Factors determining Environmental Kuznets Curve: sustainability assessment and implications for policy makers

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Abstract
Economic research seeking relations between income and environmental quality is well summarized by environmental Kuznets curve (EKC) literature, which consists of two distinct but related areas of research: an empirical strand – the majority - of mostly ad hoc specifications and estimation of a reduced form equation (relating an environmental indicator to income per capita) and a theoretical strand of models on the interaction between environmental degradation and economic growth, which includes optimal growth, endogenous growth and overlapping generations models. These studies suggest to policy makers to pursue economic growth, seen as a sufficient condition to improve environmental quality.
The aim of this paper is to investigate which factors determine the EKC, in order to derive some useful suggestions for policy makers. The RICE99 model (Nordhaus and Boyer, 2000) allows us to infer the hypothesis underling the U-inverted relation between environmental quality and income (namely technological progress). The analysis focuses on scenarios developed by considering different hypothesis regarding technological progress (in term of productivity growth and decreasing emission per output) and regulation (Kyoto Protocol). Following a sustainable development approach, an assessment of economic and social sustainability is made, considering as indicators a non-declining income path and a better distribution of income. Theoretical findings are compared with IPCC data. Results have important policy implications.

Paper structure

1. Introduction (why introducing a conceptual model to investigate global sustainability)
2. Sustainability and EKC
    - 3 conflicting dimensions underlining the sustainability concept, that must be taken into account when assessing the impact of different policy alternatives
    - EKC investigates the links between income and environmental quality. EKC literature emphasises the role of structural change, technology and demand for environmental demand, as determining factors to test an EKC.
3. A conceptual model to assess global sustainability
    - description of the model
    - factors determining the EKC
    - choice of environmental, economic and social global sustainability indicators
    - theoretical results
4. Empirical analysis
5. Policy recommendations
6. Concluding remarks and future research

1. Introduction

Pressure of the economic activity on the environment is straightforward. The links between economic activity and the environment constitute a long-standing debate. Most of the literature concentrates on the links between environmental degradation and economic growth. Last ten years saw and increasing of research relating to the Environmental Kuznets Curve (EKC, hereafter). The basic funding of the EKC literature is that with increasing income environmental pressure of the economic activity decreases: as a consequence, policy makers should pursuit economic growth to obtain environmental improvements (Stern et al., 1996). Environmental policy, as a consequence, is not necessary. This conclusion has been questioned by some authors (Arrow et al., 1995), which emphasise the decisive role played by policy in decreasing the growth pressure on environment.

In last years the EKC literature analysed other factors determining the U-inverted relationship between environmental quality and income, ethical concerns enter the debate: some authors analysed the relation between the EKC and the original Kuznets curve, as it was described in 1955 by Kuznets. This part of the literature focus on the influence of income distribution on the existence and turning point of EKC, with contrasting results. Whereas some authors (Magnani, 2000; Torras and Boyce, 1998) underlined the impact of a more equal income distribution on the formation of the median voter preferences towards a greater environmental policy, others (Borghesi,) point out that with non equal income distribution the EKC exists, but also that the turning point is at a low level respect a more equal income distribution.

This short overview shows clearly that EKC literature encompasses the three sustainability dimensions, which have known a greater popularity after the publication of Brundtland report (WCED, 1987). The aim of this paper is to group these findings in a comprehensive model that, starting from the EKC hypothesis, allows policy makers to design policies by taking into account the consequences of the factors determining EKC.

The article is organised as follows. In paragraph 1 a sustainable development and EKC literature review are presented. Our aim is to underline that the main theoretical findings are not useful to policy maker interested in designing or evaluating environmental sustainable policies in a comprehensive manner, and a theoretical effort should be made in order to build a comprehensive model that encompass all sustainability dimensions. A global sustainability model is described in the third paragraph. Following a sustainable development approach, an assessment of environmental, economic and social sustainability is made, considering as indicators a non-increasing pollution level, a non-declining income path and a better distribution of income. Theoretical findings are compared with IPCC data. Results have important policy implications.

2. Sustainability and the EKC

The relations between environmental degradation and economic growth are the point of a long-standing debate. Victor (1972) emphasized that economic growth should be a threat for the environment, as economic activities use environmental resources as inputs for production of goods and services, and release on the environment waste behind its carrying capacity. Meadows et al. (1972) denounced that economic growth was no longer sustainable because of exhaustability of natural resources.

