Ecological Indicators 122 (2021) 107318

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

The biocapacity adjusted economic growth. Developing a new indicator

Giampaolo Gabbi [a], Massimo Matthias [b], Nicoletta Patrizi [c], Federico M. Pulselli [c,*], Simone Bastianoni [c]

[a] *SDA Bocconi School of Management – Bocconi University, Milan, Italy*
[b] *Department of Business and Law, University of Siena, Italy*
[c] *Ecodynamics Group, Department of Physical Sciences, Earth and Environment - University of Siena, Italy*

ARTICLE INFO

Keywords:
Ecological Footprint
Output Gap
Risk
Sustainability
OECD

ABSTRACT

The environment may constrain economic growth potential. In other words, economic growth cannot be pursued in spite of ecological limits any longer. Here we present an economic growth indicator adjusted by taking into account the current tendency of national economies to overcome the availability of natural resources and ecological dynamics. We combine two indicators: 1) the Output Gap, a measure of production capacity of the economy based on the difference between actual and potential GDP, as a per cent of potential GDP; 2) the difference between the Ecological Footprint and the Biocapacity of a country, systemic indicators representing the extent to which a country operates within or beyond ecological limits. That combination gives rise to the Biocapacity Adjusted Economic Growth indicator which enables a categorization of countries based on assessment of growth patterns in line or not with sustainability principles.

1. Introduction

All countries consider economic growth a priority. Many of them aim to couple economic policies and sustainability choices, especially in the environmental field. The approval of the Agenda 2030 and the Sustainable Development Goals on September 25th 2015 (UN, 2015) testifies this tendency. In particular, the European Union deserves a mention, since from its foundation, Article 2 of the Maastricht Treaty codifies that:

> "The Community shall have as its task, by establishing a common market and an economic and monetary union […] to promote throughout the Community a harmonious and balanced development of economic activities, sustainable and non-inflationary growth respecting the environment, a high degree of convergence of economic performance, a high level of employment and of social protection, the raising of the standard of living and quality of life, and economic and social cohesion and solidarity among Member States."

The article quoted has been commented on a great deal and one of the elements often found is that it contains potential internal contradictions. How, for example, can high employment and low inflation coexist with long-term growth respecting the environment? The rationale for the conflict is that economic growth, according to a mainstream approach, tends to produce greater demand for resources whose scarcity is a stimulus to price increases. And price stability is one of the main economic policy objectives, especially in the EU.

In the field of sustainability studies, the debate on the adequacy of economic growth and its measure (i.e. GDP) for orienting human behaviour and actions has been rising for many years; nevertheless, the main aim of policy makers is still economic growth. However, an effective solution for solving this problem lies on acknowledgment of the complementarity of information from different indicators rather than on complete replacement of GDP. In particular, this goal depends on what the economic and environmental potentials are, and how these can fruitfully complement each other.

To get out of a logic for which development takes place by "consuming" ecological resources and not, on the contrary, taking advantage by multiplying them, it is essential to refine the measurement metrics and quantify whether there really is a trade-off between economic growth and environmental protection. Moreover, according to Bastianoni et al. (2019), sustainability should be understood in a systemic viewpoint to recognize the fundamental role of the environment and resources it provides to mankind to thrive. Thus: "*the extensive aspect prevents from partial or myopic approaches that privilege one aspects* (e.g. *that of one single component in isolation or only the economic aspect) calling for measures and thresholds that reflect global conditions*" (Bastianoni et al.,

* Corresponding author.
E-mail address: federico.pulselli@unisi.it (F.M. Pulselli).

https://doi.org/10.1016/j.ecolind.2020.107318
Received 23 May 2020; Received in revised form 5 November 2020; Accepted 23 December 2020
Available online 4 January 2021

2019).

Our paper focuses on these elements, proposing a growth indicator that aims at conceiving an assessment of economic growth adjusted for environmental sustainability and ultimately becoming a key performance indicator for policy makers and analysts. For the first component we propose to use a measure that indicates the differential between current production and full production. In a similar way we propose a similar indicator for environmental potential.

The current literature (e.g. Adelle and Pallemaerts, 2009; Bohringer and Loschel, 2004; Tampakoudis et al., 2014) typically addresses the problem by separating growth and sustainability indicators, the latter being related to social, governmental or environmental dimensions. Other studies present measures of cross-layer correlations between economic, financial and environmental flows in different layers based on reciprocity (e.g. Hanna, 2010; Ruzzenenti et al., 2015; Vozzella et al, 2019).

Multi-factorial productivity measures (MFPs) provide an aggregate picture of the economy, with a retrospective approach, where the environment is included in the indicators as a productivity factor contributing in terms of natural capital.

An attempt to combine growth and environmental factors was proposed by the OECD in 2016 (OECD, 2016), when the Environmentally Adjusted Multifactor Productivity (EAMFP) was introduced. This indicator measures a country's ability to generate income from a given set of inputs, while accounting for the consumption of natural resources and production of undesirable environmental by-products. It corresponds to the share of pollution-adjusted output growth that is not explained by changes in the use of inputs (residual growth). Therefore, for a given growth of input use, the EAMFP increases when GDP increases or when pollution decreases. As part of the growth accounting framework underlying the EAMFP indicator, the growth contribution of natural capital and growth adjustment for pollution abatement indicators are derived:

- Growth contribution of natural capital - measures to what extent a country's growth in output is attributable to natural resource use;
- Growth adjustment for pollution abatement - measures to what extent a country's GDP growth should be corrected for pollution abatement efforts - adding what has been undervalued due to resources being diverted to pollution abatement, or deducing the excess growth which is generated at the expense of environmental quality.

