_S - 1) \\ \ln[E_F/\theta_W] \end{pmatrix} < 1 \qquad (8_S)$$

Where VCB_S and VCB_S are the value changes of β in developed and less-developed countries, respectively, VCG_S and VCG_S are the value changes of γ in developed and less-developed countries, respectively, and W represents the world (global) value based on the weighted populations, with:

$$\alpha_W = p_N\alpha_N + p_S\alpha_S$$

$$\theta_W = p_N\theta_N + p_S\theta_S$$

Numerically, $\Delta\alpha_N = -0.56$ and $\Delta\alpha_S = -0.66$.

Note that from $U_N = U_F$ and $U_S = U_F$, we can also obtain unfeasible solutions: $\Delta\alpha_N = -0.64$ and $\Delta\alpha_S = -0.78$. Moreover, $U_{F,DG} = 1.204$, $U_{C,DG}$ (developed countries) = 1.600, $U_{C,DG}$ (less-developed countries) = 1.165 (i.e., $U_{F,DG} > U_{C,DG}$ only in less-developed countries). Finally, under strong sustainability, sustainability is not achieved since

$E_N = 5.74 > E^* = 1.7$ and $E_S = 2.14 > E^* = 1.7$. Achieving strong sustainability will require a reduction of current consumption of Earth's resources by 71% in developed countries and by 21% in less-developed countries.

The main analytical and empirical results are summarized in Table 2. Note that, under a-growth, it is assumed that the maximum transition costs that the current generation is willing to pay (i.e., 22,880 billion US$ = 24% of world GDP) is enough to move from θ to θ_{AG}. For example, the Italian government funded an ecological transition with 10 billion € per year for the next 6 years, which amounts to around 0.6% of the yearly Italian GDP (i.e., 1/40 of 24%).

Under the combination of a-growth and de-growth, if the technological transition occurs in the current period (i.e., conditions in 6_{cur}, 8_N, and 8_S are combined), the following relationship between changes in the consumption preferences (VCA_{cur}) and technology improvement (TI) must be met (9_{cur}):

$$VCA_{cur} = -\frac{VCB\begin{pmatrix}-\beta_N + \beta_S - \beta_S\gamma_N VCG + \\ \beta_N\gamma_S VCG\end{pmatrix}\ln\left[E_F\right]}{\alpha_N \ln\left[\circ/\theta_N\right] - \alpha_N\gamma_S VCG \ln\left[\circ/\theta_N\right] - \\ \alpha_S \ln\left[\circ/\theta_S\right] + \alpha_S\gamma_N VCG \ln\left[\circ/\theta_S\right]}$$

With $\circ = E_F/TI$ and where VCB is the value change of β in both developed and less-developed countries and VCG is the value changes of γ in both developed and less-developed countries.

Under the combination of a-growth and de-growth, if the technological transition occurs in the future period (i.e., conditions in 6_{fut}, 8_N, and 8_S are combined), the following relationship between the change in consumption preferences and technology improvement must be met (9_{fut}):

$$VCA_{fut} = \frac{VCB\begin{pmatrix}\beta_N\left(1-\gamma_S VCG\right) + \\ \beta_S\left(\gamma_N VCG - 1\right)\end{pmatrix}\ln\left[E_F\right]}{(\&)\ln\left[E_F\right] + \alpha_N\left(\gamma_S VCG - 1\right)\ln\left[\theta_N\right] + \\ \alpha_S\left(1-\gamma_N VCG\right)\ln\left[\theta_S\right]}$$

$$\ln\left[TI_{fut}\right] = \frac{\left[@ + p_N VCG(\#) + p_S VCG(\S)\right]\ln\left[E_F\right] + \\ \alpha_N\beta_S\ln\left[\theta_N\right] - \alpha_S\beta_N\ln\left[\theta_S\right]}{\left(\alpha_N p_N + \alpha_S p_S\right)\begin{pmatrix}\beta_S - \beta_S\gamma_N VCG + \\ \beta_N\left(\gamma_S VCG - 1\right)\end{pmatrix}}$$