The main findings of the EKC literature reverse these conclusions: environmental damage first increases with income and eventually, after a turning point, decreases. As stated by Panayotou (1993) “At higher levels of development, structural change towards information-intensive industries and services, coupled with increased environmental awareness, enforcement of environmental regulations, better technologies and higher environmental expenditures, result in levelling off and gradual decline of environmental degradation”. Economic growth, in this view, is not a threat to global sustainability and that there are not environmental limits to growth, as the economic growth is the means to attain environmental improvements (Stern et al., 1996). The factors that may aspect to offset the “scale effect” are important in determine the U-inverted relation between income and environmental degradation. These are (IBED, 1992): the structure of the economy (i.e. the goods and services produced in the economy), the efficiency of resource use (i.e. inputs used per unit of output in the economy), the substitution of resources become scarce and clean technologies, which made possible to reduce the environmental damage.

The EKC hypothesis could be explained in microeconomic terms considering the environmental quality as a luxury good: with an increasing willingness to trade off environmental quality with income, rising per capita GDP will induce society to demand cleaner environment. Furthermore, pollution effects on consumption decrease with income due to the effect of changes in the structure of the consumption.

The EKC debate has important policy implications. If the EKC hypothesis is correct, the solution to environmental problems is economic growth. As noted by Ansuategi et al. (1998) "fostering economic growth should remain the paramount policy objective of the international community, and calls for concerted global action to curb environmental problems are misplaced."

EKC consists on an empirical strand – the majority - of mostly ad hoc specifications and estimation of a reduced form equation (relating an environmental indicator to income per capita). The empirical evidence of the EKC hypotheses has been tested. Some authors underlined that the EKC hypothesis was tested for some pollutants, whereas for others the relationships between income and environmental degradation do not follow this trend. Even for the pollutants presenting a U-inverted trend, for higher stages of development an increasing trend was found (N-shaped curve), contradicting the main conclusion of the former studies (Ansuategi et al., 1998).

Differences in these results reflect differences in methodology employed and on model specification. Stern et al. (1996) stress the main problems with the estimation of EKC. They concern the simultaneity of the model, data problems and international trade. Regarding the first aspect, ECK does not consider the feedback from the state of the environment on economic growth. If this kind of feedback exists, i.e. economic activities depend on the environmental resource use (Arrow et al., 1995), then growth in the earliest stage of development could compromise the ability of a country to growth in the future. Furthermore, the use of observations which are aggregations over a number of subunits could give rise to heteroskedasticity problem. Finally, with the international trade some countries (normally the developed ones) will specialize to human capital and manufactured-capital intensity activities, whereas others (the developing ones) on labour and natural resource intensity activities. As a consequence, part of the reduction of the environmental damage in developed countries could reflect this specialisation.

On the other side, the EKC literature consists of a theoretical strand of models on the interaction between environmental degradation and economic growth, which includes optimal growth, endogenous growth and overlapping generation models.

Apart from the empirical evidence of EKC hypothesis, a certain number of studies focus on other variables that could impact on the environmental degradation.

A strand of research regards the relationships between EKC and an equitable distribution of income (Magnani, 2000; Torras and Boyce, 1998). Torras and Boyce (1998) stress the importance of considering the distribution of income, for testing the EKC hypothesis. The link is investigated by considering environmental quality as a luxury good, which demand augments as income increases. Considering only the average income is not sufficient. With an increasing income, a greater consumption could bring to an increasing pollution level. The increasing income, if we expect that EKC hypothesis is verifies, should be channelled through environmental goods. Empirical evidence produces mixed effects. Magnani (2000) stated that: "voters' preferences over consumption of private goods and public goods, such as environmental amenities, depend on their relative position in income distribution function. (…) While growth in per capita income may increase the capacity to pay for environmental amenities (the absolute income effect), income inequality may drastically reduce a country's willingness to pay (the relative income effect) by shifting the median voter's preferences away from consumption of the public good "environmental amenity".". The study shows that a high demand for pollution abatement depends on an absolute income effect and a relative income effect, which impact on the ability to pay and the willingness to pay for environmental protection.

Other authors investigated the link between technological progress and sustainability (Pasche, 2002).

Innovation is divided into "autonomous" and "induced" (Hicks, 1932), where the former is exogenous and the latter endogenous. The EKC hypothesis requires that technology effect offset the scale effect. This induced innovation could be caused by market signals (e.g. rising resource costs) or government policies (regulatory standards, taxes, tradable emission permits).

All these research, in overall, encompass the three dimensions that characterized the sustainability concept. None of them try to systematize these findings in a unique research. Our aim, in this paper, is to elaborate a conceptual model that allow policy maker to infer some policy prescriptions in terms of sustainability considered as a multidimensional concept.

