ECOLOGICAL TRANSITION: A GAME THEORETIC AND STATISTICAL CHALLENGE

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Abstract. The challenges of global warming and environmental sustainability require a urgent move to the era of ecological transition. We survey contributions from the game theoretic approach modelling ecological transition as a collective action problem in a multiplayer social dilemma, highlighting the main coordination failure challenges and outlining potential solutions such as balanced budget policy measures and cooperative initiatives under the form of energy communities.

We also explain how the green revolution implies the move from the standard *productivity* to the novel *circularity* target and, as such, it requires a bridge between economic, statistic and natural science disciplines. The implications in terms of new competences and statistical indicators are discussed in reference to impact evaluation and hybrid circularity measures.

Keywords. ecological transition, circular economy, impact evaluation

1. Introduction

Global warming and environmental sustainability of economic development are the most daunting challenges of our future which require a thorough revision of our economic and statistical paradigm. The success of mankind in the last 2000 years has been witnessed by an increase in population (a long run proxy of economic prosperity) from 230 million to around 8 billion world inhabitants, paralleled by a rise in life expectancy from 24 to 73 years at world level (Dasgupta, 2020, Maddison, 2001). This change corresponds to a dramatic increase in the life year potential of the stock of living world population (the difference of the product between population and life years today and 2000 years ago) of around 578 billion years. Population and life expectancy have stagnated for centuries since most of this change has occurred after the Industrial Revolution and under the economic paradigm centered on the goals of efficiency and productivity, fueling the drive for creating and selling on the market as much as possible goods and services per unit of time. It is no wonder that at its origins, starting from a limited population, the industrial revolution did not pose to itself the question of the environmental sustainability limits of its expansion.

The problem, however, has now dramatically emerged due to the growing stock of carbon emissions in the atmosphere that is responsible for the sharp (actual and future expected) increase in the average world temperature from its preindustrial levels.[1] This is why the goal of most developed countries is zero net emissions in 2050 and their reduction of 55% by 2030.

Our current problems are embedded in the heritage of our old "reductionist" theoretical paradigm. In this paradigm the economic system is essentially made by household and firms that meet each other in product and labor markets determining demand, supply and prices of goods and services sold in equilibrium. Under this standard approach the effects of production and consumption on the ecosystem disappear so that economic activity is neutral on the environment. Under the new scenario of a broadened economic paradigm the separation between economics with human activities and natural sciences with the equilibrium of natural environments disappears. What is first acknowledged is that consumption and production wastes (and the same production processes) have strong impact on the ecosystem, weakening in turn its provision of services (quality of air, quality of water, fertility of soil) that are essential for human life with an estimated market value equal to the global GDP (Howarth and Farber, 2002).

The modified economic paradigm has now to consider environmental sustainability and, more specifically, according to the Do No Significant Harm principle (DNSH), the effect of any economic action on six main dimensions: mitigation (of carbon emissions), adaptation (to global warming and modified environment), quality of air, water, circular economy and biodiversity.

In essence, the revolution we need can be resumed in the move from the imperative of productivity and efficiency to that of circularity, where for circularity we mean the capacity of creating economic value in an environmentally sustainable way, that is, saving on raw materials and with as little as possible carbon and air polluting emissions. Circularity therefore implies a decoupling between creation of economic value and use of natural resources. The change in paradigm makes what appeared as a technological frontier just a few decades ago the most inadequate solution to the challenge. The example is throwaway plastic bottles we were proud of, a product that is used only once and cannot be recycled that is exactly the opposite of what we need in the era of circularity where the our target is creating product 100% made of recycled and not raw materials.

In our paper we start from the main policy responses needed to tackle the global challenge using as a synthetic scheme the Kaya equation which identifies four directions of policy action (population, living standards, use of energy, energy

[1] Climate change cannot be denied due to the wide evidence based on historical data. The anthropogenic cause of climate change is acknowledged by around 99 percent of scientific papers (Lynas et al. 2021).

efficiency in terms of carbon emissions). We then discuss how this challenge implies a redefinition of the economic paradigm and of the statistical approaches that must bridge competences between economic and natural sciences if they want to measure circularity. Last but not least, we describe the global warming challenge as a multiplayer social dilemma and explain that it is not possible to address the problem we face only with top-down policies, as acknowledged by the same United Nations with its Sustainable Development Goals at Goal 12 (responsible consumption and production).

