POLITECNICO DI TORINO

Department of Management and Production Engineering

Class LM-31 Degree: Management Engineering

Master's Degree Thesis

Environmental protection and economic development:

are they mutually exclusive goals?

Thesis supervisor:

Prof. Anna D'Ambrosio

Candidate:

Claudio Muroni

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Summary

The aim of the thesis is to analyze the relationship between two goals which, sometimes, seem to be incompatible: environmental protection and economic development. The first one, with particular attention to global warming, is a challenge shared by all countries on the planet and represents a highly debated topic which involves researchers, economists and politicians at the same time. Accordingly, the related literature is wide and divided, sometimes even incoherent, but also relatively young.

The thesis follows a path in order to analyze all the elements required to answer the question proposed as title. The first chapter does not consider the economic aspect, it explains why we need to measure the impact of human activities on the environment and the attempts to define a mathematic relationship to express it (represented by Scale, Composition and Technique effects). This initial step is useful to understand how much the planet health is related to humankind development and to define the main responsible parameters. The second chapters is dedicated to the Environmental Kuznets Curve, which represents the most popular attempt to describe the environmental impact of a country while its population richness increases. It takes in consideration just a few variables, this is why a further step is necessary. Hence, chapter three focuses on more detailed hypothesis which includes, first of all, trade and environmental policy in the relationship analysis. This chapter could be considered a snapshot of literature so far, including main discussed theories (Pollution Haven Hypothesis and Porter Hypothesis), case studies examples and general findings. Finally, chapter 4 resumes the proposed work in order to add personal considerations on the actual situation and early future.

General Index

1. Impacts of human activities on the environment

The goal of this chapter is to introduce the relationship between humankind and pollution, to do this, it explores a few attempts to define the variables cause of environmental impact and to express this relationship through an equation. As an anticipation, after almost fifty years of research there is still no exhaustive formulation approved by the scientific community but only some interesting equations.

1.1. Environmental impact

1.1.1. Environmental indicators

The terms “environmental impact”, “pollution” or analogue will be constantly recurrent along the thesis and in most cases used without deeper explanation but behind these words it could be open a wide topic that cannot be summarized in this paragraph. What it is important to underline here, is that defining and measuring environment health is a complex matter that must be evaluated case by case to choose the right indicators.

First, the indicators should be chosen respecting a list of criteria, there is not a single list commonly used but a good example to cite is the one proposed by Dale and Beyeler in their paper “Challenges in the development and use of ecological indicators”, according to them the chosen the selected indicators should:

- Be easily measured.
- Be sensitive to stresses on system.
- Respond to stress in a predictable manner.
- Be anticipatory.
- Predict changes that can be averted by management actions.
- Be integrative.
- Have a known response to natural disturbances, anthropogenic stresses, and changes over time.
- Have low variability in response.

Second, the indicator selection process should take in consideration the cause-effect relationship between the different actors inside the environment. A common way to achieve this goal is to use a framework like the PSR or the DPSIR one (which can be represented as causal chains), where PSR is the abbreviation for Pressure-State-Response following the logic: *"pressure on the environment from human and economic activities, lead to changes in the state or environmental conditions that prevail as a result of that pressure, and may provoke responses by society to change the pressures and state of the environment"* (reported in OECD, 1999. "Environmental Indicators for Agriculture: Volume 1 Concepts and Frameworks"). The DPSIR framework is based on the PSR one adding the elements "Driving force" and "Impact", *"it distinguishes between indirect driving forces such as social and economic developments and pressures such as emissions that directly influence the environment"* and *"it further distinguishes between the state of the environment (for example concentrations of pollutants) and the impacts of (changes in) the environmental state on human health, ecological systems and materials"* as explained by Niemeijer and de Groot in 2006 ("A conceptual framework for selecting environmental indicator sets"). In this paper they tried to go further the DPSIR framework proposing an enhanced version of it (eDPSIR) introducing the more detailed concept of "causal network" instead of "causal chains". It is not necessary to explain these concepts exhaustively because, as written at the beginning of the paragraph, the goal is to understand the complexity of the topic and remember that, when in the following chapters it will be used a simple variable to represent the environmental impact, it hides a lot more.