Furthermore, even if the EKC hypothesis would be confirmed, the relationship between environmental degradation and economic growth, as studied in EKC literature, do not allow policymakers to choose between policy alternatives, because this focuses mainly on the relationship between economic growth and the environment, thus not considering the explaining factors of this relationship, namely environmental regulations, technology and industrial composition (Grossman and Krueger, 1995). For this reason, we are interested in analysing the factor determining EKC to infer some useful information for policy makers. First it will be useful to take a step backwards in analysing (briefly) the issue of measurement of sustainable development.

Economists offered a coherent definition of sustainable development and its measurement (Solow, 1986; Pearce et al., 1994; Pearce and Atkinson, 1993). Sustainable development is defined as some measure of non-declining per capita human well-being. Different approaches to sustainable development exist, considering the conditions satisfying the achievement of sustainability. Whereas weak sustainability approaches call for a conservation of the total amount of capital (man-made and natural), strong sustainability approaches stress that sustainability is achieved only conserving certain component of natural capital stock. The fundamental difference between the two approaches consists on the degree of substitution between natural and man-made capital. Apart from the approach chosen, both require that the definition should be made operative through sustainability indicators. Pearce et al. (1999) illustrate some example of economic and ecological indicators. They stress that the measurement of the sustainability concept "will mean that sustainable development can be more than a vague commitment on the part of governments and instead become a measurable concept with wide-ranging policy implications" (p. 188).

The Brundtland report emphasises that development should encompass three elements. The first is that economic development should be considered together with environmental protection and ethic concerns. The publication of the report entails a progress toward measurement of sustainable development.

Another important issue in sustainable development debate is the role of technology. Considering that economic system should not harm ecosystems, the way economy develops depends on technological development. Furthermore technology influences the efficiency on natural resource uses.

3. A model to assess global sustainability

3.1 The model

Nordhaus and Boyer (2000)'s RICE is the most recent version of a regional dynamic general equilibrium model originally proposed by Nordhaus for the study of the economic aspects of climate change (Nordhaus and Yang, 1996). The RICE model basically considers a single sector optimal growth model suitably extended to incorporate the interactions between economic activities and climate. There is one such model for each of the eight macro regions into which the world is

divided: USA, Other High Income countries (OHI), OECD Europe (Europe), Russia and Eastern European countries (REE), Middle Income countries (MI), Lower Middle Income countries (LMI), China (CHN), and Low Income countries (LI).
Within each region a central planner chooses the optimal paths of fixed investment and carbon energy input that maximizes the present value of per capita consumption.
Nordhaus and Boyer's starting assumption is that in their model's world there is a Social Planner who optimally runs his/her own region, indexed by *n*, by maximizing the following discounted utility:

$$(3) \qquad \underset{\{C(n,t)\}_{t=1}^{T}}{Max} \sum_{t=1}^{T} \beta(t)^{t-1} C(n,t)$$

where C stands for consumption and β is the discount factor. The maximization process is subject to some constraints that capture the economic dynamics as well as the environmental ones.

The Resource Constraint of each region links consumption with net output production Y and with physical investments I. The following equation identifies the Resource Constraint:

$$(4) \qquad C(n,t) = Y(n,t) - I(n,t)$$

The gross value added obtained from the production process is described by the following equation:

$$(5) \qquad Q(n,t) = A(n,t)[K(n,t)^{\gamma} CE(n,t)^{\alpha n} L(n,t)^{(1-\gamma-\alpha n)}] - p_e(n,t)CE(n,t)$$

where A denotes the state of the technology, K is physical capital, CE is carbon energy, L is population level, and p_e is the price of carbon energy. Apart from A and L, all the inputs of this value-added equation are endogenously determined. Note that the evolution of A accounts for productivity growth as the production-enhancing technical change. In the model this index follows an exogenously determined increasing path over time.

There is a wedge Ω between gross and net output production due to climate alterations; this wedge is inversely related to and driven by the damage function D:

$$(6) \qquad Y(n,t) = \Omega(n,t)Q(n,t)$$

$$(7) \qquad \Omega(n,t) = 1/D(n,t)$$

$$(8) \qquad D(n,t) = \theta_{1,n}T(t) + \theta_{2,n}T(t)^2$$

The environmental damage is a key variable explaining how the model describes the capital accumulation by including environmental resources. We refer to natural resources (intended as a flow) and not about environmental capital stock, because the basic assumption of this model lays on an unlimited stock of natural resource and a carbon energy demand always satisfied by the supply (as suggests the Say's Law). The scarcity is reflected only into carbon price.
The factors driving EKC are expressed in the model by a set of equations and variables.
The green technological effect is described by