2. The required policy response

A synthetic benchmark we can use for understanding the proper policy response to global warming is represented by the Kaya equation

$$CO_2 = POP * \frac{GDP}{POP} * \frac{E}{GDP} * \frac{CO_2}{E} \tag{1}$$

where CO2 is carbon emission, POP is population, GDP is gross per capita income and E is energy. The Kaya equation is an identity that however makes clear our options for tackling the climate threat, as it identifies four drivers determining greenhouse emissions: population, the population living standard, plus two factors of ecological efficiency of economic production. The first is the energy used per unit of GDP produced and the second is greenhouse emissions per energy used. Therefore, the identity indicates four potential directions for policy action. The first of them is a Neo-Malthusian policy aiming to control population growth. As is well known, beyond a few remaining cases, most countries in the world share the same cultural background and have reproduction rates below 2.2 per woman, that is, below the reproduction rate that maintains the population constant. The United Nations forecast that the world population will reach a peak around 9 billion and then will start to decrease. Population dynamics is therefore going to be under control and, on the contrary, depopulation is becoming a serious problem in some high-income economies. The second direction (reduction of GDP per person) cannot be a program of any political party that aims to win elections. Although the reduction of living standards cannot be a straightforward goal, the literature on drivers of life satisfaction with its rationales for the Easterlin paradox (Easterlin and O'Connor, 2022) and the wisdom of spirituality of many religious thoughts (not last the Laudato Si encyclical) clarifies that there is no linear positive relationship between per capita GDP and happiness and that we can significantly increase the quality of our life by reducing those parts of GDP that actually harm and cultivating those virtues and attitudes that are invisible and not counted in GDP.

Given what was considered above, most of the work must be done in the other two directions of making our economy more environmentally efficient and sustainable. The drive toward renewable energy is the main policy measure needed to reduce greenhouse emissions per energy used. As is well known, even in a life cycle assessment perspective where we consider emissions from input extraction to final waste disposal, we find that wind and solar produce from 100 to 200 less emissions per gigawatt hour of electricity than coal, oil and gas. Other advantages of renewables are the more efficient use of energy (much less energy power dispersed), lower air pollution impact, lower prices, more independence from gas and oil countries and lower exposure to inflation shocks as the last two both caused by fossil fuel prices (at end 70es with the oil price shock and in these years with the gas price shock). The fourth indicator of the Kaya identity (energy used per unit of GDP produced) clearly indicates the direction of circular economy that is, the decoupling between creation of economic value and use of energy. A main pillar of circularity is the increase in the share of reuse, recycle and regeneration in inputs used for new production.

3. The ecological collective action problem

Global warming is one of the most complex environmental problems, also from a theoretical point of view. If we use the 2x2 taxonomy based on appropriability/renewability for classifying environmental goods we have four classes of environmental goods with problems of increasing complexity. For environmental goods that are renewable and appropriable such as wood there are exact rules that ensure non decreasing stocks based on the compatibility between cut rates and growth rates. Non appropriable renewable goods are subject to the tragedy of the commons (Hardin, 1968) and to the problem of overexploitation that can solved with limited use rights and can be preserved in the most virtuous examples simply due to the social norms of local communities (Ostrom et al. 1999). Raw materials are typically appropriable non-renewable goods which economists tend to be much less optimistic about their risk of exhaustion. This is because when scarcity begins prices go up thereby stimulating research and technological progress in productive processes that save the given raw material. As far as technological progress identifies substitutes to the given raw material exhaustion is not a problem. While in the fossil era the exhaustion challenge was on oil (with grim predictions who always underestimated technological advances in extraction and substitution) the focus is now on materials needed for the wind and solar infrastructure. Again, progress in the circular economy and discovery of new processes saving the use of such materials can lead us out of new fears of scarcity.

The problem of climate change and global warming is the most difficult to handle. Climate is not just non-renewable and non-appropriable but is also a global public good. The additional complexity here is that, while with local public goods there is a superior (local) authority who can sanction non cooperative behavior, this is not the case when the public good is global. Everything is therefore left to the nonenforceable willingness to cooperate of sovereign entities. This is the reason why when the US under the Trump government left the Paris Agreement no authority having enforcement power could sanction and prevent them from doing so. The further complexity is given by the weakness of political leaders negotiating in the cooperation game of emission reduction with political leaders of other countries. Political leaders do not represent only their own will but have been elected by their citizens and, therefore, have the weakness of depending on polls and on domestic public opinion. They can therefore be personally convinced that ecological cooperation and reduction of carbon emissions is the right thing to do, but they can pay the cost of doing it if attacked by opposition and opinion of their voters that do not want to pay the cost of ecological transition.

All these factors contribute to explain the limits of COP meetings in solving the ecological dilemma…and explain why the same international institutions are aware that solutions are almost impossible to work without participation of citizens (as in UN Goal 12 of responsible consumption and saving). For all these reasons several contributions in the literature model the climate game as a social dilemma (Carraro and Siniscalco, 1993; Wang et al., 2009; Heitzig et al., 2011; Heugues, 2013; Nordhaus, 2015; Mielke and Steudle, 2018).