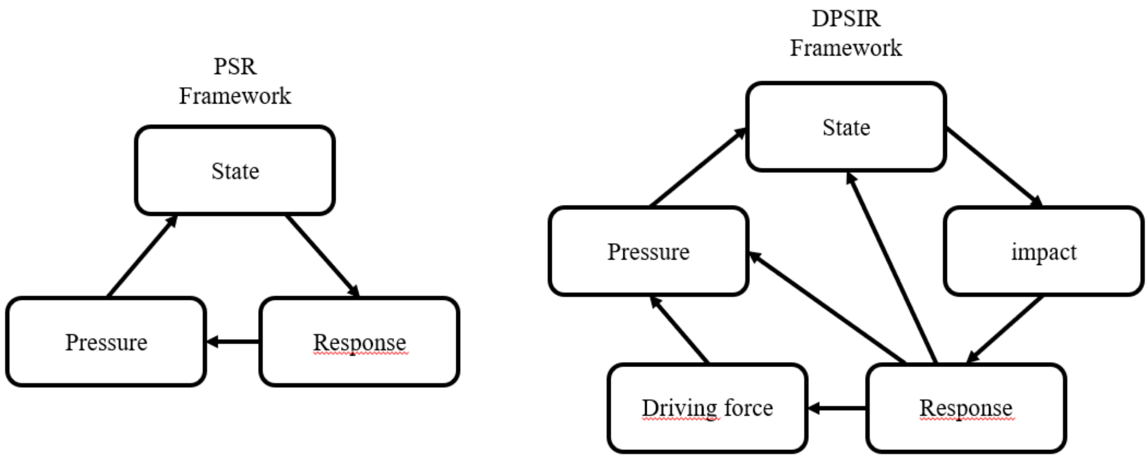

Fig. 1.1: PSR Framework and DPSIR Framework

1.1.2. Global warming

Today (year 2024), global warming is the main concern regarding the impact of human activities on the environment (but not the only one): it has been proved that starting from the industrial revolution, the massive emission of greenhouse gases led to a remarkable increment of the natural greenhouse effect of Earth atmosphere. This phenomenon has (and will have) several impacts on human life, such as: melting glaciers and following raising of sea level, desertification of arable land and various problems caused by the effects on climate. For this reason, in this thesis the focus will be about the emissions of this gases too, sometimes simply called GHGs (GreenHouse Gases).

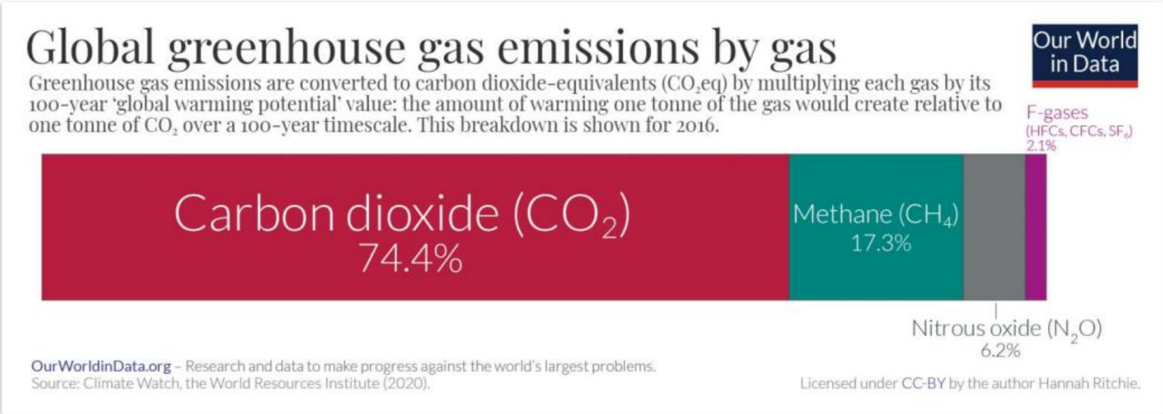

Fig. 1.2: Main greenhouse gas emissions. Source: (OurWorldInData.org)

The main driver of Global Warming is the concentration of Carbon Dioxide in the atmosphere. Its rapid growth is caused mainly by two human factors: the direct emission through fossil fuel combustion and indirectly through deforestation (reducing vegetation able to absorb the emitted CO_2, the net value can only increase). Being so relevant and commonly known, CO_2 is also used as a reference to measure the impact of other GHGs in term of CO_2-equivalent.