$$(9) \quad E(n,t) = \varsigma(n,t)CE(n,t)$$

Notice that the coefficient ς, in (9) captures the second form of technical change of the RICE99 model, consisting in an emission-reducing technical change. This index of carbon intensity is exogenously determined and follows a negative exponential path over time. In this way, Nordhaus and Boyer (2000) make the assumption of a gradual, costless improvement of the green technology gained by the agents as time passes.
The international policy by the equation:

$$(10)\ \ E(n,t) \leq Kyoto(n)$$

implying the implementation of an emission permits market.
The scale effect is influenced by the total factor productivity A(n,t). A(n,t) is an exogenous variable shaped by Nordhaus guessing a declining rate of growth. The composition effect and preferences cannot be represented in RICE99 because is a one-good model and there is no a commodity market.
The model is based on a weak sustainability approach, since there are no constraints on some components of natural capital.
This model allows us to investigate the links between EKC and different concepts of sustainability in different scenarios. These scenarios (see table 1) are built considering different hypothesis concerning factors driving EKC.

Table 1 – Scenarios built on the basis of different hypothesis about regulation and technology.

Scenario	ς ***(n,t)***	**A(n,t)**	**Regulation**
No exogenous green progress Exogenous industrial progress No regulation (NEN)	ς *(n,t)*=1	A(n,t) grouwth rate is exogenously shaped and follows an exponential negative path over time	Business as usual scenario
Exogenous green progress Exogenous industrial progress No regulation (EEN)	ς *(n,t)* is exogenously shaped and follows an exponential negative path over time	A(n,t) grouwth rate is exogenously shaped and follows an exponential negative path over time	Business as usual scenario
Exogenous green progress Exogenous industrial progress Regulation (EER)	ς *(n,t)* is exogenously shaped and follows an exponential negative path over time	A(n,t) grouwth rate is exogenously shaped and follows an exponential negative path over time	"Kyoto for ever constraint" with emissions trading for all Annex1 countries
No exogenous green progress exogenous industrial progress regulation (NER)	ς *(n,t)* is exogenously shaped and follows an exponential negative path over time	A(n,t) growth rate is exogenously shaped and follows an exponential negative path over time	"Kyoto for ever scenario" with emissions trading for the Annex1 countries.
No exogenous green progress No exogenous industrial progress No regulation (NNN)	ς *(n,t)*=1	A(n,t) growth rate is 0	Business as usual scenario
Exogenous green progress No exogenous industrial progress No regulation (ENN)	ς *(n,t)* is exogenously shaped and follows an exponential negative path over time	A(n,t) growth rate is 0	Business as usual scenario
No exogenous green progress No exogenous industrial progress Regulation (NNR)	ς *(n,t)*=1	A(n,t) growth rate is 0	"Kyoto for ever scenario" with emissions trading for the Annex1 countries

The last column explains the policies that can be chosen by the policy maker in order to pursue sustainable development. These are:

- No regulation, where technological improvements (both green and industrial) are exogenous;

- Regulation, that in our case is coincident with the implementation of the Kyoto Protocol.

3.2 Sustainability assessement

The next step is to rank these scenarios, on the basis of meaningful indicators. The sustainable development literature, in the last 15 years, stressed the importance of measuring sustainable development in order to address policy design and evaluation (Pearce et al., 1999).

In order to rank the two alternative policies we evaluate the different scenarios using as indicators:

- for economic sustainability a non declining income and consumption path. A common used sustainability indicator is the “green GNP” (Rennings and Wiggering, 1997). We consider only the GNP as indicator because environmental dimension is captured by the following indicator;
- for environmental sustainability a non increasing pollution. It is evident that this is a weak sustainability indicator;
- for social sustainability a more equal income distribution. This choice is based on what concluded in Magnani and on equity considerations

4. The empirical findings

These scenarios are run by the non-linear program solver GAMS and others could be added on the basis of the effective feasibility.

The results for each region deriving from the scenarios mentioned above are aggregated obtaining world data and evaluated according to three different concepts of sustainability:

a) Economic sustainability: the best scenario is the one showing the highest non-declining income and consumption.
b) Environmental sustainability: the best scenario is the one showing the lowest carbon concentration and temperature increase. Another aim of this paper is to test the hypothesis of the EKC considering global data obtained from the model.
c) Social sustainability: the best scenario is the one showing the lowest income concentration among regions and the highest world income per capita.

<u>Economic sustainability</u>

From our simulations we infer that the scenarios with exogenous industrial progress show an increasing path and the highest consumption per capita (EER, EEN, NEN, NER). Exogenous green progress and regulation do not largely affect the consumption per capita and seem not to be determining factors influencing growth (see the figure 1 in the Appendix 1).