Following Becchetti and Salustri (2016) we can model the multi-player ecological game considering the presence of n players whose strategy set is made by the following two actions: choose the ecologically responsible (V) or the standard (A) action.

As a consequence of their choice their payoff is

$$U_i(V) = [(j+1)/n]b + a - c \tag{2}$$
$$U_i(V) = (j/n)b \tag{3}$$

where *j* is the number of individuals who choose the ecologically responsible action, b is the "political" benefit (positive externality of the solution of global warming) of the responsible choice accruable in terms of its own payoff, a is the social preferences (warm glow) of the ecologically responsible choice for the individual who chooses it, and c is the cost differential between the ecologically responsible and the standard action. We assume that there are no income constraints in the model ($Y_i > c$ for all i) so that the ecological choice is economically feasible for all players.

As is clear from the scheme the effect of b (the positive 'political' effect on the individual reward of the ecological action) crucially depends on the share of participants in the game choosing that action. If all participants choose it, the share is equal to 1 and the entire 'political' benefit b is gained. If the individual is the only one to choose that action on a very large number of players, the share tends to zero and the 'political' effect is nil. This is what happens at the extreme if only one Earth inhabitant makes the ecological choice on the planet. In the absence of this 'political' benefit, the individual chooses ecological action only if a-c>0 and the problem reduces to a classic case of charity giving where the decision to give is taken when the benefit driven by other preferences is higher than the cost of giving. As is well known, the literature tells us that the two main rationales for other-regarding preferences are altruism (the presence in my utility function of the utility of another individual) and warm glow (the enjoyment proportional to my giving irrespective of the effect of my action).

Given the game characteristics, ecological games end up in the classical prisoner's dilemma. The dominant strategy is choosing the standard non ecological action so that the Nash equilibrium of the game is that where all players choose the non-ecological strategy and the global warming problem is not solved. The paradox is obviously that this Nash equilibrium is Pareto dominated by the opposite equilibrium where all players choose the ecological action, and the ecological problem is solved.

In technical terms in the two player game the Prisoner's dilemma occurs when the cost differential between the ecological and the non-ecological action is neither too high (in such case it is optimal for all players to choose the non-ecological action, and this becomes both the Nash and the Pareto superior equilibrium) nor too low (in such case it is nonetheless optimal to choose the ecological action, and this becomes both the Nash and the Pareto superior equilibrium). The boundaries of the Prisoner's dilemma region (as shown in Figures 1-3) depend on values of b and a and get larger when these values grow. Another typical feature of the game is that, as the number of players grows, the Prisoner's dilemma region grows larger, and this occurs for a downward extension of the area. This implies that the increase in the number of players makes it less likely that a reduction in the cost differential between the two actions makes the ecological choice the Nash equilibrium.

Becchetti et al. (2016) outline in an experimental setting a policy measure that could eventually lead to the cooperative equilibrium of the game. More specifically, they devise a balanced budget mechanism by which the government levies a small lump sum tax on all players choosing the non-ecological action redistributing total tax revenues in equal parts among players who choose the ecological action. The policy measure obviously has the property of transferring large sums to those choosing the ecological action when they are a few, thereby creating an incentive for an increase in their number. The other main advantage of the policy measure is that it is budget balanced, a property not shared by mechanisms used in Italy (Conto energia, superbonus) and in many other countries, and based on a lump sum subsidy to players choosing the ecological action that is eventually paid by all taxpayers. These alternative approaches have the problem of not keeping under control public expenditure if the number of players choosing the ecological action grows.

The experiment on the balanced budget policy measure is run for 20 rounds where the policy measure is introduced after the 10^{th} rounds. During the first 10 rounds we record a typical behavior of human populations: the share of cooperative players choosing the ecological action is very high at the beginning (around 90%) but it progressively declines in the following rounds gradually converging to a share just below 20%. This result is almost a stylized fact in behavioral economics where several experiments suggest that human populations have a large share of conditional cooperators (I cooperate only if the other cooperate) and a smaller share of unconditional cooperators. Back to our benchmark model, we can conveniently assume that for the latter a-c>0 depending on different rationales that can account for their other regarding preferences.