The second most important gas in this list is Methane (CH4) mainly emitted by agriculture, fossil fuel production and the management of waste, it *"is a much stronger greenhouse gas than CO_2 in terms of its 'warming potential'. Over a 100-year timescale, and without considering climate feedbacks, one tonne of methane would generate 28 times the amount of warming as one tonne of CO_2"* (Ritchie et al, 2020). At the same time its life in the atmosphere is much shorter, just one or two decades compared to centuries necessary for natural CO_2 removal, this means that reducing emissions today will show results about the concentration "quickly".

In third place there is Nitrous Oxide (N_2O) typically related to nitrogen fertilizers used in agriculture, this gas is not only much stronger than CO_2 but even much more then Methane: *"Over a 100-year timescale, and without considering climate feedbacks, one tonne of nitrous oxide would generate 265 times the amount of warming as one tonne of CO_2"* (Ritchie et al, 2020). Its stay in the atmosphere is not long as Carbon Dioxide but the average value is over one hundred years.

Different other molecules could be taken in consideration and if necessary, some of them will be introduced in the next paragraphs.

1.2. IPAT and Kaya Identities

The IPAT identity is a very simple equation introduced in the early 1970s to define environmental impact as the product of three factors, the reason of this name become obvious knowing that the formula is expressed as:

$$I = P \times A \times T$$

where:

$I\ is\ the\ environmental\ Impact,$

$P\ is\ the\ Population,$

$A\ is\ the\ Affluence,$

$T\ is\ the\ Technology.$

The main idea is to define and measure I and A to calculate (and define) T. The environmental impact is the indicator of interest, like for example emissions of CO2, while *"The typical measure of A is per capita economic activity, so PA became total economic activity"* (Dietz, Rosa. 1997) and the natural choice is to use per capita and total GDP. At this point, T can be simply calculated as I / (PA), but this parameter 'T' *"represents not only technology per se, but also [...] all facets of human life other than population and economic activity"* (Dietz, Rosa. 1997). So, this equation is not able to show any relationship with a precise cause.

This is why, in the late 1990s, T. Diaz and E.A. Rosa proposed a stochastic model variation of the original IPAT equation:

$$I = a \times P^b \times A^c \times T^d \times e$$

Which can be implemented case by case by different researchers defining a, b, c, and d as parameters or even functions (while e is the residual term representing every other variable not included in the model). *"The key change from the traditional IPAT approach is that an independent measure of T must be used: the researcher must specify what is meant by technology rather than solving for T as I/(PA)."* (Dietz, Rosa. 1997).

Looking at the literature, the IPAT equation and its variations do not seem to have found a great utilization, but there is another identity (based on the IPAT structure) which, it is still used to represent the evolution of CO2 emissions. This formula is called Kaya Identity, by the name of the economist who introduced it in the early 1990s, and it is formulated as:

$$CO_2 = P \times \frac{GDP}{P} \times \frac{E}{GDP} \times \frac{CO_2}{E}$$

where:

$CO_2 \ is \ the \ emission \ of \ CO_2 \ (I \ in \ the \ IPAT \ Identity)$,

$P \ is \ the \ population \ (like \ in \ the \ IPAT \ Identity)$,

$\frac{GDP}{P} \ is \ the \ GDP \ per \ capita \ (A \ in \ the \ IPAT \ identity)$,

$E \ is \ the \ energy \ consumed$,

$\frac{E}{GDP} \ and \ \frac{CO_2}{E} \ are \ the \ energy \ and \ carbon \ intensity \ (T \ in \ the \ IPAT \ Identity)$.

This equation is easy to understand, and it is also easy to notice how most of the terms can be eliminated reciprocally to reduce the equation at the equality $CO_2 = CO_2$. Like the IPAT identity, the Kaya equation is not used to find the precise cause of the CO2 emissions growth, but it is useful to represent it, along with parameters representing the humankind growth expressed from a dimensional, an economical and a technological point of view.