<u>Environmental sustainability</u>

The absence of exogenous green progress is the most important factor explaining pollution (see the figures 2 and 3 in the appendix 1). The scenarios with the three highest carbon concentration and temperature increase are the ones without the exogenous green progress (NEN, NER, NNN). The absence of green progress could be adequately compensated only by regulation and by the absence of industrial progress (NNR).

Industrial progress and the Kyoto Protocol influence pollution with a reduced impact.

Not surprisingly the best scenario is the one with exogenous green progress but without exogenous industrial progress, that was not economic sustainable (ENN).

The joint presence of exogenous industrial progress and absence of exogenous industrial progress generate a positive and increasing relationship between income per capita and emissions (NEN NER. See the figure 4 in the Appendix 1). If the green progress and the industrial progress are absent there is a decreasing relationship suggesting a bell shaped relation beyond the turning point (NNN, NNR).

Social sustainability

We can notice that all the distributions concerning scenarios including exogenous industrial progress (EEN, EER, NEN, NER) are Lorenz dominant over time except the first periods and the gap between them and the distributions realized in scenarios excluding exogenous industrial progress (ENN, NNN, NNR) becomes more and more wedge over time (see the Figure 5 in the Appendix 1).

Regulation and exogenous green progress do not influence social sustainability.

Considered that the income per capita in all scenarios including exogenous industrial progress is higher than the others, we conclude on the basis of the Atkinson theorem that exogenous industrial progress improves welfare.

Given that industrial progress is the most important factor determining the growth and the welfare, when it is present in a certain scenario, there is a high risk in terms of environmental sustainability if there is not a sufficient green progress to reduce the pollution.

5. Policy recommendations

Our simulations confirm that the three sustainability objectives are conflicting, at least considering environmental and socio-economical objectives and the policy instruments to be used to attain sustainability goal.

We can clearly conclude that a crucial factor to obtain economic and social objective is industrial progress, whereas green progress plays a great role in reducing environmental degradation. Not surprisingly, the Kyoto Protocol has not a great impact on the attainment of environmental objectives.

The model we have used considers technological progress as exogenous, thus not taking into consideration the cost in R&D necessary to boost technological improvements.

A further step of analysis will be to consider technological improvements as endogenous and assess how this affects our results.

6. Concluding remarks

This paper, using a RICE99 model, investigates how the factors determining EKC affect sustainability, considered as a multidimensional concept.

Our results show that in order to attain environmental sustainability, measured by non-increasing level of pollution, a green technological progress is the crucial element. Economic and social sustainability, measured by non-declining consumption level and a more equal income distribution is influenced by industrial technological progress.

Our results call for a public intervention in the form of incentives to technological progress, both green and industrial.

One shortcome of this model is that it considers technological change as exogenous and, by definition, free. It would be interesting, in future analysis, to consider technological progress as endogenous and assess how this affects our results. Pasche (2002) demonstrates that green progress can lead to positive growth rate with decreasing level of pollution. Furthermore, after a certain point, growth rate converge to zero and, given the expenditures from the current income necessary to encourage green technical progress, this will entail a decreasing level of consumption.

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Appendix 1

Figure1: Consumption per capita (trillions of 1990 US$/millions of population)

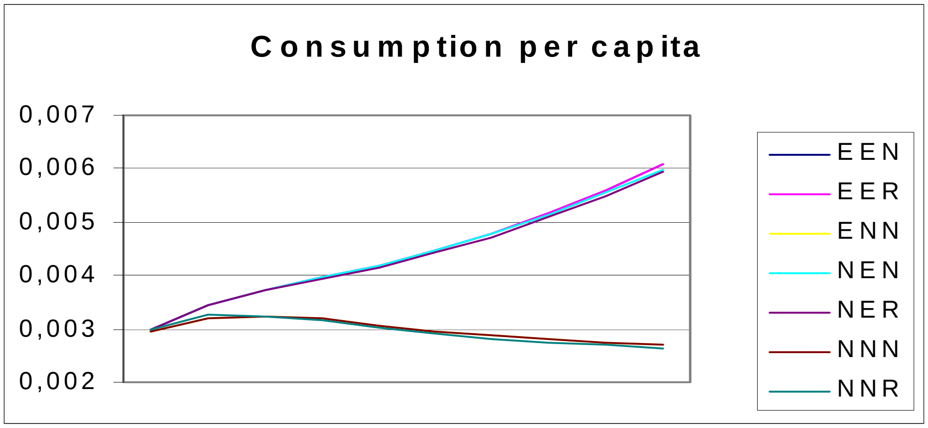


Figure2: Atmospheric concentration of carbon (gigatons)