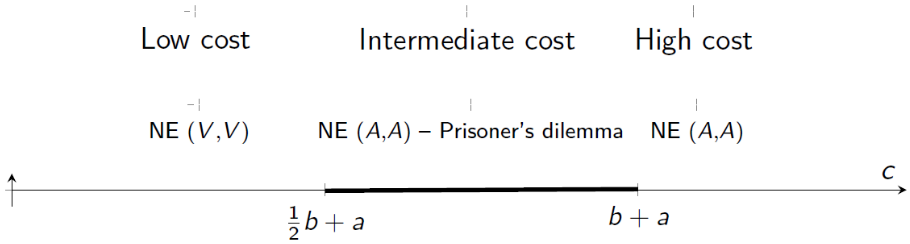
The introduction of the balanced budget policy measure from the 11^{th} round makes joint cooperation the Nash equilibrium and therefore produces a jump up in the share of players doing the ecological choice. The policy measure devised in the experiment is different from what was enacted in many countries and in Italy in the last years. It is a balanced budget and, therefore, by definition, sustainable in terms of government debt. With Conto Energia and Superbonus (the two main Italian energy subsidies of the last decades the logic was reversed and the measures were not budged balanced. In both cases, “players” making the ecological choice (installation of solar panels producing energy from renewable sources in the first case, house retrofit to reduce net emissions in the second case) were subsidized, and the total cost of subsidies was paid by taxpayers. The obvious consequence of this approach was that, with the growth of players doing the ecological choice the taxpayers bill (or alternatively the government deficit) grew substantially so that the measure was in the end not sustainable and had to be suspended. More specifically on the superbonus, the measure could have been made sustainable even without having the properties of that described in our experiment with the definition of an yearly expenditure threshold and with all new potential recipients exceeding that threshold being postponed to the next year government budget.

Figure 1 – *The two-player ecological game.*

		P2	
		V	A
P1	V	$b+a-c, b+a-c$	$\frac{1}{2}b+a-c, \frac{1}{2}b$
	V	$\frac{1}{2}b, \frac{1}{2}b+a-c$	$0, 0$
PD conditions (i.e. (A, A) is NE but is inefficient)			
$\frac{1}{2}b+a<c<b+a$			

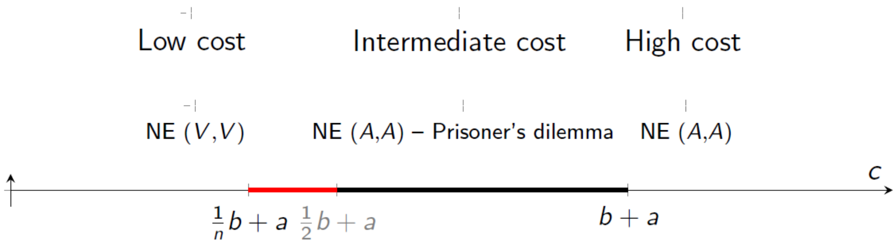
Source Becchetti and Salustri (2016).

Figure 2 – *The Prisoner's dilemma interval in the two-player ecological game.*



Source Becchetti and Salustri (2016).

Figure 3 – *The Prisoner's dilemma interval in the multiplayer ecological game.*



Source Becchetti and Salustri (2016).

The recent literature investigates in depth the social dilemma of ecological transition trying to understand which factors can affect the decision to act ecologically or can change the structure of the game. Magli and Manfredi (2022) reviewed this literature and discussed how a recent strand of contributions argued that the increasing severity of the problem can elicit coordination, since the negative effects of lack of coordination have increasingly suffered in the short and not in the long run. However, the consequence can also be, on the opposite an enhanced conflict on increasing scarce environmental resources leading to climate wars. Therefore, the conclusion of Magli and Manfredi on this more optimistic perspective is critical.

Trying to provide an answer to these research questions Becchetti and Salustri (2023) show in an empirical analysis on EU citizens on European Social Survey data that the willingness to take ecological action is crucially affected, on the positive side, by the perceived severity of the problem and the perception that government in other countries will take ecological actions. The last variable answers the typical critique ("what about India and China ?") that ecological effort is useless if effort in most virtuous countries is not accompanied by that of all other countries (emphasizing again the coordination problem in the global warming challenge). The results of this paper show that social capital is a key variable affecting the impact of these two factors (perceived severity of the problem and expectations about ecological effort of others). More specifically,ecological action of individuals in countries with higher social capital is much more positively affected by perceived severity and much less so by expectations on action of other countries. In synthesis these findings support the hypothesis that higher social capital eases the transition from conditional to unconditional cooperation in climate games.

The solution of the climate change collective action problem can arise also from new forms of energy production from renewables that can modify the game theoretic structure of the dilemma. One of these new forms is renewable energy communities that should account, according to EU targets, for around 16% of energy produced from renewable sources and already represent an important form of energy production in other countries (such as the US) in the rural regions less inhabitated (Reis et al. 2021; Eu Commission 2018; Campann et al. 2016).

