

Primal-Dual Approach to Environmental Kuznets Curve Hypothesis: A Demand and Supply Side Analyses of Environmental Degradation.

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20 **Primal-Dual Approach to Environmental Kuznets Curve Hypothesis: A Demand and**
21 **Supply Side Analyses of Environmental Degradation.**

22 **Abstract**

23 Global warming and its unavoidable negatives effects on man and the environment have been a
24 key if not the most important issue occupying policy makers in the world at large today. The
25 much talked about green economy nowadays seeks to achieve sustainable economic growth and
26 development without compromising environmental quality. The relationship between
27 environmental degradation and economic growth is largely explained by the environmental
28 Kuznets Curve (EKC) hypothesis. By employing the basic postulation of the baseline EKC
29 framework, this study proposes and tests the existence of a dualistic approach of the EKC
30 hypothesis. Geometry is used to illustrate the proposed dualistic model. Meanwhile, the novel
31 dynamic common correlation effect econometric technique is employed to test the existence of
32 the dualistic EKC within a panel of 109 countries from 1995 to 2016. The outcome from the
33 estimated models shows that, in the global sample, the existence of the dualistic U-shape and N-
34 shape EKC hypothesis is validated. When the sample is split into sub samples based on income
35 levels, the U-shape EKC hypothesis is validated for lower income and high income economies
36 meanwhile, the N-shape dualistic EKC is mostly associated with high income economies.

37 **Keywords:** Environmental Quality, Economic Growth, EKC, primal-dual approach, DCCE.

38 **JEL Code:** C01, C02, C33, Q56, Y10.

39

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41 **1. Introduction**

42 In a bid to combat climate change, enhance economic prosperity and attain the set goals of the
43 21st Conference of the parties (COP21 hereafter), it is very important to comprehend the effects
44 of variations in economic growth on the environment (Allard et al. 2018). According to the
45 IPCC (2014), continuous environmental degradation can lead to devastating consequences for
46 humanity, with unavoidable effects like floods, droughts, adverse effects on growth, health and
47 the destruction of ecosystems. According to goal number thirteen (13) of the United Nations
48 Sustainable Development Goals - agenda 2030, emphasis is laid on the urgent need to take action
49 towards combating climate change and its adverse impacts (UN, 2015). This clarion call to
50 combat the negative effects of climate change and reduce global warming has been topical in the
51 recent Conferences of the Parties (COP22, COP23, COP24) due to the damaging effects of
52 climate change to nature as well as mankind. Thus, many targets have been agreed upon by
53 nations geared towards keeping the rise in global temperature well below 2°C.

54 The United Nations (2020) noted that although the COVID-19 outbreak may result in a 6% fall
55 in Greenhouse gas emissions in 2020, this will still fall short of 7.6% annual reduction in order to
56 limit global warming to 1.5 °. This is largely due to investments in fossil fuels which
57 continuously show higher trends. Climate change has exacerbated the frequency and severity of
58 natural disasters affecting more than 39 million people in 2018 (United nation 2020). Meanwhile
59 goal number eight (8) of the UN Sustainable Development Goals emphasizes the need to
60 promote sustained, inclusive and sustainable economies. Reconciling the desire of nations to
61 achieve economic growth without degrading the environment is one of the major issues
62 economists and policy makers around the globe are faced with today.

63 The debate as to whether increase in wealth and income will sow the seeds of increasing
64 ecological problems or if continuous economic growth will always lead to more harm to Mother
65 Nature or the environment have been a topical debate among economists and policy makers since
66 the advent of the Environment Kuznets Curve (EKC) hypothesis since the early 1990s
67 (Grossman and Krueger, 1991; Beckerman, 1992; Panayotou, 1993). The EKC hypothesis posit
68 that environmental degradation and income indicate an inverted U-shape relationship, showing
69 an increase in pollution at low income or output levels and consequently decreasing at high
70 income levels. This relationship is illustrated in figure 1 below.

71 **[Insert figure 1 here]**

72 From Figure 1, it is noticed that as income increase from an initial low level, the rate of
73 environmental degradation increases up to a certain maximum level, whereby an increase in
74 income will be associated with a fall in environmental degradation (environmental
75 improvement).

76 This hypothesis has been investigated in different countries using different proxies to account for
77 environmental quality or degradation with diverse outcomes. Most studies have used different
78 polluting greenhouse gases with CO₂ being the most used since the late 1990s till date (Ike et al.,
79 2020; Ahmed et al., 2020; Al-mulali and Ozturk, 2016; Balaguer and Cantavella, 2016). Other
80 greenhouse gases used include sulfur dioxide (SO₂) emission (Akboştañcı et al. 2009). Authors
81 like Ulucak and Bilgili (2018), Altıntaş and Kassouri (2020), Aydın et al. (2019), Ulucak and
82 Apergis (2018) among others have noted the weaknesses of such measures of environmental
83 quality. Recent authors have prioritised the use of ecological footprint which is a broader measure
84 of environmental degradation. As noted by Wackemangel (2002), ecological footprint refers to

85 how much environment is demanded by people and it observes how much biocapacity of Mother
86 Nature is used up at a given time. The ecological footprint index accounts for cropland footprint,
87 fishing grounds footprint, build-up land footprint, grazing land footprint and carbon footprint
88 which is broader in scope than the frequently used greenhouse gases like CO₂. Using the
89 ecological footprint equally allows for the use of peoples ecological budget or nature
90 regenerative capacity (biocapacity). McDonald and Patterson (2004) noted that the use of
91 ecological footprint helps to emphasize the direct and indirect impacts of consumption and
92 production activities on the environment.

93 In this study, we make use of the ecological footprint and present a novel dualistic approach of
94 investigating the EKC hypothesis. Our approach treats human extraction from nature as a
95 demand side analyses meanwhile the remaining ecological carrying capacity of the world at any
96 given time is observed as the supply of nature to mankind at any given time. We employ
97 geometry to illustrate the dynamic relationship that can exist between the available degree of
98 usage of Mother Nature and the available stock that Mother Nature offers at a given time. This
99 illustration is done with the introduction of a duality box. In the same vein, we use mathematical
100 expressions and signs to provide an insight on how the existence of the dualistic approach can be
101 validated. We then use a panel of 109 countries to empirically investigate the newly proposed
102 dualistic analyses of the EKC hypothesis. For the empirical investigation, we adopt the newly
103 proposed dynamic common correlation effects (DCCE) technique proposed by Chudik and
104 Pesaran (2015) due to the advantages it presents over conventional estimations techniques like
105 the panel ordinary least square (OLS), dynamic OLS, fully modified OLS, system and difference
106 generalized method of moment, pooled mean group, Panel smooth threshold regression
107 technique among others.

108 **2. Literature review**

109 **2.1.Theoretical framework**

110 The IPAT equation developed by Ehrlich and Holden (1971) is believed to be the first well-
111 known work on environmental quality. The IPAT equation describes the relation between
112 pollution, population growth, per capita income and technology. Whence, the establishment of
113 the Intergovernmental Panel on Climate Change in 1988 aroused research interest on the
114 economic growth and environmental quality nexus thereby leading to the path-breaking work of
115 Grossman and Krueger (1991). However, the theoretical basis in explaining the link between
116 economic growth and environmental quality often makes reference to the Environmental
117 Kuznets Curve (EKC) Hypothesis, which was born in the early 1990s following the celebrated
118 works of Grossman and Krueger (1991), and Shafik and Bandyopadhyay (1992). Nevertheless,
119 the EKC is named after Simon Kuznets, who in 1955 first hypothesized that as an economy
120 grows, income inequality initially increases and then falls after a threshold level of income
121 (Kuznets, 1955).