To solve these issues, OECD has also proposed the measure of pollution-adjusted GDP growth. Pollution-adjusted GDP growth accounts for both the economic (GDP) and environmental (pollution) aspects of growth performance. OECD evaluates countries where economic growth occurred at the expense of environmental quality, and must thus be adjusted downwards. On the other hand, it also shows countries that managed to reduce the emissions intensity of their economic growth and hence should have their income growth adjusted upwards. Correctly reflecting such abatement efforts is important because they require directing scarce resources towards improvements in environmental quality rather than to producing marketed goods.

A first problem of this indicator is that it does not identify the potential for exploitation of environmental resources and their sustainability, but it focuses only on the growth due to pollution abatement. A second issue that remains unresolved in the OECD measure is that pollution in itself does not measure the environmental capacity to support economic growth. The latter should be more linked to the environmental budget (i.e., the amount of renewable resources) that each country inherently own thanks to its stock of natural capital. By highlighting this link, each country can understand how to optimise environmental resources and adopt coherently sustainable policies. The environmental budget can be appraised in terms of biocapacity, that is a physics-based entity that belongs to the Ecological Footprint methodology (Wackernagel and Rees, 1996; Borucke et al., 2013; Lin et al., 2018); it has in fact a systemic logic, referring to the entire system under study rather than focussing on a single punctual aspect.

Due to its ability to keep track of human consumption, Ecological Footprint results have been often combined to some socio-economic indicators. Moran et al. (2008) have combined the UN-HDI (Human Development Index; Anan and Sen, 1992) and Ecological Footprint, in order to monitor progress of Nations in advancing human well-being without compromising their biocapacity. Results of that combination revealed that countries with the highest HDI values tend to have high per capita Ecological Footprints (Moran et al., 2008). A similar approach, starting from the HDI/EF relationship, has been proposed by Wackernagel et al. (2017) who observed high HDI and (unfortunately) high EF for countries that show progress towards the Sustainable Development Goals. This relationship clearly demonstrates that there is still the need of integrated approach in assessing countries' ranking and the development of integrated approaches in which all the sustainability dimensions are taken into account (Wackernagel et al., 2017; Bastianoni et al., 2019).

A positive correlation between Ecological Footprint and GDP has been demonstrated, among others, by Jorgenson and Burns (2007); Niccolucci et al. (2007); Patrizi et al. (2010); Galli et al. (2012); Weinzettel et al. (2013). Coscieme et al. (2016) have also showed a cross-country correlation between ecological deficit and GDP, but no correlation between GDP and ecological surplus (being the surplus a measure of natural capital rather). Our proposal is based on different measures to capture the capability of policy makers to address strategic decisions aimed at finalizing both the economic and the ecological developments.

Recently, the Global Footprint Network (GFN) and the United Nations Environment Programme Finance Initiative (UNEP FI) launched the project E-RISK (Environmental Risk in Sovereign Credit analysis): the project proposes improved analytics able to take into consideration the growing natural resource constraints for sovereign credit risk. According to the promoters, "environmental risks are material, unevenly distributed between countries and not adequately reflected in sovereign credit risk analysis" (UNEP FI and GFN, 2012; 2016).

Sumaila et al. (2015) proposed an index (ECO^2) combining ecological and financial debits to assess consequences on the overall economic performances of countries due to ecological deficit. The results show increasing ecological deficits due to trading of natural resources for financial gains.

In this paper we aim to identify a single indicator for biocapacity adjusted economic growth by calibrating potential growth with consistent measures of sustainability. On one side, we apply the so-called output gap (instead of GDP) to capture the potential (and not the actual) growth. On the other, we adjust the output gap with the consumption (or, possibly, the creation) of biocapacity, in order to identify the impact of policy choices.

For this reason, we go into both growth measures and environmental sustainability measures in greater depth, in order to define an indicator that can provide a snapshot of a country's current position and indicate possible strategies for an optimal growth (i.e. better economic and environmental performances at the same time).

2. The measure for potential growth

If we want to identify a growth measure that is useful for defining economic policy strategies that are more consistent with the capacity of the environment to support them, we must first look for a measure that is not a backward looking production measure – that is based on historical measures –, but rather one that estimates forward looking potential, based on the gap between the actual growth and the economically feasible future growth margin, taking into account the inputs that are not fully used. This measure is called Output Gap (OG). A measure of this kind is decisive for us in determining the room for manoeuvre that policy makers can have to direct a growth pattern in line with sustainability criteria.

While this measure is well known in economic literature, it is an original contribution within the ecological studies because it gives the opportunity to measure the impact of economic policy on sustainability.

Comparing the actual with the full production, we estimate how single countries may reach a certain growth and how, adjusting this metric, they do that consuming ecological factors.

The OG refers to the production capacity of the economy (i.e., the productive resources, entrepreneurial capabilities and production linkages, determining the capacity of a country to produce goods and services), i.e. to the difference between actual and potential GDP, as a per cent of potential GDP. Typically, during a recession, actual economic output decreases below its potential; therefore, we record a negative OG. In contrast, when an economic upturn occurs, output increases above its potential level, producing a positive OG. A positive OG means that growth is above the trend rate and is inflationary. A negative OG means an economic downturn with unemployment.

The issue at the heart of the debate is the nature of the OG, which is not directly observable but needs an estimate. In fact, the OG is a measure to calculate the difference between potential and actual growth, i.e. a key indicator that is used to understand the potential development if a full production would be reached.

When a country is characterized by this gap, policy makers may adopt many different strategies: some of them are ecologically sustainable, some are not.