Renewable energy communities are made by households, local administrations and profit and not for profit organizations, that create a society to promote, develop, and implement renewable energy projects in a specific geographic area or community. By doing this renewable energy communities can have three sources of economic gains. First, their members do not have to buy the energy they produce. Second, they can sell the energy they produce and do not consume the market. Third, they are remunerated by the government with a subsidy for the share of energy produced and self-consumed. The rationale for this subsidy is the flexibility service to the electricity grid that is going to be overcharged with the growth of renewables. This is why a world of prosumers producing and consuming in place the energy they need is a value reducing a potentially negative congestion externality that deserves to be paid. Becchetti and Salustri (2023) show that, based on existing regulatory features, renewable energy communities transform the ecological game structure from the standard collective action problem of multiplayer prisoner dilemmas into a stag-hunt game and eventually, under reasonable parametric conditions, a cooperation game where making ecological choices is the Nash equilibrium and private and social optimum coincide thereby eliminating the failure of the market.

4. The statistical challenge: the development of circularity indicators

The climate challenge leading to the new era of ecological transition requires a parallel revolution of statistical indicators. By definition, the move from productivity to circularity implies a move from the goal of creating economic value by increasing good and services sold per unit of time to the goal of creating economic value in an environmentally sustainable way. This radical change in turn implies the move from entirely financial/economic indicators, traditionally used at micro and aggregate level, to a new generation of composite indicators creating a bridge between traditional financial/economic and environmental indicators. The change in indicators needs to be paralleled by a change in skills in accounting, economic, and financial profession where, in the new transition scenario, the impact of economic choices on the ecosystem must be evaluated along the six DNSH dimensions (with more specific reference to water footprint, air pollution, and carbon emissions).

Table 1 – *Co2/per unit of GDP ranking of Italian regions, 2019.*

Region	Co2 Emissions (kg) 2019	GDP (PPP) 2019	Co2/GDP Ratio
Bolzano / Bozen	3507491840	25796599808	0.136
Lazio	29245026304	201726803968	0.145
Trentino-Alto Adige / Südtirol	7674959360	47287103488	0.162
Campania	18659567616	110967996416	0.168
Liguria	9170577408	50174603264	0.183
Lombardia	74458587136	399339814912	0.186
Trento	4167467776	21490499584	0.194
Toscana	23819608064	122085793792	0.195
Marche	8329537536	42624000000	0.195
Veneto	37110632448	166407585792	0.223
Abruzzo	7428625408	32901199872	0.226
Valle d'Aosta / Vallée d'Aoste	1177827200	4868499968	0.242
Piemonte	34146744320	137827500032	0.248
Emilia-Romagna	40445800448	162860498944	0.248
Friuli-Venezia Giulia	11297149952	39292502016	0.288
Umbria	6905760256	22960900096	0.301
Calabria	11723196416	33323700224	0.352
Sicilia	31388049408	89189703680	0.352
Basilicata	5507922944	12656799744	0.435
Puglia	35778920448	75769200640	0.472
Molise	3175282944	6478899712	0.490
Sardegna	18511435776	35085799424	0.528

Source: Becchetti et al. (2022).

Table 2 – *Per capita disposable income / PM10 ranking of Italian provinces (euro per mg/mc), 2019.*

Province	Ranking	Per capita disposable income / PM10	Province	Ranking	Per capita disposable income / PM10
Sud Sardegna	1	1690	Reggio nell'Emilia	55	699
Bolzano	2	1389	Ravenna	56	690
Verbano-Cusio-Ossola	3	1365	Piacenza	57	690
Trieste	4	1228	Fermo	58	689
Savona	5	1188	Pescara	59	680
Cuneo	6	1180	Lodi	60	672
Siena	7	1156	Foggia	61	661
L'Aquila	8	1095	Vercelli	62	660
Gorizia	9	1049	Messina	63	650
Aosta	10	1046	Ferrara	64	648
Belluno	11	1013	Asti	65	642
Bologna	12	990	Vicenza	66	628
Genova	13	987	Torino	67	628
Pistoia	14	985	Verona	68	621
Lecco	15	979	Treviso	69	615
Trento	16	977	Lecce	70	612
Massa-Carrara	17	972	Teramo	71	611
Udine	18	970	Latina	72	607
Ancona	19	969	Mantova	73	597
La Spezia	20	937	Avellino	74	594
Macerata	21	936	Terni	75	593
Chieti	22	925	Venezia	76	593
Viterbo	23	901	Pesaro e Urbino	77	591
Biella	24	877	Bari	78	586
Varese	25	869	Sassari	79	586
Sondrio	26	863	Trapani	80	584
Imperia	27	854	Catanzaro	81	578
Isernia	28	851	Alessandria	82	568
Campobasso	29	848	Padova	83	568

Table 2 – *Per capita disposable income / PM10 ranking of Italian provinces (euro per mg/mc), 2019 (continued).*