122 Hence, Grossman and Krueger (1991) posit that environmental degradation and income have an
123 inverted U-shape relationship, with pollution increasing with income at low levels of income and
124 decreasing with income at high levels of income. This shows that there is an initial direct
125 relationship between pollution and income and a subsequent indirect relationship at high income
126 levels, as seen in figure 1. We deduce from this position a new approach to this phenomenon by
127 proposing that if at a given time t , the ecological asset (EA) of a given country or the world can
128 be calculated, then this implies that the quantity of nature's ecological supply is known. Hence,
129 nature's ecological asset at a time $t+1$ (supply (EAS) at the time $t+1$)) will be the difference

130 between nature's ecological asset at the time t and the total demand from t to t+1. This can be
131 represented mathematically as:

$$132 \quad \quad \quad EAS_{t+1} = EAS_t - \delta(EAD) \quad (1)$$

133 Where EAD denotes ecological assets demanded or used, EAS stands for ecological assets
134 supplied and $\delta(EAD)$ is the rate of degradation of the environment or environmental demand
135 from period t to period (t+1). Hence, it can be deduced that at the initial low income level of
136 economic growth, there is a continuous fall in available biocapacity of a country up to a certain
137 marginal level, but as the country moves to a high income level, there is improvement or increase
138 in available biocapacity thereby showing an initial indirect relationship between available
139 biocapacity and economic growth and a subsequent direct relationship as seen in figure 2.

140 **[Insert figure 2 here]**

141 Based on the primal EKC model proposed by Krugman and Gross and the corresponding dual
142 model proposed in this study, it can be deduced that at a certain time t+p if the total of nature's
143 demand is equal to the total nature's supply at the period t+(p-1) then, an environmental
144 equilibrium is attained such that nature's supply is equal to nature's demand. This level of
145 equality can be seen as the highest level at which societal demand from Mother Nature can be
146 sustained (sustainably absorbed) by Mother Nature's supply. If at a given time t+(p+1), EAS is
147 less than EAD, then the country or the world at that level will be operating at a deficit. At this
148 point, increase pressure on the environment will be met with increasing negative effects (floods,
149 plaque, hunger, pandemics among others) on the society since the absorptive capacity of the
150 country or the world is less than societal pressure (ecological degradation).

151 On the other hand, if at the time $t+(p+1)$, EAS is greater than EAD, then societal rate of
152 consumption of mother earth's resources falls below the absorptive capacity and as such mother
153 nature is able to limit the degree of the effect of environmental degradation. On a more specific
154 note, it can be deduced that as human income or output rises while the rate of degradation is
155 increasing, available absorptive capacity will be falling up to a certain level whereby the
156 absorptive capacity will equal the rate of degradation. If after this point (Overshoot day)
157 economic growth continues to degrade the environment, then we are moving to the situation of
158 an environmental deficit. This situation of deficit will be a springboard of our basic presentation
159 on the dual relationship between environmental overshoot and environmental pollution. This
160 relation can be presented as in figure 3 below which we denote as the environmental duality box
161 1.

162 **[Insert figure 3]**

163 From figure 3, the initial available earth biocapacity (overshoot value) is the distance I_1-C_1 . From
164 the demand side, as economic growth increases from I_1 to I_2 , human demand of nature (ecological
165 footprint) rises to point b and the area $I_1-b_1-I_2$ is the level of degradation of nature to attain the
166 desired income I_2 . Equally, from the supply side, due to the increase in human activity to attain
167 the growth point I_2 , available earth biocapacity drops by the area $C_1-a_1-C_2$. Since at this point
168 ecological overshoot is still greater than ecological footprint, the world will be operating at an
169 ecological surplus represented by the area $a_1-e_1-b_1$. Note that at this level, available
170 environmental quality has fallen from the initial point I_1-C_1 to a_1-b_1 . As countries continue to
171 move to higher income levels, available biocapacity continue reducing. At income level I_3 , the
172 supply of nature is equal to demand and hence the overshoot day is attained. The line A-B is the

173 overshoot day line and e_1 is the point of the overshoot day. This is the point where the distinctive
174 analysis of our proposed environmental duality box 1, 2, 3 and 4 differs.

175 Figure 3 presents a scenario whereby as per capita income increases from I_3 to I_4 , the overshoot
176 curve continues to fall up to point a_2 for the supply side meanwhile the demand side curve
177 continues to rise up to point b_2 . At income level I_4 , the world will be operating at an ecological
178 deficit since EF is greater than EOS . This deficit is represented by the distance $b_2-e_3-a_2$. If the
179 situation is not addressed through global oriented policies, and the EOS curve continues to fall
180 up to point I_5 , EF will equally attain point C_5 , and at this point there will be a disaster given that
181 the world's absorptive capacity of pollution will be zero and all of what nature offers must have
182 been exhausted. The scenario presented by the area $C_5-b_2-e_2-a_2-I_5$ is one that the sustainable
183 development goals are systematically seeking to avoid in the future and global consensus is
184 imperative since this scenario will possibly bring chaos to the world.

185 **[Insert figure 4]**

186 The environmental duality box 2 presented in figure 4, shows a scenario that explains the basic
187 EKC hypothesis within a dualistic framework. The dualistic relationship presents a situation
188 whereby as economic growth increases consistently from point I_1 up to point I_3 , EF or nature
189 demand increase up to point e_2 and the supply of nature (EOS) falls from C_1 to e_2 . At this point,
190 $EF = EOS$ and earth absorptive capacity is at its maximum and the overshoot day is reached. As
191 income increases from I_3 to I_4 , EF rather begins to fall consistently from e_2 to b_2 and pollution is
192 reduced by the area $e_2-e_3-b_2$. In the same rationale from e_2 , EOS starts rising due to improvement
193 in positive environmental policy implementations, thereby creating a new surplus of Mother
194 Nature. The gain or improvement of the environment is indicated by the area $e_2 a_2 b_2$. Such a feat

195 can be attained if there is the development of environmentally friendly technologies, efficiency
196 in the use of available resources among others. The rise and fall of the EF curve from I_1 - e_2 - I_5
197 presents an illustration of the EKC hypothesis. Conversely, the fall and rise of the EOS from C_1 -
198 e_2 - C_5 presents the dual version of the primal EKC model proposed by Grossman and Kreuger
199 (1995).

200 Authors like De Bruyn et al. (1998) argued that an N-shape EKC can occur given that when
201 environmental degradation starts decreasing with an increase in income, beyond a certain income
202 level, increase in income will again lead to an increase in environmental degradation. Torras and
203 Boyce (1998) highlighted that such a scenario is possible if the scale effect overcomes the
204 composition and technical effects. We equally present a dualistic framework to the N-shape EKC
205 hypothesis.

206 **[Insert figure 5]**

207 From the duality box 3 presented in figure 5, as income increases from I_1 to I_3 , ecological
208 footprint increases from I_1 through b_1 to point e_2 and ecological overshoot falls from C_1 through
209 a_1 to e_2 . At this point, the C_1 - I_1 - e_2 area has been consumed from nature and EF equals EOS hence
210 the earth's absorptive capacity is zero. Due to changes in technology and the adoption of
211 environment-friendly policies, as income increases from I_3 to I_4 , EF falls to b_2 and EOS increases
212 to a_2 creating an ecological surplus of a_2 - b_2 and the total area e_2 - a_2 - b_2 of societal environment is
213 improved. Subsequently, as income increases from I_4 to I_5 , the scale effect overcomes the
214 composition and technical effects and EF starts increasing from b_2 to b_3 , meanwhile EOS falls
215 from a_2 to a_3 . The movement of the EF curve through I_1 - b_1 - e_2 - b_2 - b_3 indicates the N-shape of the
216 EKC proposed by authors like De Bruyn et al. (1998). Whence, the movement of the EOS curve

217 through C_1 - a_1 - e_2 - a_2 - a_3 indicates the dual analyses of the N-shape EKC hypothesis proposed in
218 this study.