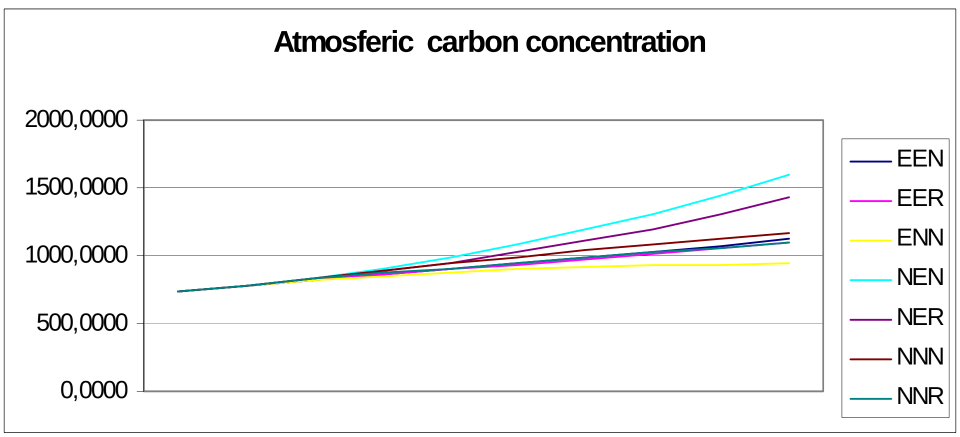


Figure3: Increase of temperature (deg)

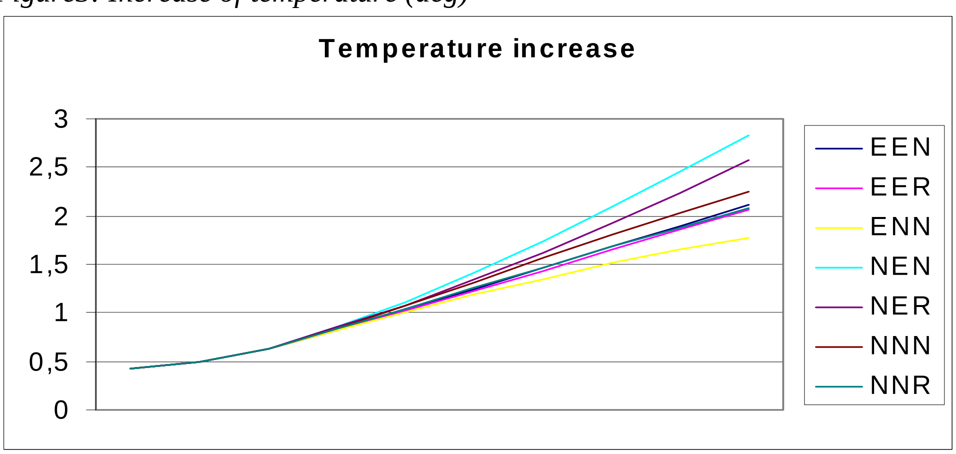


Figure4: Income per capita(trillions of 1990 US$/Millions of population) vs CO_2 emissions (Gigatons)