In other words, one estimate rather than another may lead to policies that are diametrically opposed. A restrictive policy in the presence of an unfavourable cycle would most likely be pro-cyclical with severe effects on economic prospects.

To avoid arbitrary choices, we use the OG from OECD Economic Outlook (2015). Table 1 shows the OG for OECD countries according to the OECD model for the years 2012–2015. We identify different values (positive and negative), due to the difference between potential and actual growth. We have selected four countries (Australia, Germany, Israel and United States) that in 2014 show either positive or negative values.

Table 1
Output Gap of the total economy OECD countries (2014) [expressed as % of GDP]. Data extracted on 15 Jul 2019 10:55 UTC (GMT) from OECD. Stat. The highlighted values correspond to the examples discussed along the paper.

Country	OG 2014	OG NORMmin
Australia	−1.181	3.904
Austria	−2.001	3.652
Belgium	−1.795	3.716
Canada	−0.706	4.050
Chile	0.293	4.357
Czech Republic	−2.482	3.504
Denmark	−1.555	3.789
Estonia	−0.711	4.048
Finland	−4.881	2.768
France	−1.842	3.701
Germany	0.326	4.367
Greece	−13.894	0.000
Hungary	−3.163	3.296
Ireland	−3.871	3.078
Israel	0.979	4.567
Italy	−5.432	2.599
Japan	0.444	4.403
Korea	−0.624	4.075
Luxembourg	−1.399	3.837
Mexico	−0.611	4.079
Netherlands	−2.608	3.466
Norway	−0.250	4.190
Poland	−2.057	3.635
Portugal	−6.865	2.159
Slovak Republic	−3.205	3.283
Slovenia	−5.979	2.431
Spain	−11.021	0.882
Sweden	−2.087	3.626
Switzerland	−0.455	4.127
United Kingdom	−0.675	4.060
United States	−2.758	3.420

To sort countries by the OG, we can also estimate the normalised value as a function of the minimum value with the Eq. (1):

$$Output\ \ Gap\ \ norm = \frac{OutputGap_{j,t} - \min[OutputGap]_t}{\sigma[OutputGap]_t} \tag{1}$$

where $OutputGap_{j,t}$ is the OG of country j at year t, $\min[OutputGap]$ is the minimum OG observed in year t, and $\sigma[OutputGap]_t$ is standard deviation for all $OutputGap_{j,t}$.

Almost all values in Table 1 are negative. This means that actual economic output is below its potential, which is mainly due to the impact of the financial crisis on growth and in particular on consumer demand. When we observe positive OG values, it means that an economy is outperforming expectations because its actual output is higher than the economy's recognized maximum capacity output.

The level and direction of movement of the OG is seen as providing indications about prospective inflationary pressures in product and labour markets, giving them a role to play in the conduct of economic and monetary policy. For example, when there is a negative potential output in a Member State, European rules require a correction of the structural budgetary balances, i.e. 'adjustment' or 'restrictive' manoeuvres. A positive potential output does not require this type of intervention, but could on the contrary suggest that the crisis is driven by cyclical factors, such as a fall in demand, and therefore requires counter-cyclical, expansionary demand-supporting manoeuvres.

For this reason, we will use the OG as an indicator of potential growth to be adjusted with biocapacity information for the measure of sustainability consistent in terms of the strategy adopted by policy makers.

3. The measure for sustainability

The Ecological Footprint Accounting (EFA) (Wackernagel et al., 2017) is an environmental accounting tool composed of two metrics (the Ecological Footprint and the biocapacity) able to account for the nature's contribution to human well-being expressed in global hectares (i.e. surface-equivalent biologically productive hectares) (Galli et al., 2007, Galli, 2015). This method aims to quantify, aggregate and express, in terms of ecosystem services values, both human consumption and Biosphere supply of resources (Galli et al., 2014; Mancini et al., 2018). Additivity and equivalence are the two main principles behind EFA. Additivity allows to sum-up all biologically productive space required to meet human demand. Equivalence allows to express different land types, characterized by different productivity, in a common unit of measurement (Lin et al., 2018). As such, by definition (Wackernagel et al., 2017; Borucke et al., 2013):

- The Ecological Footprint (EF) is *a measure of the demand populations and activities place on the biosphere in a given year, given the prevailing technology and resource management of that year*.
- The biocapacity (BC) is *a measure of the amount of biologically productive land and sea area available to provide the ecosystem services that humanity consumes - our ecological budget or nature's regenerative capacity*.

The EF tracks anthropogenic requirement and land appropriation as a consequence of consumer demand.

The BC tracks Nature's ability to produce ecosystem services within a country, a region or the whole planet. The BC is the counterpart of EF and reflects the current and actual productivity of ecosystems considering prevailing technologies and management practices rather than the theoretical productivity of such ecosystems (Goldfinger et al., 2014).

EF and BC are expressed in global hectares (gha) i.e. hectares with world average productivity (Rees, 1996; Galli et al., 2007), obtained by means of scaling factors, namely Yield and Equivalence Factor. Each global hectare represents the same fraction of the Earth's total bioproductivity and can be considered as an average hectare of all land types combined. Land types considered in the EFA are: cropland, grazing land, built-up land, forest land, fishing grounds and carbon uptake land. These land types originate products and services included into five leading consumption categories: food, shelter, transportation, goods and services and wastes (currently only the area required to sequester anthropogenic CO_2 emissions is considered).

The Global Footprint Network (GFN) annually provides EF and BC data for more than 200 Nations, under the name of National Footprint Accounts (NFA). EFA of a country expresses the EF of consumption (EF_C) of their inhabitants quantifying the demand of biologically productive land and sea area required to maintain their consumption's pattern considering the in house production (EF_P: EF of production within country's geographical boundaries), adding the EF embedded in imported goods (EF_I) and subtracting the EF embedded in exported goods (EF_E). Therefore, the EFA adopts a consumer-based approach (Borucke et al., 2013). A more detailed description of EFA can be found in Borucke et al. (2013) and Lin et al. (2018).