219 **[Insert figure 6]**

220 Figure 6 presents a similar scenario as in figure 5 but for the fact that there is a twofold
221 movement before the turning of the N-shape is produced and convergence occurs after deficit.
222 From figure 6, as income increases from I_1 - I_2 , EF increase from I_1 to e_1 leading to a fall of EOS
223 from C_1 to e_1 . At this point, $EOS = EF$ but as income increases from I_2 - I_3 , EF continues to rise up
224 to a_1 while EOS continues to fall to b_1 thereby creating an ecological deficit of e_1 - a_1 - b_1 . But as
225 income increases from I_3 - I_4 , with the implementation of positive environmental policies, the EF
226 starts falling while EOS starts rising up to e_3 . Here, the initial ecological deficit created is
227 reduced to zero and $EF = EOS$. As income increases from I_4 - I_5 , there is continues increase in EF
228 to b_2 while EOS continues to fall to a_2 thereby creating an ecological surplus indicated by the
229 area e_3 - b_2 - a_2 . Equally, as growth increases from I_5 - I_7 , the scale effect overcomes the composition
230 and technical effects and EF starts increasing again while EOS starts falling leading to a
231 reduction in the initial surplus created to zero at point e_5 and a subsequent deficit after this point.
232 In a world where many countries have already reached their overshoot day and with continuous
233 increase in globalization, such a twofold convergent is equally possible due to interdependence
234 between states. This is another version of explaining the N-shape EKC which haven't been
235 considered in the literature but the possibility of attaining such feat within nations is very
236 possible in the world today given that with globalisation, deficit in one country can be reduced
237 by another since a positive environmental policy in a country can possibly have a spill over
238 effect in another. This presents the undulating trend of the ecological indicators of the primal-
239 dual analyses.

240 The above paragraphs summarises the novel primal-dual approach to EKC analyses that this
241 study is proposing in explaining the effect of growth on environmental quality and sustainability.

242 **2.2. Some empirical evidence**

243 Generally, from a review of the existing literature on the EKC hypothesis and the empirical
244 investigations done this far in examining the dualistic approach proposed in this study, one
245 would conclude without bias that existing studies have been principally based on the demand
246 side analyses. Among the existing empirical works, Altıntaş and Kassouri (2020) estimated a
247 heterogeneous panel model of 14 European countries from 1990 to 2014 and concluded that the
248 ecological footprint is an appropriate environmental tool that fits the EKC prediction in contrast
249 to CO₂ emissions. They equally highlighted that the EKC is sensitive to the type of
250 environmental degradation proxy used. On their part, Ahmed et al. (2020) using the Driscoll-
251 Kraay standard error pooled ordinary least square method on a sample of 90 belt and cross road
252 countries concluded on an inverted U-shape between economic growth and CO₂ emission.
253 Beyene and Kotosz (2019) employed the pooled mean group technique in a panel of 12 East
254 African countries to examine the short and long run relationship between GDP per capita and
255 CO₂ emission. Their outcome shows a short run U-shape EKC and a long run Bell shape.

256 While re-assessing the relationship between economic growth and pollution emissions (CO₂),
257 Khan and Eggoh (2020) employed the panel smooth threshold regression (PSTR) technique in a
258 panel of 146 countries from 1990-2016 and concluded on the existence of the EKC hypothesis
259 on the global panel and the income specific sub-samples. Naqvi et al. (2020) employed the
260 common correlated effect of mean group and augmented mean group on a panel of 155 countries
261 from 1990 to 2017 and examined the relationship between economic growth per capital,

262 renewable energy, financial development and ecological footprint. While they concluded on the
263 validity of the EKC hypothesis for high income countries, their results for other income groups
264 where not reliable. Conversely, the EKC hypothesis was invalidated for a panel of 20 Latin
265 American and Caribbean countries (Jardón et al., 2017) and 15 EU countries (Ameanu et al.,
266 2018). However, Allard et al. (2018) sought to examine the N-shape EKC in a panel of 74
267 countries from 1992 to 2012 using CO₂ emissions as a measure of environmental degradation.
268 The N-shape EKC hypothesis is validated in their study for all income levels except for the upper
269 middle income countries. The N-shape EKC hypothesis has equally been confirmed by Özokcu
270 and Özdemir (2017) for a sample of 26 OECD with the help of the Driscoll-Kraay Standard
271 Errors technique. Using a panel of 28 OECD countries, Álvarez et al. (2015) employed the
272 generalized least square to affirm the existence of the N-shape EKC. In the same vein, Friedl
273 and Getzner (2003) used the pooled OLS and concluded on the existence of an N-shape EKC for
274 Austria.

275 Withal, numerous studies have sought to investigate EKC hypothesis, with little or no consensus
276 among scholars. Focus has been predominantly devoted towards the demand side analyses with
277 little or no effort made to look at the supply side. It is within the backdrop of this gap in literature
278 and quantitative approach that this study sought to propose a dual hypothetical analysis of the
279 EKC phenomenon.

280 **3. Methodological framework**

281 **3.1. Data description and sources**

282 In order to verify the proposed primal-dual EKC hypothesis in this study, data were collected
283 from two principal sources that is the world development indicators (WDI) and the Global

284 Footprint Network (GFN) data bases spanning from 1995 to 2016 for a total sample of 109
285 countries (see table 11). The study period is chosen based on data availability. While data for
286 ecological footprint and ecological biocapacity were obtained from the GFN, data for economic
287 growth per capita and other explanatory variables are obtained from the WDI database. The
288 description of these variables can be found in table 1.

289 **[Insert table 1]**

290 **3.2.Modelling framework**

291 In order to examine the dualistic type analyses of the environmental problem, we construct two
292 nonlinear models that simultaneously explain the demand and the supply side analyses. The
293 baseline model proposed is given as:

$$294 \quad Y = \alpha_1 X + \alpha_2 X^2 \quad (2)$$

$$295 \quad W = \beta_1 X + \beta_2 X^2 \quad (3)$$

296 Equation 2 and 3 present the basic model of our dualistic approach to EKC analyses. From the
297 two models, equation 2 denotes the demand side analyses that give the baseline model proposed
298 by Grossman and Kreuger (1991) meanwhile we propose equation 3 as a supply side dual model
299 of the basic primal model proposed by Grossman and Kreuger (1991). Y, X and W respectively
300 denotes ecological footprint, economic growth per capita and ecological overshoot. The
301 following analyses can be made from these equations. From table 2, if the coefficients of
302 equations 1 and 2 verifies case 1 hypotheses, then there is no ECK curve and the dual relation
303 shows continues pollution of the environment from the demand side and the continuous
304 reduction of Mother earth's biocapacity, which is shown in figure 1. This shows a situation

305 wherein, economic agents and policy makers are still to consider the negative effects of pollution
306 to the environment and as such, they continue production without a clear cut cleaning policy in
307 place. On the other hand, case two indicates that ecological footprint increases as income
308 increases, reaches a maximum and then starts falling (EKC-hypothesis) while the ecological
309 overshoot falls and reaches a certain minimum and then starts to rise (dual of the primal EKC
310 model). This demand side and supply side type analyses is illustrated in figure two. Here,
311 environmental cleaning policies are adopted and at a certain level further increase in income is
312 accompanied with fall in pollution and increase in biocapacity.

313 In order to equally examine the N-shape ECK model and equally deduce it corresponding dual
314 supply side shape, we examine the following relation:

$$315 \quad Y = \alpha_1 X + \alpha_2 X^2 + \alpha_3 X^3 \quad (4)$$

$$316 \quad W = \beta_1 X + \beta_1 X^2 + \alpha_3 X^3 \quad (5)$$

317 Equation 4 presents the primal of the N-shape EKC hypothesis meanwhile equation 5 gives the
318 dual hypothesis we propose from the primal hypothesis. We make two possible analyses from
319 these relations. Table 2 shows the variation of the different coefficients of the relation. Firstly,
320 case 3 indicates that EF first increases, attains a maximum, begins to fall, attains a minimum, and
321 then starts to increase. This explain the N-shape EKC hypothesis as shown in figure 3. Looking
322 at the dualistic model we present, ecological overshoot (EOS) initially falls, reaches a minimum,
323 tends to increase to a certain maximum and begins to fall again. This indicates that as policy
324 makers implement environmental friendly policies within a nation due to the negative effects of
325 past degradation, when environmental improvement is attained up to a certain level, economic
326 agents tend to lose focus on combating pollution and as such pollution starts increasing again.