Province	Ranking	Per capita disposable income / PM10	Province	Ranking	Per capita disposable income / PM10
Firenze	30	843	Cremona	84	565
Arezzo	31	840	Rimini	85	563
Livorno	32	837	Brescia	86	562
Pisa	33	831	Barletta-Andria-Trani	87	562
Rieti	34	828	Reggio di Calabria	88	561
Monza e della Brianza	35	824	Cosenza	89	557
Pordenone	36	783	Brindisi	90	554
Milano	37	780	Pavia	91	549
Potenza	38	777	Taranto	92	547
Como	39	765	Siracusa	93	533
Parma	40	765	Vibo Valentia	94	531
Perugia	41	756	Rovigo	95	529
Lucca	42	755	Catania	96	520
Novara	43	754	Agrigento	97	514
Prato	44	748	Oristano	98	501
Enna	45	734	Caltanissetta	99	469
Modena	46	731	Palermo	100	466
Bergamo	47	723	Crotone	101	435
Grosseto	48	722	Salerno	102	431
Nuoro	49	722	Cagliari	103	429
Benevento	50	718	Frosinone	104	427
Forlì-Cesena	51	716	Napoli	105	416
Ascoli Piceno	52	704	Ragusa	106	403
Roma	53	704	Caserta	107	400
Matera	54	700			

Source: Becchetti et al. (2022).

To give a very simple example on how this could be, we present two ranking of Italian regions based on the ratio of Co2 emissions/GDP and per capita disposable income/PM10, where PM10 is the standard particulate matter indicator that measures an important dimension of air quality. The first ranking is a direct measure of the capacity of a given area to create climate change sustainable economic value, that is economic value with the minimum possible flow of carbon emissions. The leading area in Italy from this point of view is the area of Bolzano, while at the bottom of this ranking we find the Sardinia region whose Co2 emissions/GDP ratio is almost four times higher. The interpretation of the indicator is that the Sardinia economy is far behind the region of the Bolzano in terms of capacity to create a decarbonized circular economic system. The result is affected both by the low absolute capacity to create economic value in the region, but also by the 'old economy' characteristics of that region (i.e. the scarcity of electric railways as a means of local transportation, the dependence on high-emission industrial sectors, etc.).

In the second circularity ranking we paradoxically find that a region of Sardinia (South Sardinia) jumps at first place in terms of per capita disposable income/PM10. The apparent paradox is explained by the fact that, when the environmental indicator used in the composite circularity indicator is quality of air, the geographical advantage of having strong winds and a large portion of the geographical area bordering the sea is an important advantage in terms of dispersion of particulate matter.

5. The statistical challenge: environmental impact indicators

The green taxonomy is the 'Linneus type'[2] approach chosen by the EU to measure adherence to the path of ecological transition. The taxonomy identifies activities admissible and not admissible with ecological transition for each industrial sector, in a detailed classification separately considered for each of the six DNSH domains.

The DNSH standard can be defined as a green Pareto improvement standard since an investment or an economic activity is DNSH consistent if it improves substantially the situation in at least one of the six DNSH dimensions (mitigation, adaptation, quality of air, use of water, circular economy, biodiversity) without producing significant negative effects on the other five, exactly as a Pareto improving choice in economics is something improving wellbeing of at least one individual without worsening that of all other individuals.

This approach has the limit of requiring considerable work in an attempt of examining all possible activities in each industry. The task is even more daunting given the accelerated pace of green technological innovation, so the risk that it this

[2]Carl Linnaeus was a Swedish botanist, zoologist, and physician who formalized the modern system of naming organisms (binomial nomenclature) and is therefore recognized as the father of “modern axonomy"

approach is of never has an end and, while being always in progress, it does not classify as admissible new emerging green technologies that can have more significant positive effects on environmental sustainability.

The alternative 'GIFT' approach proposed by Becchetti et al. (2020) is based on the idea of measuring the impact of a given investment/economic activity with respect to estimated counterfactual changes that define threshold changes that delimit the borders of admissible regions.

The first step of the approach consists of selecting indicators for each of the six domains as shown in Table 3. The obvious candidate for the first dimension is net Co2 emissions, while the identification of the indicator measuring the second dimension (adaptation) is naturally more complex and is found in an index of environmental vulnerability. This type of indicator is increasingly used and popular in the sense that regulatory banking authorities impose the measure of climate risk as a fundamental factor to calculate lending capital requirements. This implies that borrowers with activities and investments more exposed to climate risk and vulnerability (with lower adaptation capacity) are classified as riskier based on this indicator and therefore require a higher bank capital buffer. Adaptation indicators will therefore be increasingly used and popular in the next years. The obvious candidate to measure the third dimension is the water footprint (i.e., the overall water used to create a given product in a life cycle perspective). Two natural candidates for the circular economy dimension are production of nonrecyclable waste and consumption of primary minerals (both on the negative side). PM2.5 and PM10 are the main indicators measuring particulate matter in the fourth dimension, accompanied by indicators measuring other air polluting substances. Land use for anthropic activities and net deforestation balance are two standard measures for the last dimension of DNSH (biodiversity).