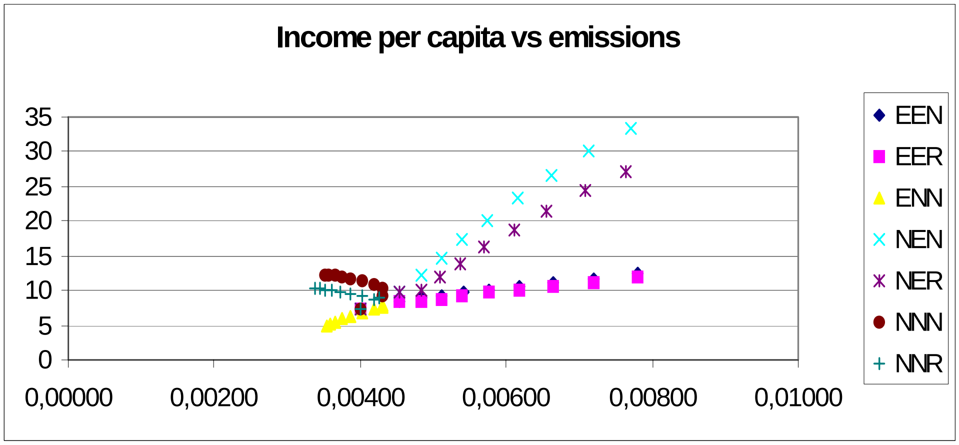
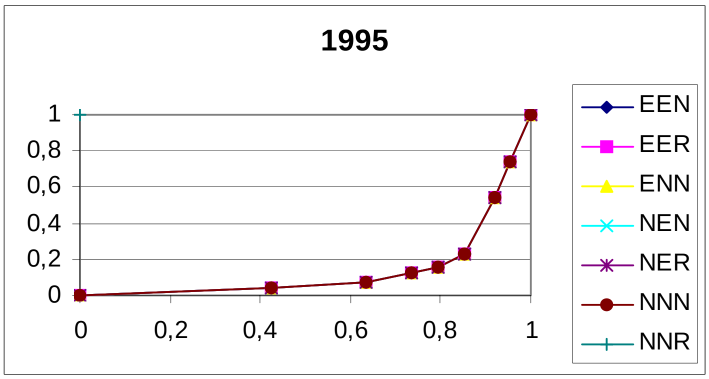
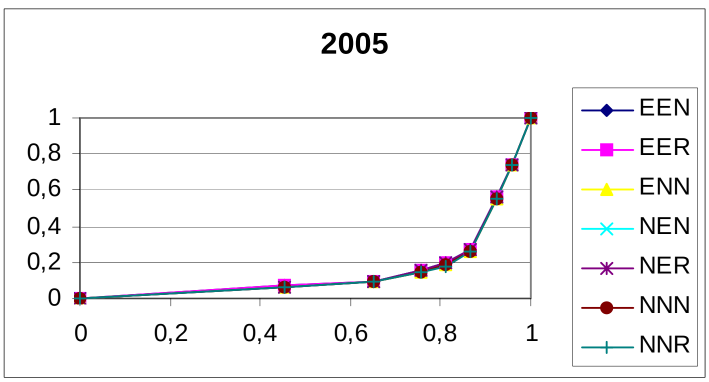
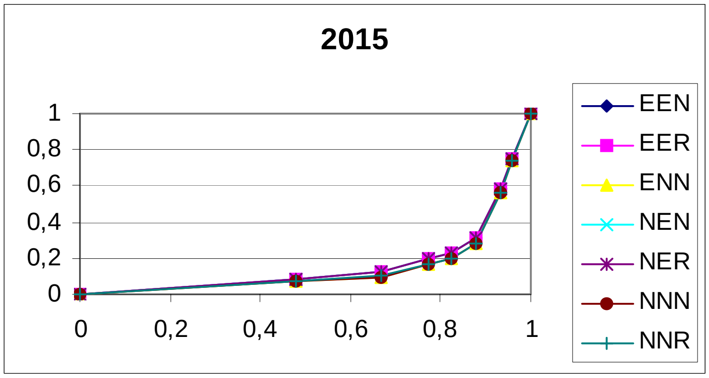