327 We further present another version of the N shape in case 4 wherein EF increases as EOS falls,
328 attains a certain point of inflexion, after which it continues to increase while EOS equally
329 continues to fall. The EF increases, attains another marginal level and starts to fall while the EOS
330 continues to fall, attains the next marginal level and starts to increase. This scenario rather
331 validates a long run convergence U-shape EKC, as the N-shape dual analysis is rejected while
332 the U-shape is accepted.

333 **[Insert table 2]**

334 Case 5 presents a scenario wherein, EF increases, attains a certain marginal level and starts
335 falling and continues to fall in the next marginal level. Meanwhile EOS decreases up to a certain
336 marginal level and starts increasing. This rejects the N-shape and rather validates the U-shape
337 EKC. Here, economic agents after realizing the negative effects of environmental degradation,
338 put in place appropriate abatement policies and continue to implement these policies thereby
339 achieving a better environment. Case 4 and 5 present another version of the U-shape EKC which
340 is rarely discussed or analyzed in the existing literature but shows a possible policy outcome of
341 the income/environmental relation.

342 **3.3. Empirical model and technique**

343 From the baseline model framework, we estimate a dynamic model. The estimated model is
344 inspired from the model proposed by authors like Grossman and kreuger (1991), De Bruyn et al.
345 (1998), Altıntaş and Kassouri (2020), Khan and Eggoh (2020) among others . The model can be
346 specified as follows;

$$347 \quad Y_{it} = \theta_i + \theta Y_{it-1} + \alpha_1 X_{it} + \alpha_2 X_{it}^2 + \alpha_3 X_{it}^3 + \lambda Z_{it} + \gamma_i f_t + \xi_{it} \quad (6)$$

348
$$W_{it} = \varphi_i + \rho W_{it-1} + \beta_1 X_{it} + \beta_2 X_{it}^2 + \beta_3 X_{it}^3 + \delta Z_{it} + \gamma_i f_t + \xi_{it} \quad (7)$$

349 Where $\vartheta, \rho, \alpha_1, \alpha_2, \alpha_3, \lambda, \beta_1, \beta_2, \beta_3, \delta$ in equation 6 and 7 are the parameters of the demand side
350 and the supply side model to be estimated which are bounded by a finite constant and
351 homogenous over cross-sectional units i . Z is a set of exogenous variables, i denotes the
352 individual unit (country) and t the year. f_t denotes an unobserved common factor with
353 heterogeneous factor loadings, γ_i and ξ_{it} are the idiosyncratic error terms.

354 We employ the novel dynamic common correlation technique proposed by Chudik and
355 Pesaran(2015). This technique is adopted because of its novelty and the ability for the approach
356 to account for cross sectional dependence. The non-consideration of cross sectional dependence
357 by conventional estimation techniques has been identified by different authors as a source of
358 biasness in estimation (Ali et al. 2020, Dinga et al. 2020, Neal, 2015). With the high degree of
359 globalization in the world today, the interdependence between states has heightened
360 tremendously, implying that empirical analyses that do not account for such interdependence will
361 be biased. Within the framework of this study, considering that cross sectional dependence is
362 very vital, economies with high level of pollution and where EF is already showing trends of
363 surpassing the EOS can always pay low polluters with much more available biocapacity to
364 conserve or to reduce their level of pollution so as to serve as a balance in the deficit in their
365 respective countries. Such interdependence between environmental debtors and creditors has
366 been a key way to maintain global pollution levels.

367 Before proceeding to estimate the different models, we first check our data for cross sectional
368 dependence since this will help select appropriate estimation techniques and to choose between
369 first or second generation tests. The Pesaran (2004) cross sectional dependence test and the

370 Pesaran (2015) cross dependence test are employed in this study. To ensure that our model does
371 not suffer from spurious regression, we test our database for unit root test. We employ the second
372 generation unit root test proposed by Pesaran (2003) CADF test and the Pesaran (2007) CIPS
373 unit root test that accounts for cross sectional dependence. Slope homogeneity in panel data
374 analyses has been highlighted as a key issue to address. Breitung (2005) noted that cross
375 sectional dependence implied countries have similarities in development and as such ensuring
376 cross sectional heterogeneity is vital for robust estimations. The most recent slope heterogeneity
377 test by Pesaran and Yamagata (2008) that is an ameliorated version of that proposed by Swamy
378 (1970) is adopted in this study. After taking into consideration the issue of slope homogeneity,
379 we proceed to examine the panel for cointegration in order to establish the existence of a long
380 term relationship. The Westerlund (2007) second generation cointegration test that considers
381 cross sectional dependence is adopted in this study. After ensuring the panel is free from all the
382 aforementioned issues that bias estimations and make them untrustworthy for inference, we
383 proceed to estimating our dualistic models explained above using a nonlinear DCCE approach.
384 Another key advantage of the DCCE technique is the ability to correct for small sample bias
385 (Ditzen, 2016). The recursive mean technique of correcting small sample bias is adopted in this
386 study. The data are compiled with the help of Microsoft excel and analyzed with STAT 14
387 software.

388 **4. Empirical outcomes and discussions.**

389 **4.1.Descriptive statistics**

390 Based on the results of the basic statistics of the variables considered as seen in table 1, the
391 average performance of ecological footprint is 2.827 with a standard deviation of 2.238 and a
392 minimum and maximum score of 0.481 and 16.965 respectively. This shows that the level of EF

393 of the sample at large has been relatively large and rarely deviates above the average of the
394 world. On the other hand, ecological overshoot indicates a mean, standard deviation, minimum
395 and maximum value of 0.937, 7.975, -14.865 and 69.202 respectively. This implies that EOS is
396 slightly positive on average within the sample and greatly deviates from the mean. The minimum
397 value is indicative of how some countries are already ecological debtors. In the same vein, the
398 average GDP, DINV, FDI and POP for the global sample of 109 countries within the period
399 under study were 2.433, 22.47, 3.892, and 1.645 with standard deviations of 4.13, 7.541, 5.372
400 and 1.47 respectively. The result shows that deviation from the mean of growth per capital has
401 been higher within the selected countries. Growth rate per capital has shown a negative value
402 implying that at least for some countries, negative growth was noticed. Same holds for DINV,
403 FDI and POP.

404 **4.2. Cross sectional dependence and unit root test**

405 With the advent of globalization, cross sectional dependence has become a vital component to
406 consider when dealing with panel data analyses. This is due to the fact that the non-accounting of
407 spillover effects of shocks from one country to another can lead to bias estimates and misleading
408 inference. Cross sectional dependence equally permits us to make a choice between first or
409 second generation tests. In this study, we employ the Pesaran (2004) and Pesaran (2015) cross
410 sectional dependence test.

411 **[Insert table 3]**

412 The results presented in table 3 indicate that the null hypothesis of cross sectional independence
413 for the Pesaran (2004) test is rejected at the 1% significance level for all the variables of the
414 study. This shows that there is strong presence of cross sectional dependence. In the same vein,

415 the null hypothesis of weak cross sectional dependence for the Pesaran (2015) test is rejected at
416 the 1% significance level thereby confirming cross sectional dependence for all the variables.

417 **[Insert table 4]**

418 After confirming the presence of cross sectional dependence, we then examine the stationarity of
419 the different variables. With the strong confirmation of cross sectional dependence, we make use
420 of two versions of second generation unit root test, that is the CADF and CIPS test proposed by
421 Pesaran in 2003 and 2007 respectively. From the panel unit root test result presented in table 4,
422 the null hypothesis of non-stationary series for the CADF test is not rejected at level for EFP and
423 EOS at all levels of significance, meanwhile the null hypothesis of homogeneous non-stationary
424 series for the CIPS test is rejected at level for the two variables. At first difference, we reject the
425 null hypothesis of both the CIPS and CADF test. This implies that EFP and EOS are stationary at
426 first difference. In the same light, we fail to reject the null hypothesis of the CIPS test for DINV
427 and POP thus we concluded that they are not stationary at level. At first difference, the null
428 hypothesis of both the CIPS and CADF test are rejected for both DINV and POP implying that
429 these variables are stationary at first difference. Equally, GDP, GDP2, GDP3 and FDI indicate
430 the rejection of the null hypothesis of both unit root test. This shows that the variables are
431 stationary at level.