Where

$$\& = \alpha_N\left(1-\gamma_S VCG\right) + \alpha_S\left(\gamma_N VCG - 1\right)$$

$$@ = \alpha_S(\beta_N + p_S\left(\beta_S - \beta_N\right) - y = \alpha_N(\beta_S + p_N\left(\beta_N - \beta_S\right)$$

$$\# = \beta_S\gamma_N - \beta_N\gamma_S$$

$$\S = \beta_N\gamma_S - \beta_S\gamma_N$$

Note that because condition 9_{cur} combines the conditions in inequalities 1 and 3, it allows cultural changes in the conditions for a-growth and technological changes in the conditions for de-growth.

Figure 1 depicts as curves the combinations of conditions for a-growth (inequality 1_{cur}) and for de-growth (inequality 3) to produce 9_{cur}. Figure 1 also depicts as points the solutions for a-growth (inequality 1_{fut}) and for de-growth (inequality 3) to produce 9_{fut} (i.e., $\Delta\alpha = 0.602$–1 at a given β and γ, but $\Delta\alpha = 0.903$–1 if β is increased by 50%, $\Delta\alpha = 0.318$–1 if γ is increased by 50%, while $\Delta\theta = 0.901$–1). Note that the conditions in equality 2 for a-growth and 4 for de-growth are depicted by values smaller than 1 for $1 + \Delta\theta$ and $1 + \Delta\alpha$, respectively (i.e., a technology improvement if $\Delta\theta < 0$ for a-growth and a consumption preference change if $\Delta\alpha < 0$ for de-growth).

Note that, by mathematical continuity, if the technological transition is implemented between the current and the future periods, the required Δα and Δθ will lie between the curve for a given color and the corresponding colored point in each scenario. In particular, the condition for weak sustainability is met since $U_C = 6.251 < 6.483 = U_{F,AG}$ if $\Delta\alpha = 0$ and $\Delta\theta = -0.39$, whereas the conditions for strong sustainability are met by definition. Moreover, a larger concern for the environment (i.e., with β increased by 50% in both developed and less-developed countries) favors the fulfillment of the conditions in equalities 4 and 2 (i.e., a smaller Δα is allowed for a given Δθ), whereas a larger concern for the future generation (i.e., with γ increased by 50% in both developed and less-developed countries) complicates the fulfillment of the conditions in equalities 4 and 2 (i.e., a larger Δα is required for a given Δθ). Finally, a current technological improvement lets us achieve sustainability at a smaller change in consumption preferences than a future technological improvement for any magnitude of technological improvement (i.e., the curve for a given color is above the corresponding colored point in each scenario). In particular, a trade-off between technological improvement and a change in consumption preferences is relevant only for a current technological improvement (i.e., the required Δα for a future technological improvement can be read on alternative curves for $\Delta\theta = 0$).

4 Discussion

In the introduction, environmental sustainability is argued to be a practical issue (i.e., the new technologies suggested by a-growth and the new values suggested by de-growth must be feasible). In addition, environmental sustainability is claimed to be an interdisciplinary issue (i.e., the achievement of a sustainable equilibrium requires a compromise between economic and ecological criteria).

With regard to the primary purpose of this study (i.e., possible synergies between a-growth and de-growth to achieve weak and strong sustainability), the main results of this study support the following statements:

- A-growth requires relative decoupling (i.e., an increase in Q at a given E or a decrease in E at a given Q) rather than absolute decoupling (i.e., both an increase in Q and a decrease in E; e.g., Kemp-Benedict, 2018; Wu et al., 2018; Frodyma et al., 2020; Haberl et al., 2020).
- Alternative conditions for de-growth (i.e., $U_C = U_{F,DG}$ and $U_{C,DG} = U_{F,DG}$) are less demanding than the condition required for

TABLE 2 Summary of the analytical and numerical results and their achievability.