Since EF and BC are expressed in the same unit (i.e. gha), the comparison between the demand (EF) and availability (BC) highlights the ecological balance. Namely, as seen before, the difference between the two entities may result in a deficit or a surplus expressed in ecological terms. When in a country (or even at the World level) the EF is greater than the BC, an ecological deficit occurs (EF > BC) (at the global level this situation is called *overshoot*); conversely when the ecological balance is positive (BC > EF) the country runs an ecological surplus (Borucke et al., 2013). In other words, in this case we can identify the difference between EF and BC as an Ecological Gap as a counterpart of the Output Gap used in the economic/financial analysis. As recently recognized by Syrovátka (2020), however, the interpretation of the national ecological balance needs to be carefully handled in deriving and assessing the sustainability level of a nation. In fact, when an ecological deficit occurs it can be both at the expenses of national biocapacity or by depleting global biocapacity. Anyhow, the ecological deficit can be understood as a first environmental alarm that a policymaker should take into account besides the economic growth.

NFAs make use of extensive data sets largely from national and international statistical and scientific bodies like UN agencies or countries' annual statistics in areas like agriculture, forestry and energy. Domestic production and trade are taken into consideration for consumption (or final demand) calculation. Data gaps are filled in with the help of a variety of governmental, academic or private sources. The margin of error of NFA based on shortcomings of the data sources is hard to quantify even though each year a quality-assurance process is followed to validate the calculations (Lin et al., 2018).

With the aim of measuring the degree of environmental sustainability, we estimate the Ecological Gap as the difference between Ecological Footprint and biocapacity (EF-BC). For each country j, we then compute Δ(EF-BC) in a period t (in our case between 2013 and 2014) to highlight the dynamics of sustainability. We underline the "dynamics of sustainability" because we use the momentum (or, a derivate) of biocapacity and not the stock of it. This way, our proposal focuses on the dynamics of growth and ecological consumption. The indicator is then oriented to show the nature of policy makers decisions.

In order to standardize this variable with positive values, we compute the gap between $\Delta(\text{EF-BC})_{j,t}$ and minΔ(EF-BC), that is the country where we observed the minimum dynamics. Finally, we scale the previous difference with the standard deviation of all the $\Delta(\text{EF-BC})_{j,t}$

Finally, to obtain a positive measurement of this indicator, we can calculate its standardised value using the following formula:

$$\Delta(EF-BC)_{norm;j,t} = \frac{\Delta(EF-BC)_{j,t} - \min[\Delta(EF-BC)]_t}{\sigma[\Delta(EF-BC)]_t} \quad (2)$$

where $\Delta(EF-BC)_{norm}$ allows to rank all the countries by the delta in biocapacity consumption. This indicator is always positive; only the country $\min[\Delta(EF-BC)]_t$ records a 0 value: the period 2013–2014 shows that the $\min[\Delta(EF-BC)]_t$ was recorded in Poland (Table 2).

4. The biocapacity adjusted output gap. Our proposals

The analysis of growth and how it is combined with the environmental variable can be dealt with in two ways: on the one hand, the two dimensions can be kept separate and how to govern growth according to the desired environmental sustainability variable can be evaluated; on the other hand, we build a synthetic indicator that can relate both dimensions (economic growth and ecological potential) in a single measure. In the first part of this section we evaluate how to interpret the two dimensions (growth and environmental sustainability) separately; then we will propose an adjusted growth indicator by means of biocapacity.

4.1. Economic growth and ecological Sustainability. Country position

After selecting 2014 as a reference year (GFN, 2018), we estimate how the expected trajectory could depend on the EF and BC values, proxies of environmental potential exploitation.

We choose four countries that show differences in Output Gap and Ecological Gap (the latter being equal to EF–BC). These are characterized by different potential growth (positive and negative) and Δ(EF–BC) observed over the period: Australia (negative OG and negative $\Delta(EF-BC)_{j,t}$), Israel (positive OG and negative $\Delta(EF-BC)_{j,t}$), Germany (positive OG and positive $\Delta(EF-BC)_{j,t}$), and United States (negative OG and positive $\Delta(EF-BC)_{j,t}$). The four countries reveal four different combinations in terms of OG and Ecological Gap dynamics. Our indicators are designed in order to classify all the potential trajectories of countries and how policy makers may calibrate their interventions in order to optimize the biocapacity adjusted economic growth. Data on OG and EF parameters for the selected countries are shown in Table 3.

Table 2
Ecological Gap (i.e. EF – BC), Delta 2014–2013 (Data from GFN, 2018).

Country	EF-BC 2014	EF-BC 2013	Delta
Australia	6.100	6.583	−0.483
Austria	5.091	5.238	−0.148
Belgium	5.920	2.954	2.965
Canada	7.264	1.381	5.883
Chile	3.240	1.111	2.130
Czech Republic	4.814	3.525	1.289
Denmark	6.341	0.830	5.511
Estonia	6.179	5.549	0.630
Finland	5.308	1.791	3.517
France	3.912	3.339	0.573
Germany	4.262	1.215	3.047
Greece	3.508	0.995	2.513
Hungary	2.818	0.721	2.096
Ireland	3.921	0.501	3.420
Israel	3.894	5.727	−1.833
Italy	3.506	1.109	2.397
Japan	3.958	0.272	3.686
Korea	5.030	0.880	4.150
Luxembourg	11.499	−0.786	12.285
Mexico	1.763	0.084	1.678
Netherlands	5.138	0.362	4.776
Norway	5.247	2.704	2.543
Poland	3.657	12.962	−9.305
Portugal	2.902	0.354	2.548
Slovak Republic	3.410	0.151	3.258
Slovenia	3.890	3.297	0.593
Spain	3.020	0.823	2.197
Sweden	5.805	0.289	5.516
Switzerland	4.065	1.926	2.139
United Kingdom	4.013	2.547	1.466
United States	7.580	0.271	7.309

Table 3
Output Gaps, Ecological Footprint, biocapacity and $\Delta(EF - BC)$ for the 4 selected countries.