432 **4.3. Slope homogeneity and cointegration test**

433 In the presence of cross sectional dependence, Breitung (2005) noted that this may imply that
434 countries are having economic development similarities and as such determining cross sectional
435 heterogeneity is important otherwise the estimates will be untrustworthy. The Pesaran and
436 Yamagata (2008) slope homogeneity test is employed in this study. The results of the slope

437 homogeneity test presented in table 5 indicates that both the EOS and the EF models reject the
438 null hypothesis of slope homogeneity for both test statistics at the 1% level of significance. This
439 shows that there is the existence of slope heterogeneity.

440 For cointegration, since there is the strong presence of cross sectional dependence, we only make
441 use of a second generation cointegration test that accounts for cross sectional dependence. The
442 result of the Westerlund (2007) second generation test presented in table 5 indicates that group
443 and panel test statistics are able to reject the null hypothesis at different significant levels (1%
444 and 5%) for the ecological footprint and ecological overshoot models. Specifically, the
445 ecological footprint model indicates that all the group test (G_a , G_t) and the panel test (P_a , P_t)
446 confirms rejection of the null hypothesis of no cointegration between EF and GDP2, DINV, FDI
447 and POP. For GDP and GDP3, cointegration is confirmed for all test statistics except the P_t test
448 statistics. This implies the strong presence of cointegration between EF and the variables of
449 interest. Similarly, the cointegration relation between EOS and the different variables of the
450 studies shows that the two group test statistics validates the presence of cointegration for all the
451 different variables. On the other hand the panel test P_t confirms cointegration only for POP while
452 P_a statistics rejects the null hypothesis for no cointegration relation for all variables except GDP.
453 This result shows the validation of cointegration for most test statistics and as such we conclude
454 that there is strong evidence of a long run relationship between the variables of the studies. With
455 the confirmation of cointegration, we proceed to empirically estimate our different models.

456 **4.4. Estimated outcome**

457 Table 6 and 7 present the outcomes of the two basic models of our dualistic approach analyses.
458 As highlighted above, the validation of a dualistic approach to environmental degradation

459 analyses will depend on the different signs of GDP per capital variable in its different forms. We
460 first start by estimating a linear model for both the EF and EOS equations. As indicated in model
461 1 and 7 in table 6 and 7 respectively, GDP is seen to have a positive sign in 1 and a negative sign
462 in 7 showing that increase growth in the world increases pollution (demand side) and reduces
463 available biocapacity (supply side) of the society at large. This result affirms a dualistic outcome
464 for the linear relationship between growth in income and the demand/supply side environmental
465 analyses. In order to empirically ascertain the dualistic model of the U-shape EKC hypothesis,
466 we estimate model 2 and 8 without any explanatory variable. The results from model 2 indicate a
467 positive sign for GDP and a negative sign for GDP² thereby validating the U-shape EKC
468 hypothesis which is in line with the findings of authors like Ahmed et al. (2020), Naqvi et al.
469 (2020) for high income countries, Khan and Eggoh (2020), Beyene and Kotosz (2019) for low
470 income countries, meanwhile the outcome contradicts Jardón et al (2017). For the supply side
471 outcome shown in model 8, GDP is seen to have a negative sign while GDP² shows a positive
472 sign on ecological overshoot. This indicates a supply side inverted bell-shape for EOS. This
473 result confirms our apriori hypothesis of a dualistic EKC hypothesis between EF and EOS. This
474 shows that on the demand side, as per capital income increase within countries, there is an initial
475 increase in environmental pollution up to a certain marginal level wherein, increase in per capita
476 income leads to ecological improvement. In the same vein, on the supply side, the outcome
477 implies that as income per capita increases, there is an initial decrease in available ecological
478 biocapacity up to a certain marginal level before it starts improving.

479 In order to examine the N-shape environmental Kuznets curve hypothesis and its proposed
480 dualistic relation, we estimate equation 3 and 9 without any explanatory variable in table 6 and 7
481 respectively. The outcome shows that for the demand side, the existence of the N-shape EKC

482 hypothesis is approved for our global sample since the coefficient of GDP, GDP2 and GDP3 are
483 positive, negative and positive respectively. For the supply side, an inverted N-shape EKC
484 hypothesis is validated for the general sample since the signs of GDP and its corresponding
485 polynomial values alternate that is negative, positive and negative. This outcome reaffirms the
486 dualistic approach to environmental quality analyses proposed in this study and it is in line with
487 our a priori expectation.

488 For robustness of the results, we estimate the baseline model with the inclusion of other
489 explanatory variables systematically for the demand side analyses (4, 5, and 6) and the supply
490 side analyses (10, 11, 12). The outcome indicates that the signs of the income per capita remain
491 consistently the same as in the baseline model with the inclusion of different explanatory
492 variables both for the ecological footprint models and the ecological overshoot models. Equally,
493 the constants of the EF estimated model are all positive whereas those of the EOS estimated
494 models are all negative, which shows that with a growth in income set at zero, other factors will
495 significantly increase EF and equally decrease EOS. This reaffirms the dualistic nature of
496 outcome between the traditional demand side analyses and the newly proposed supply side
497 analyses in this study.

498 Concerning the goodness of fit of the estimated models, all the F-statistics of the different
499 models estimated for the EF (1 to 6) and those estimated for the EOS (7-12) are all significant at
500 1%. This shows global fitness of all the models. Equally cross sectional dependence is confirmed
501 in all equations since all the CD-statistics rejects the null hypothesis of no cross sectional
502 dependence.

503 In order to capture disparity of outcome that may occur due to income levels disparity, and to
504 equally make comparative analyses, we reexamine the dualistic U-shape and N-shape
505 environmental Kuznets curve hypothesis for lower income countries (LIC), lower middle
506 income countries (LMIC), upper middle income countries (UMIC) and high income countries
507 (HIC). The outcome of the income level analysis for the dualistic approach proposed in this
508 study is presented in table 8 for the EF analyses and table 9 for the EOS analyses. From the
509 results of the EF (demand side) estimate, the U-shape EKC hypothesis is validated at all income
510 levels (LIC, LMIC, UMIC, HIC), but comparatively, this results seems to show less
511 significances for LIC and turns to be more significant for LMIC where both the quadratic and the
512 linear coefficients are seen to be significant at 5% level of significance. Equally, cross sectional
513 dependence is confirmed in all the sub panels. For the N-shape baseline income level comparison
514 presented in column 17, 18, 19 and 20, LIC and HIC within the panel indicates sufficient
515 information to validate the N-shape EKC hypothesis, but this result is seemingly more
516 significant for HIC. Meanwhile, for LMIC and UMIC countries estimate, the N-shape hypothesis
517 is not valid. The results show that, a longer period is taken for LMIC to start experiencing
518 amelioration in environmental quality meanwhile for UMIC after experiencing environmental
519 amelioration through decrease in EF, these economies will rarely return back to environmental
520 degradation as proposed by the N-shape EKC. This none validity of the model for LMIC and
521 UMIC can be due to the transition of different economies from one income level to another.

522 As shown by the supply side income level analyses in table 9, for the baseline result of the
523 corresponding dualistic U-shape EKC, the outcome affirms the existence of the U-shape dual
524 EKC as proposed in this study for LMIC, UMIC and HIC. But this outcome is not true for LIC
525 which shows an initial positive value and a negative value for the quadratic term. This result

526 validates a dualistic dual outcome from the primal outcome obtained for LMIC, UMIC and HIC
527 for the demand side analyses above. For the inverted N shape analyses for different income
528 levels, model 25 to 28 indicate that an inverted N-shape is only validated for the UMIC and the
529 HIC. But the outcome is more significant for HIC. This result highlights the importance of cross
530 sectional dependence in the analyses of the dualistic relation in environmental quality analyses,
531 since the dual-primal relation is more validated for high income countries and the CD-test statics
532 is only highly significant for HIC. The non-consideration of the high income countries which are
533 seemingly the highest polluters in the world today will bias the estimate of all the sub panels and
534 lead to the non-validation of the N-shape dualistic EKC hypothesis.