Figure5: Lorenz curves since 1995 to 2085



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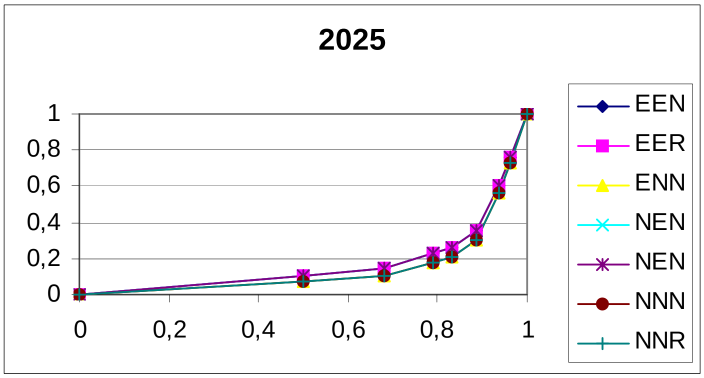
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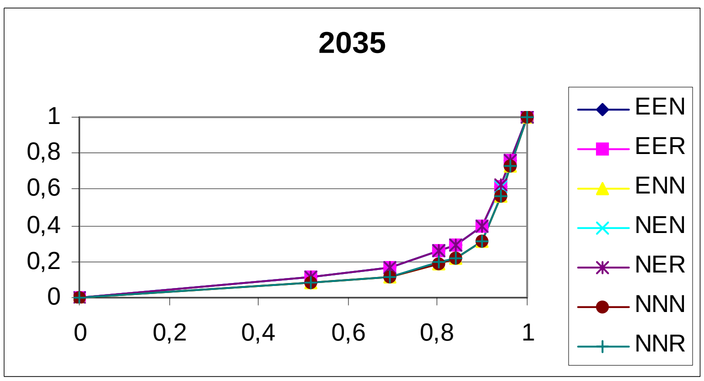
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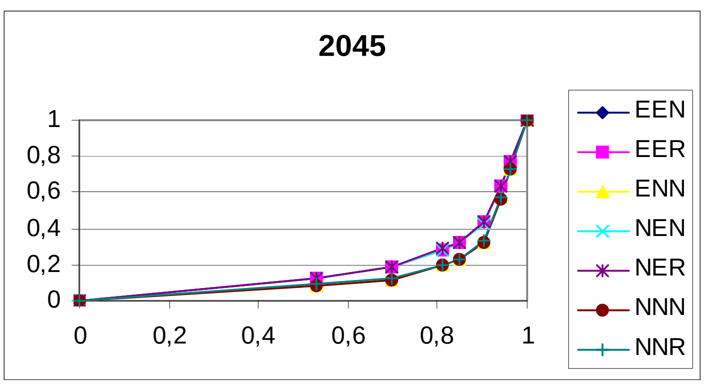
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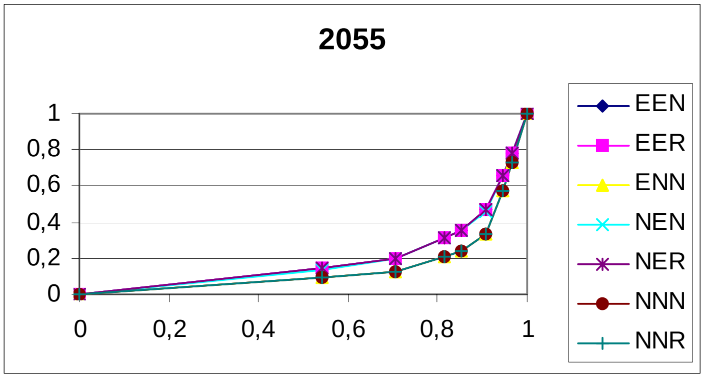
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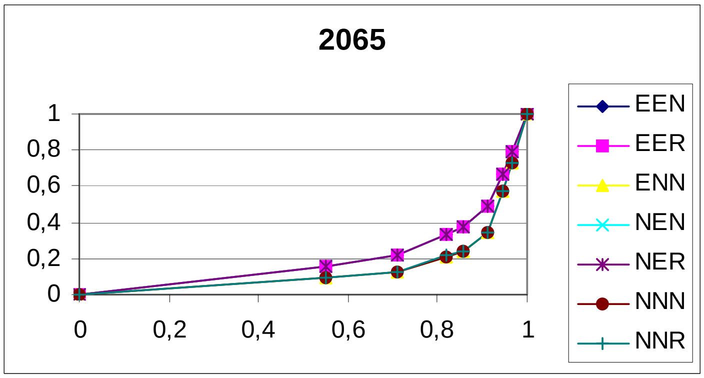
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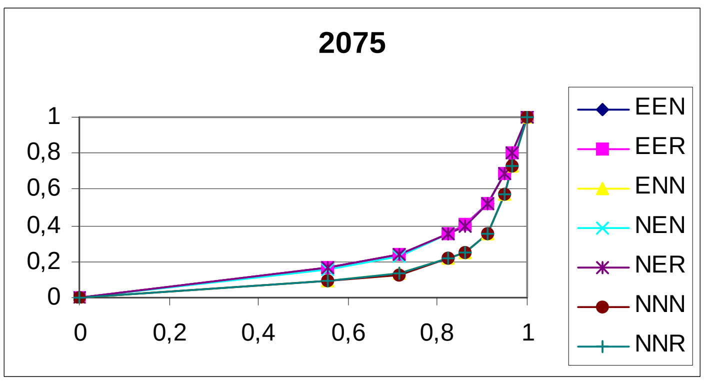
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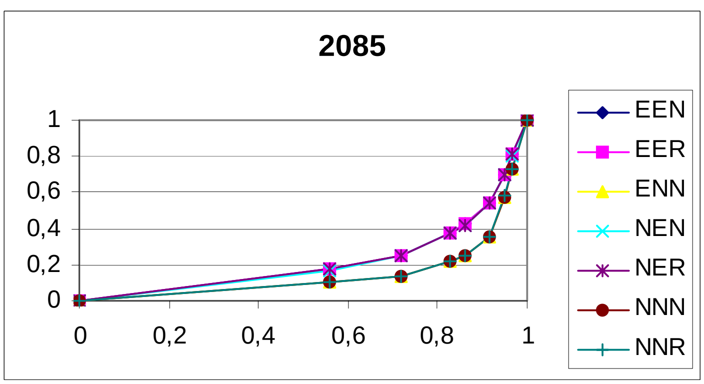
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