COUNTRY	Output Gap	$(EF - BC)_{2014}$	$(EF - BC)_{2013}$	$\Delta(EF - BC)_{j,t}$	COUNTRY POSITION
Australia	−1.181	6.100	6.583	−0.483	LGHS
Germany	0.326	4.262	1.215	3.047	HGLS
Israel	0.979	3.894	5.727	−1.833	HGHS
United States	−2.758	7.580	0.271	7.309	LGLS

Source: NFA 2018 edition referred to year 2014; Global Footprint Network

Since high levels for the $\Delta(EF - BC)_{j,t}$ show higher ecological demand, the best strategy should perform at top left of the Cartesian plane. Typically, OG and EF are positively correlated (in 2014 the correlation coefficient was 0.18), in line with previous studies in which a positive correlation has been found between EF and GDP (Niccolucci et al., 2007; Patrizi et al., 2010; Galli et al., 2012; Weinzettel et al., 2013). In other terms, the $\Delta(EF - BC)_{j,t}$ is a proxy of the ecological risk to be paid in order to push up the economic growth. The larger the Δ, thehigher the risk not to reach the growth targets. It quantifies the amount of additional biocapacity needed by a country to meet inhabitants' requirements obtained through trade of goods and therefore paid out by the economy of the country, or contracting an ecological debt with future generations for overconsumption of natural resources (leading to a lower future biocapacity) or excessive emissions of CO_2.

If we compare the OG values with the ecological sustainability trend of the country represented by the $\Delta(EF - BC)_{j,t}$, we obtain 4 combinations as represented in Fig. 1. The best case (Higher Growth Higher Sustainability, HGHS) is when a positive growth potential (OG greater than 0) meets a higher sustainability ($\Delta(EF - BC)_{j,t} < 0$). On the other side, the worst case is characterized by negative output gaps and positive $\Delta(EF - BC)_{j,t}$values. This case may be defined Lower Growth and Lower Sustainability (LGLS). The other two cases (HGLS and HGLS) are intermediate combinations. Due to the positive correlation between economic performances and resource consumption (e.g. the abovementioned correlation between GDP and EF), HGLS and LGHS are easily understandable; at the same time HGHS and LGLS are rather counterintuitive and, for this reason, the status of HGHS, though desirable, is hard to achieve.

Fig. 2 shows how the four countries are combined in terms of the two dimensions. More specifically, the country with the best tendency in our matrix is Israel, because its positive OG is associated to a lower $\Delta(EF - BC)_{j,t}$, meaning that it is able to obtain a positive OG while reducing its ecological deficit (i.e. a positive but decreasing EF-BC) in time.

On the opposite side, the United States are in the worst combination, since the negative OG is combined with a tendency to a lower sustainability. Australia and Germany are in two intermediate positions, the former with good ecological and bad economic performance, the latter with bad ecological and good economic performance.

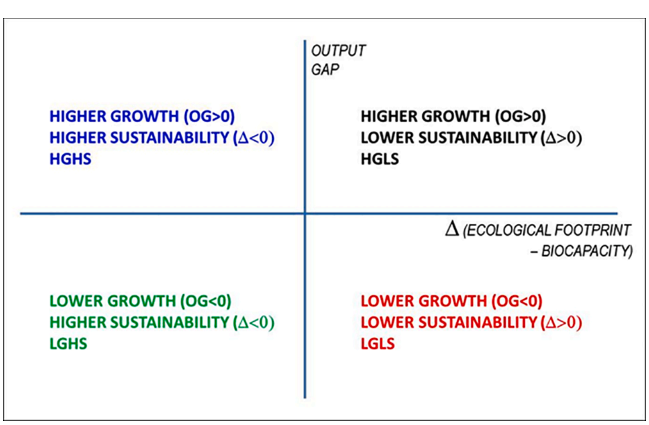

Fig. 1. OG and Delta (EF-BC) country combinations.

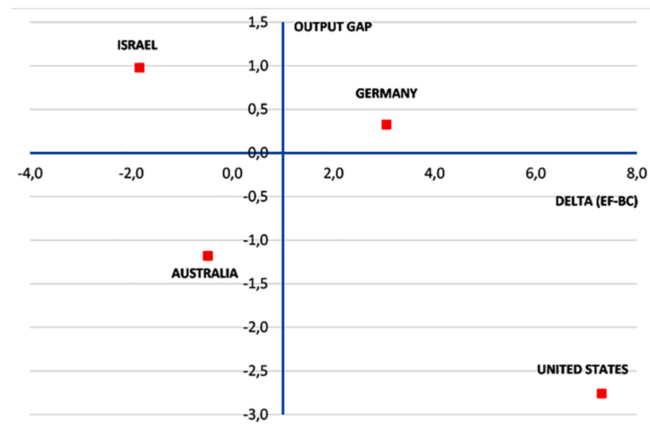

Fig. 2. OG and Delta (EF-BC) combinations for 4 countries (2014).