535 In order to ascertain the robustness of the outcome obtained from this study, we conduct second
536 generation unit root test on all the 28 estimated models. The results obtained from the CADF and
537 CIPS second generation unit root test presented in table 10 indicate that, the null hypothesis of
538 panel residuals containing unit root is rejected for all the 28 models for the CADF and CIPS test.
539 This shows that our estimated results are stable and valid for all the inferences made.

540 **5. Conclusion**

541 In this study, we sought to present a new approach of analyzing the nexus between
542 environmental degradation and income in the world. On the one hand, we analyzed the demand
543 side of human activities from nature with the use of ecological footprint and on the other hand,
544 nature supply side was analyzed with the use of nature ecological overshoot. We employed
545 geometry to present our basic dualistic analyses meanwhile mathematical demonstration is
546 employed to elucidate the expected dualistic model. To test our proposed dualistic model, we
547 used a balanced panel of 109 countries from 1995 to 2016. Given the level of globalization in the

548 world today, we first test our data for cross sectional dependence using the Pesaran (2004, 2015)
549 cross sectional dependence test in order to choose appropriate test and estimation techniques.
550 With the confirmation of cross sectional dependence in our data, we employed second generation
551 tests for unit root, cointegration and slope homogeneity that account for cross sectional
552 dependence.

553 Our adopted estimation technique is the dynamic common correlation technique proposed by
554 Chudik and Pasaran (2015) that accounts for cross sectional dependence within panels. From the
555 different results obtained, there is clear evidence of the existence of our proposed dual U-shape
556 and dual N-shape EKC. Equally, when we separate our panel into different income levels, the
557 Dual U-shape EKC hypothesis is validated for all our sub panels but for LIC. For the income
558 level dual N-shape EKC hypothesis, the dual N-shape is confirmed principally in HIC. Based on
559 these outcomes, this study proposes the following recommendations:

560 The equilibrium or maximum absorbable level of pollution where biocapacity equals the
561 pollution level should be determined both at individual country level and the world at large, so as
562 to encourage countries to clean their environment and stay below this equilibrium point in order
563 to avoid future environmental disasters. This should be a principal task for international
564 organizations like the United Nations.

565 Advanced economies should aid less developed economies with new and efficient abatement
566 technologies that will help this economies better clean their environment. The developed
567 economies should equally give ample financial aid to developing and less industrialized
568 countries especially those with high available biocapacity in order for these economies to adopt

569 cleaner and environment-friendly industrialization policies, like the encouragement of renewable
570 energy sources.

571 The enhancement of data collection techniques in middle income and low income countries and
572 the consideration of countries with limited information about environmental degradation are
573 necessary, in order to obtain accurate information with respect to biocapacity and rate of
574 environmental degradation. The availability of adequate information on biocapacity and the rate
575 of environmental degradation will help policymakers to better handle the problem of
576 environmental pollution in a global and holistic manner and promote interstate cooperation in
577 such key issues that affect humanity.

578 **Declarations**

579 ➤ **Ethics approval and consent to participate**

- 580 • Not applicable.

581 ➤ **Consent for publication**

- 582 • Not applicable

583 ➤ **Availability of data material**

584 The data sets used and/or analyzed during the current study are available from the corresponding
585 author on request.

586 ➤ **Competing Interests**

587 The authors declare that they have no competing interest.

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590 ➤ **Authors Contribution**

591 **GDD** participated in the conceptualization, writing, analyses and interpretation in the manuscript

592 **DCF** participated in the conceptualization, writing, editing and interpretation of the manuscript.

593 **DEA** reading and editing

594

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688

689

[Insert table 11]