In Table 4 we illustrate similarities and differences between the GIFT and the green taxonomy approach emphasizing how the GIFT approach has the advantage of providing a ready-to-use flexible tool that can adapt to all ongoing changes in green technology. In Table 5 we resume results of an experiment on costs of use of the GIFT approach as a percentage of net sales for different firm sizes. The fixed cost of GIFT evaluation is obviously higher in percent for smaller firms, and higher if firms do not dispose of an in-house life cycle assessment. In any case the cost is never lower than 0.01 percent of net sales (for the lowest size class), while falling to 0.0005 percent for the highest size class. We can also consider that a good GIFT evaluation can produce indirect positive reputation effects in corporate non-financial reporting that can balance its cost, and that standardization of evaluation and procedures could further reduce costs evaluated in 2020.

Table 3 – *Similarities and complementarities between GIFT and EU taxonomy (Source: Becchetti et al., 2022).*

Similarities between GIFT and EU Taxonomy	Complementarities between GIFT and EU Taxonomy
• Environmental improvement and fulfilment of the DNSH principle with respect to 6 environmental objectives: 1. Climate change mitigation. 2. Climate change adaptation. 3. Sustainable use and protection of water and marine resources. 4. Transition to a circular economy. 5. Pollution prevention and control. 6. Protection and restoration of biodiversity and ecosystems. • Compatibility check with sustainability criteria of EU Taxonomy before assessing an investment through the GIFT.	• The GIFT applies a generic DNSH logic and does not define sustainability criteria for specific activities. • The GIFT aims to assess the environmental performance of investments (variation of environmental burdens compared to a counterfactual) through LCA-based KPIs. • While work for the EU Taxonomy is ongoing, the GIFT offers a ready-to-use and flexible tool (which can be adapted to adhere to future developments of the EU Taxonomy).

Table 4 – *GIFT Key Performance Indicators (Source: Becchetti et al., 2022).*

Area	KPI (unit)	Methodological references
1. Climate change mitigation	I1. Net emission of GHGs (kg $CO_{2,\ eq}$)	Calculation of life cycle GHG emissions to and removals from the atmosphere, and characterisation of their overall Global Warming Potential over 100 years (GWP100) based on the IPCC model, as described in the EU Environmental Footprint (Zampori and Pant, 2019).
2. Climate change adaptation	I2. Climate change vulnerability proxy (dimensionless)	Characterisation of the vulnerability of the analysed system through the quali-quantitative assessment of its exposure (E), sensitivity (S) and adaptation capacity to extreme climatic events (adapted from GIZ (2014)).
3. Sustainable use and protection of water and marine resources	I3. Water scarcity footprint ($m^3_{eq.}$)	Calculation of the overall water consumed from a life cycle perspective, corrected for its scarcity according to the AWARE model, as described in the EU Environmental Footprint (Zampori and Pant, 2019).
4. Transition to a circular economy	I4a. Consumption of fossil fuels and non-regenerative biomass (MJ) I4b: Consumption of primary minerals (kg) I4c: Generation of non-recyclable waste (kg)	Calculation of a) consumption of fossil fuels and non-regenerative biomass, b) consumption of primary minerals, c) production of non-recyclable waste, adopting a LCA perspective aligned to the EU Environmental Footprint (Zampori and Pant, 2019).
5. Pollution prevention and control	I5a. Emission of particulate matter (disease incidence) I5b. Photochemical ozone formation (kg NMVOCeq.) I5c. Acidification (mol H+eq.) I5d. Freshwater eutrophication (kg Peq.)	Calculation of life cycle emissions of pollutants of concern (e.g., PM2.5, NMVOCs, NOx, SOx, NH3) and characterisation of the impacts associated with emission of particulate matter (UNEP (2016a) model), photochemical ozone formation (LOTOS-EUROS model), acidification (Accumulated Exceedance model), freshwater eutrophication (EUTREND model), as described in the EU Environmental Footprint (Zampori and Pant, 2019).
6. Protection and restoration of biodiversity and ecosystems	I6a. Direct land use for anthropic activities (m^2a) I6b. Net deforestation balance (m^2)	Calculation of a) direct land use (green areas excluded) associated with the investment, b) difference between direct deforestation (positive value) and direct reforestation and afforestation (negative values), adopting a LCA perspective aligned to the EU Environmental Footprint (Zampori and Pant, 2019).

Note: KPIs were defined with reference to a primary environmental area. Because of the interconnected nature of cause-effect mechanisms, these KPIs partly address the six areas and can have an influence on more than one area.