	Analytical solutions	Numerical solutions	Welfare impact	Overall comment
A-growth	Equation 6_{cur} Equation 5	Δθ (welfare condition) ≥ +250% Δθ (environment condition) = −39%	$\Delta U_C = +10\%$	Impossible
A-growth	Equation 6_{fut} Equation 5	Δθ (welfare condition) ≥ −16% Δθ (environment condition) = −39%	$\Delta U_C = -24\%$	Impossible
De-growth	Equations 8_N, 8_S Equations 7_N, 7_S	Δα (developed countries) = −66% Δα (less-developed countries) = −87%	$\Delta U_N = 0$ $\Delta U_S = 0$	Unfeasible
A-growth and de-growth	Equations 9_{cur}, 9_{fut} Figure 1	$0 \leq \Delta\alpha \leq -40\%$ $0 \leq \Delta\theta \leq -30\%$	$-62\% \leq \Delta U_N \leq +30$ $-51\% \leq \Delta U_S \leq +36\%$	Feasible

"cur" and "fut" refer to contexts in which the technological improvement occurs in the current and future periods, respectively; Δθ = technology change (i.e., production technology improvement if Δθ < 0); ΔU_C = increase or decrease in the current generation's welfare, Δα = value change (i.e., consumption preference reduction if Δα < 0); ΔU_N and ΔU_S = increase or decrease in the current generation's welfare in developed and less-developed countries, respectively.

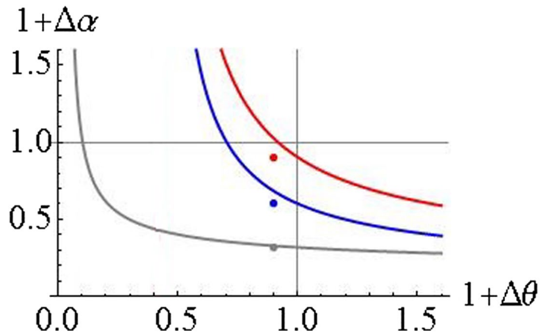

FIGURE 1
The relationship between the improvements in production technology (Δθ < 0) and the changes in consumption preferences (Δα < 0) is required to achieve both strong and weak sustainability. Legend: Blue curve and point for β and γ at current levels. Red curve and point for γ at current levels, but increased β. Gray curve and point for β at current levels, but increased γ. Notes: Blue curve for β and γ at current levels in developed and less-developed countries with Δθ and Δα occurring in the current period. Red curve for γ at current levels, but β increased by 50% in developed and less-developed countries with Δθ and Δα occurring in the current period. Gray curve for β at current levels, but γ increased by 50% in developed and less-developed countries with Δθ and Δα occurring in the current period. Blue point for β and γ at current levels in developed and less-developed countries, with Δα occurring in the current period but Δθ occurring in the future period. Red point for γ at current levels, but β increased by 50% in developed and less-developed countries, with Δα occurring in the current period but Δθ occurring in the future period. Gray point for β at current levels, but γ increased by 50% in developed and less-developed countries, with Δα occurring in the current period but Δθ occurring in the future period.

"happy" de-growth (i.e., $U_C = U_{C,DG}$; e.g., Büchs and Koch, 2019; Akizu-Gardoki et al., 2020).

By combining the conditions for a-growth and de-growth, the present study achieved the following insights:

- Sustainability is an ethical issue *more* than a technological issue (i.e., it can be achieved by a value change, but it cannot be achieved by a technological improvement).
- *Some* environmental ethics favor a solution toward sustainability (i.e., concern for nature), whereas *other* environmental ethics decrease the likelihood of sustainability (i.e., concern for future generations).

In other words, implementing both technology improvements and value changes makes a-growth rely on relative rather than absolute decoupling and makes de-growth require realistic rather than unrealistic changes in consumption preferences.

Note that sustainability as an ethical issue to a greater extent than a technological issue implies that sustainability is an institutional problem. Emphasis should be put on institutions that shape the rules of interactions (conventions, norms, and legal rules) and institutions that aggregate the values of societies (communication, treatment, and representation of complexity). Next, the ethical concern for nature as more favorable than the ethical concern for future generations implies that religious and secular institutions fostering any environmental sensitivity should be supported. Think of inter-religious dialog on environmental precepts, for example, a focus on trusteeship and parsimony in Islam, maintaining equilibrium for every single organism in Hinduism, and avoiding pain for sentient animals in Buddhism (Zagonari, 2020b; Zagonari, 2023). Similarly, think of education for environmental responsibility at different education levels (i.e., from elementary pupils to university students) and at different environmental scopes (i.e., from local to global problems), for example, education about the environment, education through the environment, and education for the environment (Kopnina, 2020; Rousell, 2020).