690

Figures

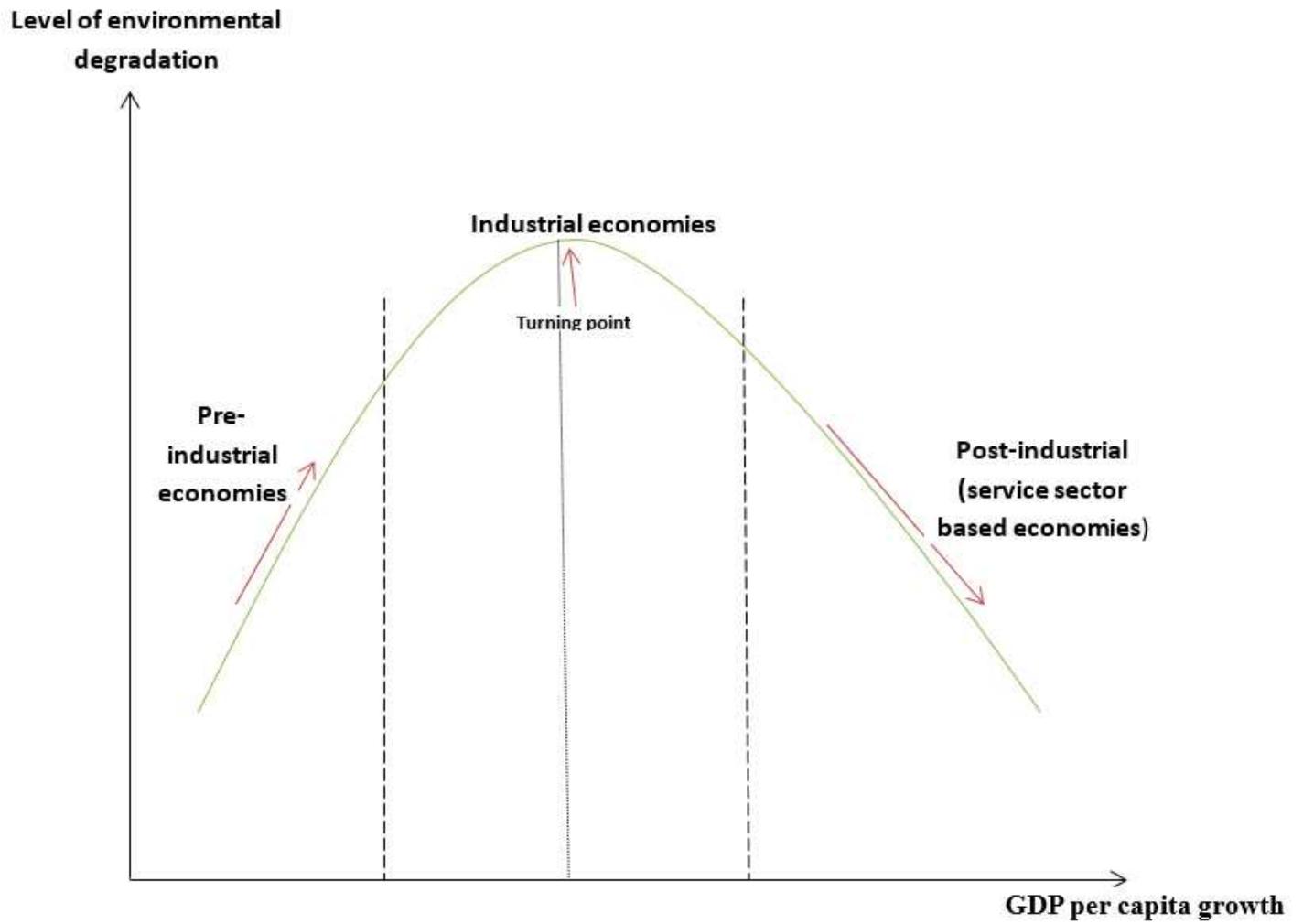


Figure 1

Basic Primal EKC

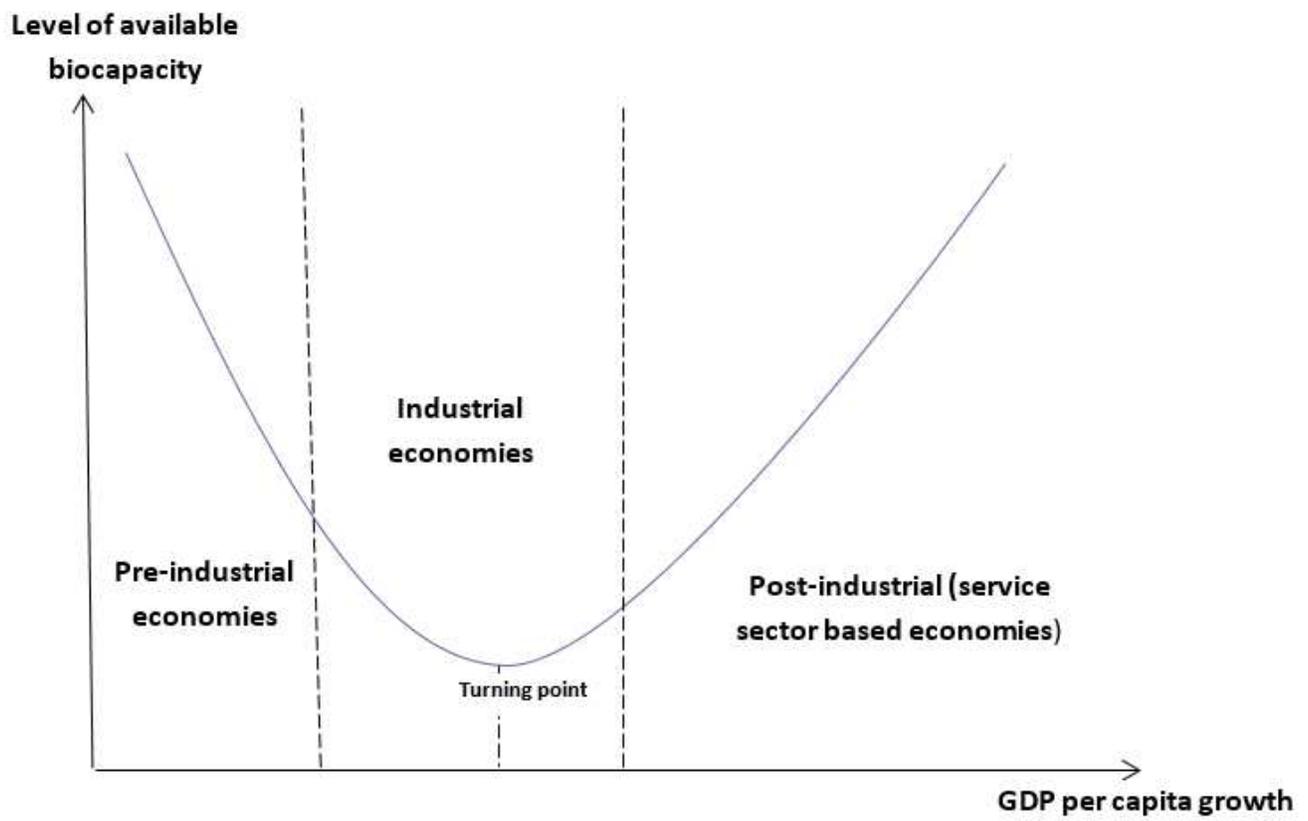


Figure 2

Basic Dual EKC

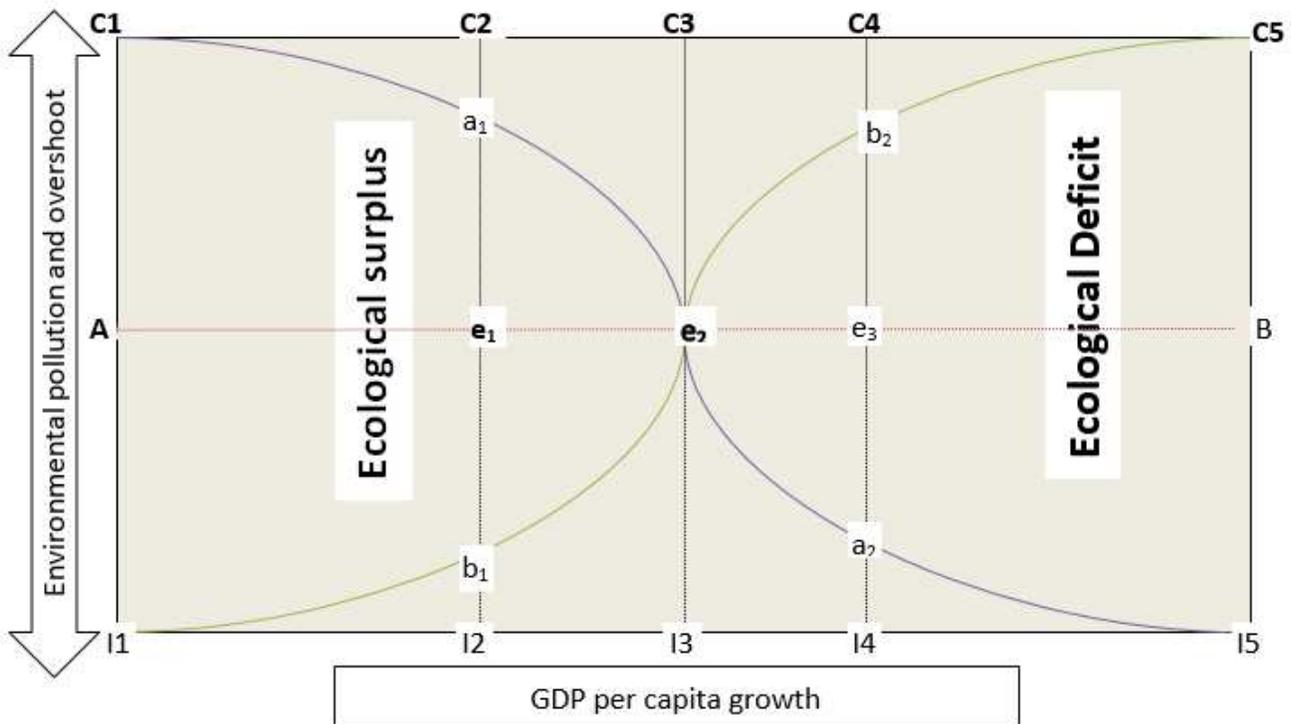


Figure 3

Environmental duality box 1.