Table 5 – *Costs (in EUR) associated with the application of the GIFT approach for different sizes of companies (Source: Becchetti et al., 2022).*

Type of company	A. Cost for conducting a LCA study [(a) (b)]	B. Cost for quantifying GIFT's KPIs for an investment [(b), (c)]	C. Other costs (digital platform, audit, certification) [(b), (c)]	D. Total costs in case no LCA is available (D = A+B+C) [% of D vs. net sales]	E. Total cost in case LCA is available (E = B+C) [% of E vs. net sales]
Type I: - Net sales: < EUR 100 million	10′000–18′000	1′800–3′000	1′000–1′500	12′800–22′500 [0.013%–0.023%]	2′800–4′500 [0.003%–0.005%]
Type II: - Net sales: EUR 100–1′000 million	12′000–20′000	2′000–3′500	1′000–1′500	15′000–25′000 [0.003%–0.005%]	3′000–5′000 [0.001%–0.001%]
Type III: - Net sales: > EUR 1 billion - Products/ services offered: < 100	20′000–30′000	2′800–4′000	1′000–1′500	23′800–35′500 [0.002%–0.004%]	3′800–5′500 [0.0004%–0.001%]
Type IV: - Net sales: > EUR 1 billion - Products/ services offered: > 100	30′000–50′000	3′500–5′000	1′000–1′500	34′500–56′500 [0.003%–0.006%]	4′500–6′500 [0.0005%–0.001%]

Notes:
[(d)] EUR 100 million for type I, EUR 550 million for type II, EUR 1 billion for types II and III.
[(a)] LCA study needed to quantify GIFT's KPIs.
[(b)] Estimations from ESGeo, the ESG service provider involved in the pilot project.
[(c)] The cost implies that the ESG evaluator makes at least 100 evaluation per year.

6. Conclusions

The industrial revolution promoted and supported by the neoclassic economic paradigm has produced an astounding increase in global population, life expectancy and living standards under the goal of corporate profit maximization that stimulated the production of the highest possible number of goods and services that could be sold on the market. This successful drive has neglected that economic actions occur within an ecosystem providing fundamental services for life and the same productive activity. The consequences have been the progressive depletion of natural capital and environmental resources. The problem can be in some way accommodated in presence of appropriable and renewable/non-renewable environmental goods, while it becomes more serious and difficult to tackle when dealing with a non-renewable/non-appropriable environmental resource such as climate.

In our paper, we show that climate is a global public good whose preservation requires the solution of a collective action problem that can typically be formalized as a multiplayer Prisoner's dilemma. We therefore show that the socially optimal choice where everyone chooses the ecological action is not attained due to a coordination failure problem, while the less desirable outcome where everyone chooses the less expensive ecological action is the Nash equilibrium of the game.

In the paper we discuss conditions and policies under which the paradox can be addressed.

More specifically, we show that balanced budget policy measures based on subsidizing the ecological, while taxing the non-ecological choice can bring to the socially optimal ecological equilibrium and be sustainable in terms of government budget, at the same time. We also discuss how green subsidies historically enacted do not almost always correspond to these measures. We also show and discuss how social capital, the perceived severity of the ecological problem, and the expectation about moves of other countries/players significantly affect the decision to act ecologically in the game. We also explain how some bottom-up approaches to energy production, such as that of renewable energy communities, can modify the structure of the game, transforming it from a prisoner's dilemma into a stag hunt, and eventually a cooperative game in which the coordination failure problem is solved. Our conclusion on this point is also that, as renewables become mainstream, industrial competition in renewables can foster coordination. The question "what about China and India?" discouraging effort of individuals and countries most concerned about transition can change into "how can I catch up leaders in ecological transition? "Provided that industrial activities in this sector will become more and more profitable as the demand for renewables grows due to their economic convenience.

In the second part of the paper, we argue that entering the era of ecological transition requires a deep change in our statistical measures. If the change implies the move from the goal of productivity to that of circularity, statistical indicators for ecological transition need to be bridges between standard economic/financial/accounting indicators and environmental indicators requiring a good knowledge of natural sciences.

To illustrate this in more practical terms we discuss an approach to evaluate impact consistent with the Do No Significant Harm standard, evaluating the effect of investment in the six standard (DNSH) domains and compare it to the EU green taxonomy approach. We also show that monitoring ecological transition requires the construction of a new set of hybrid composite indicators based on the ratio between economic and environmental variables. We apply them to Italian regions and provinces to identify those whose economy is more in line with the new circularity target.

Our conclusion is that success in tackling the global warming challenge requires fundamental ingredients such as higher levels of civic virtues and social capital, policy measures that reward ecological choices, new hybrid indicators to measure circularity, and with them, necessarily the development of proper competences requiring the match between standard economic and financial skills with knowledge of the natural sciences.

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