In addition, with regard to the secondary purpose of this study (i.e., possible linkages and interactions between ethical assumptions and implications), the main features of the theoretical model combining a-growth and de-growth can be summarized as follows: the objective unit is the average welfare (i.e., like in weak sustainability and a-growth); intra-generational efficiency is disregarded (i.e., like in de-growth and strong sustainability); intra-generational equity is disregarded (i.e., like in weak sustainability and a-growth); and the constraint unit is the per-capita environmental status (i.e., like in de-growth and strong sustainability).

The present study has the following methodological weaknesses:

- It depicts an individual perspective by referring to representative individuals in developed and less-developed countries. However, the analysis can be performed at a deeper level of detail if the required data are available.

- The burdens that must be borne by developed and less-developed countries to achieve sustainability are based on equal percentage losses. However, the analysis can be performed with different criteria if equity is preserved.

The present study has the following methodological strengths:

- The four main sustainability paradigms are included in a single theoretical framework.
- Sustainability conditions were validated using real-world data.

Note that the lack of unconditional analytical solutions due to the many parameters that are involved is irrelevant since numerical solutions based on real data are essential to solve such a practical problem. Next, sensitivity analysis is not required since the analytical models are based on production and utility functions, which are continuous in both variables and parameters, while the numerical results are depicted in a graphical framework which is based on continuous changes in parameters.

5 Conclusion

The purpose of this study was to test whether synergies were possible between a-growth and de-growth to achieve weak sustainability and strong sustainability as two theoretically distinct sustainability paradigms. The results show that a-growth is impossible whether the technological improvement occurs in the current period or the future period (due to the inconsistent technological changes that are required), whereas de-growth is unfeasible (due to the huge change in consumption preferences that are required). However, a combination of a-growth and de-growth was feasible, and it brought the weak and strong sustainability solutions closer together. In other words, the practical similarities between a-growth and de-growth (e.g., reduced working hours) should be stressed rather than ideological differences (e.g., efficiency in a-growth and equity in de-growth).

In summary, a-growth and de-growth have two different goals (efficiency and equity, respectively) and two different units (welfare based on the instrumental value of nature and the environmental status based on the intrinsic value of nature, respectively), although they both refer to the duty to future generations. A-growth adds externalities with respect to weak sustainability, whereas de-growth defines equity in terms of the minimum individual's welfare. In de-growth, value changes ($\Delta\alpha$) enable the achievement of an ecological stable equilibrium ($E(0)$) at a smaller loss in terms of welfare by attaching a larger value to a good environmental status. This value change amounts to the internalization of the environmental status in a-growth, although it implies the loss of individual's identity assumed by a-growth (i.e., each individual as a set of fixed preferences). In a-growth, technological changes ($\Delta\theta$) attach a smaller value to consumption in terms of the environmental status by enabling the achievement of a given level of welfare from consumption at a better environmental status. This technological change favors the satisfaction of the relative decoupling assumption in de-growth, although it requires the presence of complete and perfect information assumed by a-growth (i.e., the types of capitals to be focused on are properly identified). In combining a-growth and de-growth, the present study achieves intergenerational efficiency in terms of welfare (i.e., $W_{FG}(E(0)) \geq W_{CG}(E(0))$) and the intergenerational equity in terms of the environmental status (i.e., $E = E(0)$). Note that $W_{FG} \geq W_{CG}$ does not imply the social stability as defined in the economic models, whereas $E = E(0)$ does not imply the ecological resilience as defined in the ecological models.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found at: http://data.worldbank.org and http://www.footprintnetwork.org.

Author contributions

FZ: Writing – original draft, Writing – review & editing.

Funding

The author declares that no financial support was received for the research, authorship, and/or publication of this article.

Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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