4.2. A proposal for a biocapacity adjusted growth indicator

The analysis of potential economic growth and the EF in relation to BC, i.e. the approach followed in section 4.1, allows the positioning of countries along the two dimensions identified to be highlighted, but does not allow a clear and synthetic representation of economic performance and ecological risk.

Following the experience of risk-adjusted performance indices introduced in finance (Sharpe, 1966, Treynor, 1965, Gabbi, 2005) aimed at comparing portfolios by synthesising returns and volatility, we propose the construction of an indicator capable of summarising to an extent the capacity of a country's economic growth in relation to its ecological demand.

Our Biocapacity Adjusted Growth indicator (BAG) is the ratio between the two dimensions already described above: the normalized OG on one side, and the Delta norm on the other (Eqs. (1) and (2)). Its rationale is that the economic growth potential (as numerator of the ratio) is conditioned by the biocapacity exploitation potential (as denominator of the ratio) (Eq. (3)).

$$BAG = \frac{OutputGapnorm}{\Delta(EF - BC)_{norm;j,t} + 1} \quad (3)$$

where $\Delta(EF - BC)_{norm;j,t}$ is an estimate of increasing ecological risk and a proxy for the sustainability of growth, as well as being a measure of the trend in biocapacity consumption. The higher the value of the denominator of the ratio, the more serious the ecological situation of the country appears.

A high value of the indicator, which is desirable, may depend on two factors: on the one hand, in the case of a high level of growth with respect to the potential of the production factors (with a positive output gap), the numerator increases. On the other hand, if the country manages to "save" its biocapacity and in particular if the trend is improving, the denominator decreases.

To our knowledge, this is the first contribution to the literature on sustainability that applies at the level of a single indicator simultaneously a measure of growth potential (the output gap) and an environmental potential, based on the dynamics of Ecological Footprint and biocapacity.

Compared to the OECD measure introduced in 2016 (EAMFP), we avoid using GDP that is backward looking, replacing it with a forward looking measure (OG). Moreover, with regard to the sustainability component, we do not use pollution measures but systemic sustainability measures, such as biocapacity.

The indicator can be considered as an estimate of the country's economic performance corrected for environmental risk.

In other words, this indicator is a measure of "sustainability risk" that could even direct the dynamics of investment towards one system or another also on the basis of its ability to physically support new infrastructure, settlements, processes and the like.

Based on the variation of growth and environmental sustainability factors and not on their level, the BAG provides a prospective trend indicator of the decisions taken by policy makers, and less conditioned by country-specific dependent factors on which government authorities are unlikely to structurally change.

From this point of view, the BAG is more consistent with the logic used in the financial sphere to assess debt sustainability, especially public debt. If policy makers allocate the financial resources raised on the capital markets (especially bonds) for investments that lead to an improvement in the BAG, it can be considered that the debt is, all other things being equal, more sustainable and therefore deserves a higher rating.

Table 4 summarizes the BAG factors and the final value for the OECD countries. By means of Eq. (1) we estimated *OutputGapnorm* for all the OECD countries in 2014. Due to the formula, all the *OutputGapnorm* values are positive. Only the $\min[OutputGap]$ assumes value 0, and in 2014 it was assumed by Greece, while the highest level (4,567) was assumed by Israel.

The most virtuous value for $\Delta(EF - BC)_{norm}$ was recorded by Poland, with the best decrease in biocapacity consumption in the considered period. The $\Delta(EF - BC)_{norm}$ ranges from 0 (Poland) to 6.326 (Luxembourg) giving the signal of the pattern of unsustainable decisions for each country.

The BAG indicator allows to summarize in which terms the growth potential of a country (OG norm) can be pursued in relation to the trends in environmental sustainability, especially considering the trend of biocapacity consumption in the country.

Since the two factors may have different dynamics, the positioning of the country in the ranking of the indicator may in some cases benefit more from the growth factor, in others from the environmental component.

As expected, among the four countries we selected in our paper, Israel highlights the best of the BAG values for its position as an HGHS country. In contrast, the United States has the lowest value (among the four countries analyzed) for its LGLS position.

Table 4
OGNorm min, Delta Norm and BAG for the OECD countries. Source: OECD. Stat and NFA 2018 edition referred to year 2014; Global Footprint Network.

Country	OG NORMmin	Delta Norm	BAG
Australia	3.904	2.585	1.089
Austria	3.652	2.683	0.992
Belgium	3.716	3.596	0.809
Canada	4.050	4.451	0.743
Chile	4.357	3.351	1.001
Czech Republic	3.504	3.104	0.854
Denmark	3.789	4.342	0.709
Estonia	4.048	2.911	1.035
Finland	2.768	3.757	0.582
France	3.701	2.895	0.950
Germany	4.367	3.619	0.945
Greece	0.000	3.563	0.000
Hungary	3.296	3.441	0.742
Ireland	3.078	3.829	0.637
Israel	4.567	2.189	1.432
Italy	2.599	3.429	0.587
Japan	4.403	3.807	0.916
Korea	4.075	3.943	0.824
Luxembourg	3.837	6.326	0.524
Mexico	4.079	3.218	0.967
Netherlands	3.466	4.126	0.676
Norway	4.190	3.472	0.937
Poland	3.635	0.000	3.635
Portugal	2.159	3.473	0.483
Slovak Republic	3.283	3.681	0.701
Slovenia	2.431	2.900	0.623
Spain	0.882	3.370	0.202
Sweden	3.626	4.343	0.679
Switzerland	4.127	3.353	0.948
United Kingdom	4.060	3.156	0.977
United States	3.420	4.869	0.583

5. Conclusions

Economic growth and environmental protection are often on the political agenda, albeit with different accents. The indicators used to assess the effectiveness of policy makers' choices are rarely comparable. Nor has any attempt been made to find synthetic indicators to define objectives and measure results for sustainable economic growth, in the environmental sense.