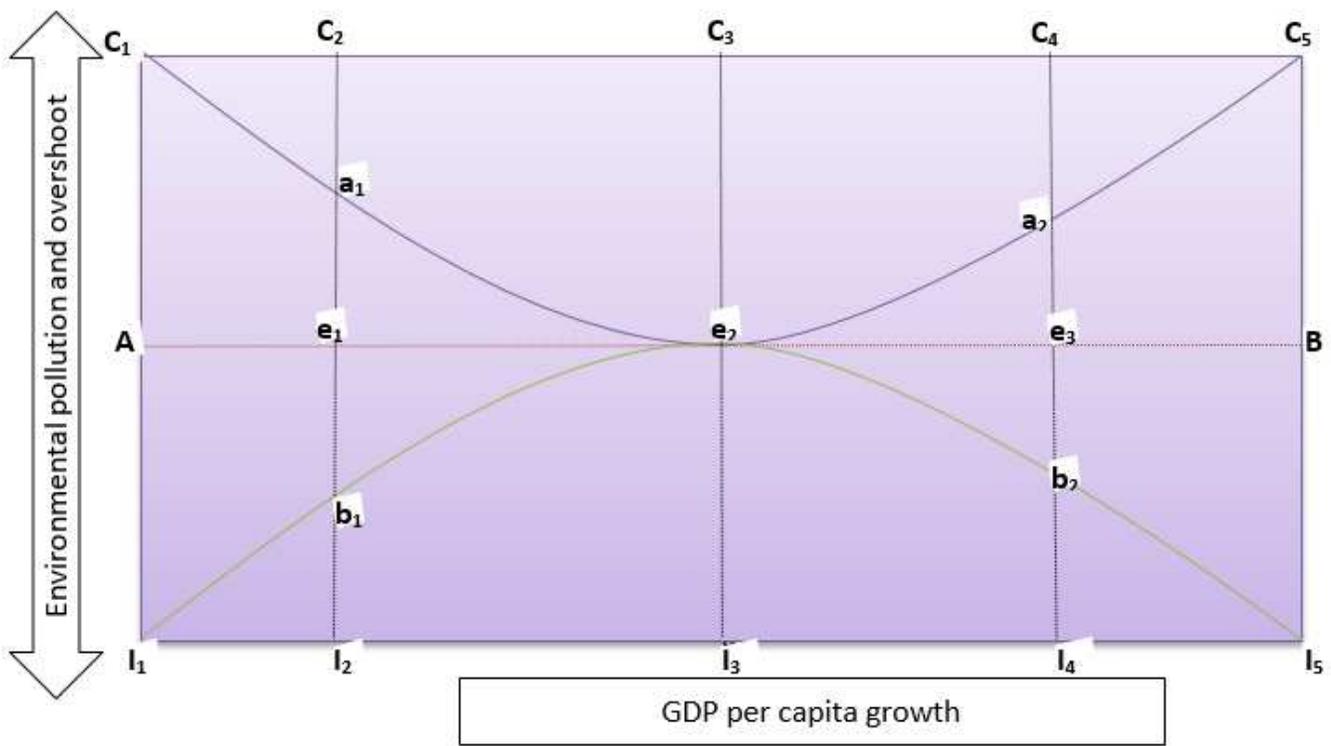


Figure 4

Environmental duality box 2.

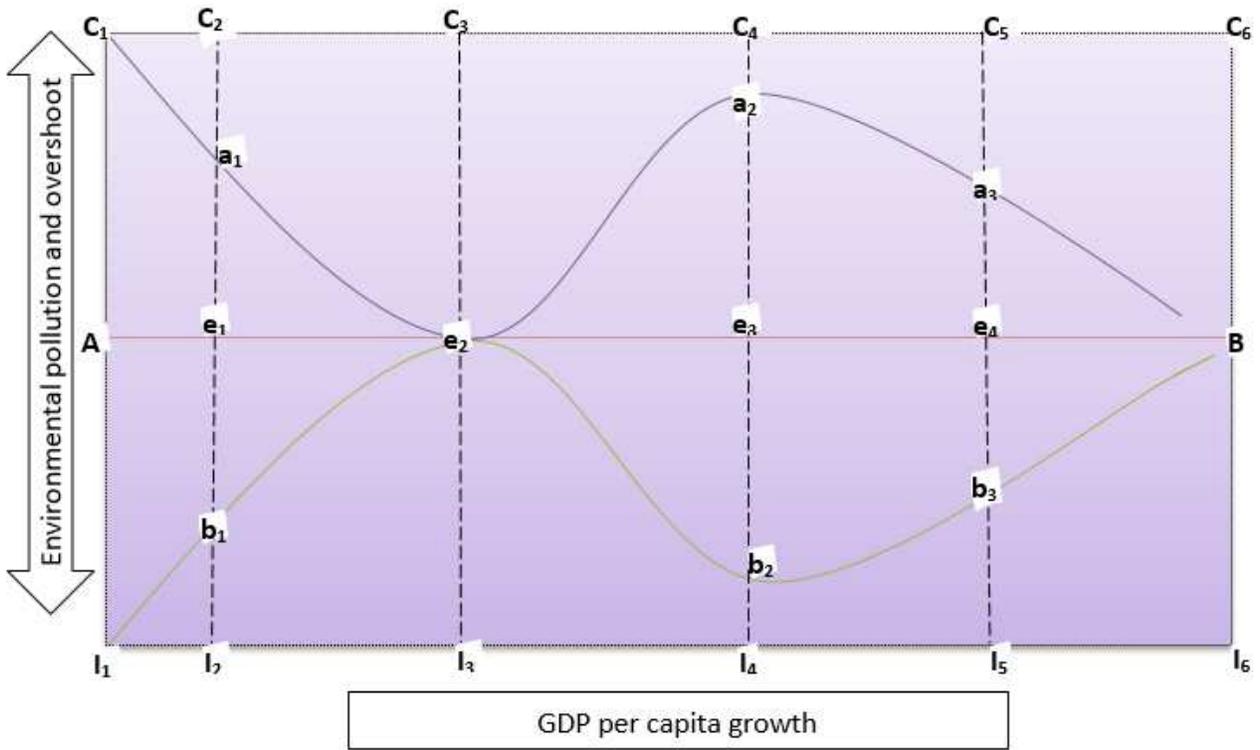


Figure 5

Environmental duality box 3.

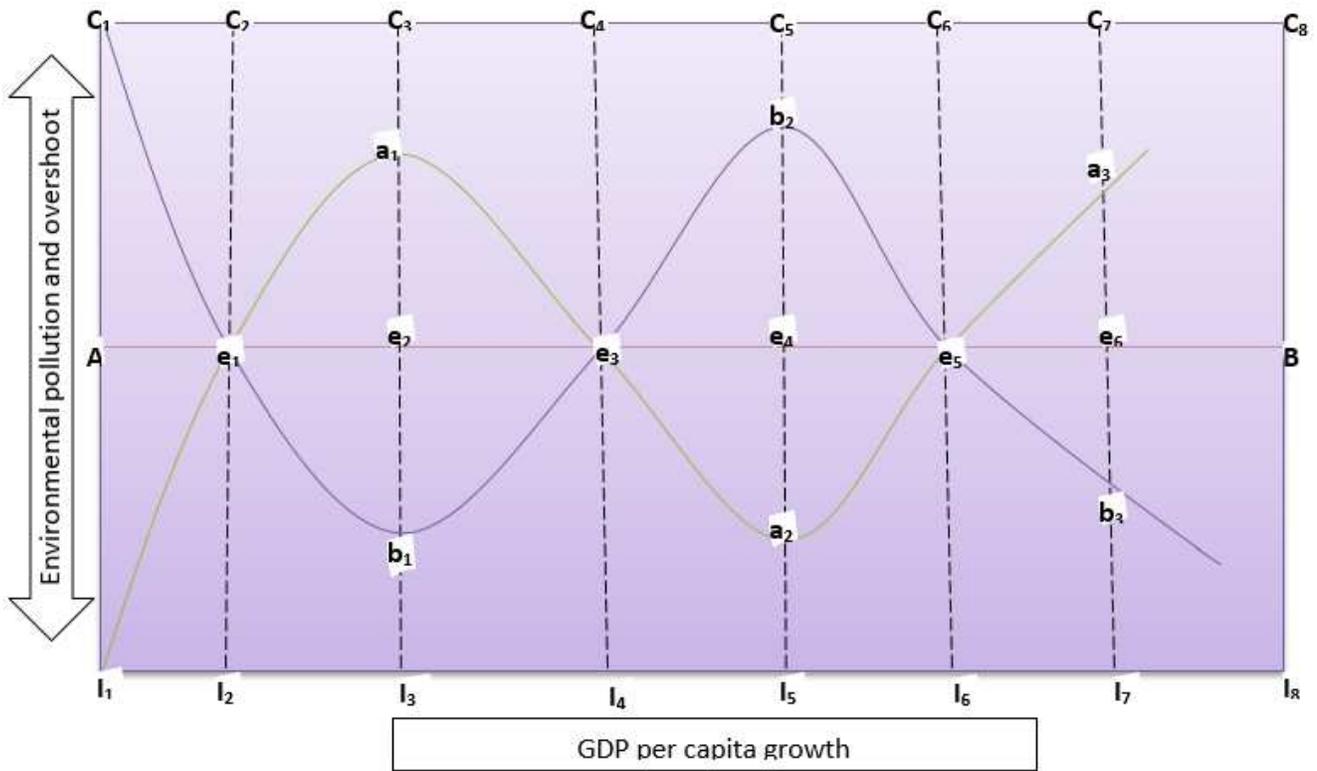


Figure 6

Environmental duality box 4.

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