Our contribution is aimed at proposing a ratio whose meaning is to categorize countries in terms of potential growth adjusted by their trend in biocapacity consumption. The *Biocapacity Adjusted Growth* (BAG) indicator has been introduced to highlight the position of the country in a given moment, distinguishing four positions according to the level of growth and the trend in ecological consumption.

The originality of our contribution lies in the possibility of identifying, on the one hand, the positioning of each country in terms of sustainable growth. The proposed indicator makes it possible to identify in a synthetic way the growth potential of an economy and the rate of consumption of biocapacity, the latter being considered a significant risk factor for further economic prosperity, due to the supportive role played by Natural Capital for human activities. The indicator also has significant applicability to economic and environmental policies, in line with EU objectives. By measuring growth factors that are neutral in terms of consumption of the Ecological Footprint, it is possible to identify the potential growth of each country with a view to ensuring its own sustainability.

Aggregating indicators into a synthetic indicator often implies loss of information. For this reason, it has been necessary to propose an analysis of single indicators before combining them. Anyhow, in the case of indicators, appropriate disaggregation of information may help understand how and why a result has been obtained, and the way in which that information can be used.

In terms of policy implications, we suggest a way to find out the potential for economic growth exploiting the balance between EF and BC. Maximising the BAG ratio is possible only coupling highly sustainable growth policies in environmental terms.

Though the values of EF and OG used and computed here are not up to date, the purpose of the paper was to illustrate how to combine and possibly interpret information through the construction of a synthetic indicator, rather than present a worldwide diagnosis of countries.

A further application of the proposed indicator is more strictly financial. By intercepting the potential growth component and correlating it for the biological capacity to bear it, BAG is an indicator that financial analysts and rating agencies can incorporate into sovereign risk assessment models.

Countries that make economic policy decisions are able to positively influence this indicator in a direction that is clearly more sustainable in the medium and long term. With a time horizon that is similar to that of the maturities of public debt bond issues and which favours a "through-the-cycle" approach, characterised by less volatile estimates and able to capture the more robust components of credit risk estimates.

Author Contributions

MM conceived and designed the BAG indicator; GG collected and computed the economic data; NP, FMP and SB developed the ecological part; MM developed the economic-financial part; NP collected and computed the environmental data; all authors interpreted the results and wrote the paper.

CRediT authorship contribution statement

Giampaolo Gabbi: Data curation, Resources. **Massimo Matthias:** Conceptualization, Methodology, Validation, Writing - original draft. **Nicoletta Patrizi:** Methodology, Validation, Writing - original draft. **Federico M. Pulselli:** Data curation, Validation, Writing - original draft. **Simone Bastianoni:** Data curation, Validation.

Declaration of Competing Interest

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

References

Adelle, C., Pallemaerts, M., 2009. Sustainable Development Indicators, An Overview of relevant Framework Programme funded research and identification of further needs in view of EU and international activities. Brussels: European Commission.

Anand, S., Sen, A., 1992. Human Development Index: Methodology and Measurement. United Nations Development Programme, Human Development Report Office Occasional Paper, p. 12.

Bastianoni, S., Coscieme, L., Caro, D., Marchettini, N., Pulselli, F.M., 2019. The needs of sustainability: The overarching contribution of systems approach. Ecol. Ind. 100, 69–73. https://doi.org/10.1016/j.ecolind.2018.08.024.

Bohringer, C., Loschel, A., 2004. Measuring Sustainable Development: The Use of Computable General Equilibrium Models. ZEW Discussion Papers, No. 04-14.

Borucke, M., Moore, D., Cranston, G., Gracey, K., Iha, K., Larson, J., Lazarus, E., Morales, J.C., Wackernagel, M., Galli, A., 2013. Accounting for demand and supply of the biosphere's regenerative capacity: The National Footprint Accounts' underlying methodology and framework. Ecol. Ind. 24, 518–533. https://doi.org/10.1016/j.ecolind.2012.08.005.

Coscieme, L., Pulselli, F.M., Niccolucci, V., Patrizi, N., Sutton, P.C., 2016. Accounting for "land-grabbing" from a biocapacity viewpoint. Sci. Total Environ. 539, 551–559. https://doi.org/10.1016/j.scitotenv.2015.09.021.

Gabbi, G., 2005. Semi-correlations as a tool for geographical and sector asset allocation. The European Journal of Finance 11 (3), 271–281. https://doi.org/10.1080/13518470500039220.

Galli, A., 2015. On the rationale and policy usefulness of Ecological Footprint Accounting: The case of Morocco. Environ. Sci. Policy 48, 210–224. https://doi.org/10.1016/j.envsci.2015.01.008.

Galli, A., Kitzes, J., Niccolucci, V., Wackernagel, M., Wada, Y., Marchettini, N., 2012. Assessing the global environmental consequences of economic growth through the Ecological Footprint: A focus on China and India. Ecol. Ind. 17, 99–107. https://doi.org/10.1016/j.ecolind.2011.04.022.

Galli, A., Kitzes, J., Wermer, P., Wackernagel, M., Niccolucci, V., Tiezzi, E., 2007. An exploration of the mathematics behind the Ecological Footprint. Int. J. Ecodyn. 2 (4), 250–257.

Galli, A., Wackernagel, M., Iha, K., Lazarus, E., 2014. Ecological Footprint: Implications for biodiversity. Biol. Conserv. 173, 121–132. https://doi.org/10.1016/j.biocon.2013.10.019.

Global Footprint Network (GFN), 2018. National Footprint Accounts, 2018th ed.; Global Footprint Network: Oakland, CA, USA. Available at: http://data.footprintnetwork.org/#/.

Goldfinger, S., Wackernagel, M., Galli, A., Lazarus, E., Lin, D., 2014. Footprint facts and fallacies: A response to Giampietro and Saltelli (2014) "Footprints to Nowhere". Ecol. Ind. 46, 622–632. https://doi.org/10.1016/j.ecolind.2014.04.025.

Hanna, R., 2010. US Environmental Regulation and FDI: Evidence from a Panel of US-Based Multinational Firms. Am. Econ. J.: Appl. Econ. 2 (3), 158–189. https://doi.org/10.1257/app.2.3.158.

Jorgenson, A.K., Burns, T.J., 2007. The political-economic causes of change in the ecological footprints of nations, 1991–2001: a quantitative investigation. Soc. Sci. Res. 36, 834-853.Koske, I. and N. Pain (2008), "The Usefulness of Output Gaps for Policy Analysis", OECD Economics Department Working Papers, No. 621, OECD Publishing, Paris. https://doi.org/10.1787/241172520210.

Lin, D., Hanscom, L., Murthy, A., Galli, A., Evans, M., Neill, E., Mancini, M.S., Martindill, J., Medouar, F.Z., Huang, S., Wackernagel, M., 2018. Ecological Footprint Accounting for Countries: Updates and Results of the National Footprint Accounts, 2012-2018. Resources 7(3), 58.

Mancini, M.S., Galli, A., Coscieme, L., Niccolucci, V., Lin, D., Pulselli, F.M., Bastianoni, S., Marchettini, N., 2018. Exploring ecosystem services assessment through Ecological Footprint accounting. Ecosyst. Serv. 30, 228–235. https://doi.org/10.1016/j.ecoser.2018.01.010.

Moran, D.D., Wackernagel, M., Kitzes, J.A., Goldfinger, S.H., Boutaud, A., 2008. Measuring sustainable development — Nation by nation. Ecol. Econ. 64 (3), 470–474. https://doi.org/10.1016/j.ecolecon.2007.08.017.

Niccolucci, V., Pulselli, F.M., Tiezzi, E., 2007. Strengthening the threshold hypothesis: Economic and biophysical limits to growth. Ecol. Econ. 60 (4), 667–672. https://doi.org/10.1016/j.ecolecon.2006.10.008.

OECD, 2015. OECD Economic Outlook, Volume 2015 Issue 1. OECD Publishing, Paris,. https://doi.org/10.1787/eco_outlook-v2015-1-en.

OECD, 2016. Environmentally Adjusted Multifactor Productivity: Methodology and Empirical results for OECD and G20 countries, OECD Green Growth Papers, September 2016, DOI:https://doi.org/10.1787/5jlr2z7ntkf8-en.

N. Patrizi C. Capineri B. Rugani V. Niccolucci "Socio-economic design and nature": a possible representation through ecological footprint C.A. Brebbia A. Carpi Design and Nature Press V. WIT 2010 Southampton U.K. 527 534.

Rees, W.E., 1996. Revisiting Carrying Capacity: Area-Based Indicators of Sustainability. Popul. Environ. 17, 195–215.

Ruzzenenti, F., Joseph, A., Ticci, E., Vozzella, P., Gabbi, G., 2015. Interactions between Financial and Environmental Networks in OECD Countries. PLoS ONE 10 (9).

Sharpe, W.F., 1966. Mutual Fund Performance. Journal of Business. 39, 119–138.

Syrovátka, M., 2020. On sustainability interpretations of the Ecological Footprint. Ecol. Econ. 169, 106543. https://doi.org/10.1016/j.ecolecon.2019.106543.

Tampakoudis, I.A., Fylantzopoulou, D., Nikandrou, K., 2014. Examining the Linkages between GDP Growth and Sustainable Development in the Eurozone, Journal of Economics and Business, Vol. XVII, No 2, 15–37.

Treynor, J.L., 1965. How to Rate Management of Investment Funds. Harvard Business Review 43 (1), 63–75.

UNEP FI and Global Footprint Network, 2012. E-RISC: A New Angle on Sovereign Credit Risk. UNEP Finance Initiative and Global Footprint Network: Geneva, Switzerland.

UNEP Fi and Global Footprint Network ERISC PHASE II: How Food Prices Link Environmental Constraints to Sovereign Credit Risk ISBN 978-92-807-3561-1 2016 DTI/1983/GE.

United Nations (UN), 2015. Transforming our world: the 2030 Agenda for Sustainable Development. General Assembly, Seventieth session. A/RES/70/1.

Vozzella, P., Ruzzenenti, F., Gabbi, G., 2019. Energy and Environmental Flows: Do Most Financialised Countries within the Mediterranean Area Export Unsustainability? Sustainability, Vol. 11 No. 13, 3736.

Wackernagel, M., Hanscom, L., Lin, D., 2017. Making the Sustainable Development Goals Consistent with Sustainability. Front. Energy Res. 5, 18. https://doi.org/10.3389/fenrg.2017.00018.

Wackernagel, M., Rees, W.E., 1996. Our Ecological Footprint: Reducing Human Impact on the Earth. New Society, Gabriola, BC, Canada.

Weinzettel, J., Hertwich, E.G., Peters, G.P., Steen-Olsen, K., Galli, A., 2013. Affluence drives the global displacement of land use. Glob. Environ. Change 23 (2), 433–438. https://doi.org/10.1016/j.gloenvcha.2012.12.010.