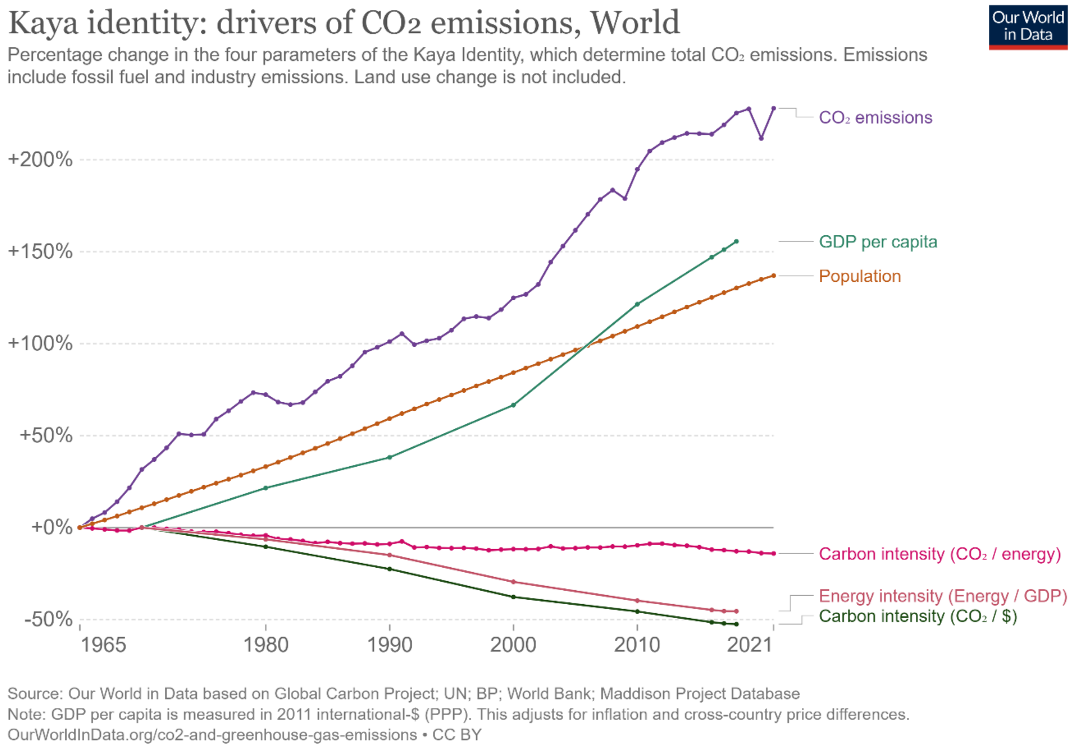

Fig. 1.3: Kaya Identity for global CO2 emissions. (Source: OurWorldinData.org)

1.3. Scale, Composition and Technique effects

A different approach began in 1991, when G. Grossman and A. Krueger published their study entitled “Environmental impacts of a North American Free Trade Agreement”, which was one of the first to analyze the impact of trade liberalization on the environment and introduced some critical concepts that are the base for most of the following literature on this topic.

This part of the chapter covers the concepts of the Scale, Composition and Technique effects, defined the first time by Grossman and Krueger as: *“three separate mechanisms by which a change in trade and foreign investment policy can affect the level of pollution and the rate of depletion of scarce environmental resource”*. More generally, these three effects are the decomposition of the impact generated by a particular event on the environment.

The second fundamental study to cite is “North-south trade and the environment” written by B.R. Copeland and M.S. Taylor in 1994 which recall the concepts introduced by Grossman and Krueger in 1991 but it gives more specifics definitions of the three effects and defines a mathematical model to represents the consequences of trade between a country with strict environmental regulation and a country with poor one.

1.3.1. Scale effect

The scale effect looks only at the size of an economic activity and directly links its quantitative changes with how much that activity is going to pollute:

"The scale effect reflects the increase in pollution created by an increase in the level of economic activity in the relevant jurisdiction, holding constant the techniques of production and the composition of final output." (Copeland, Taylor. 1994)

In general, this concept simply sounds as a warning: an uncontrolled growth of the economy (in terms of production, population, urbanization…), without changing anything else, can only lead to a faster depletion of natural resources and to a non-turning point of the planet health. To reduce this effect the only way is to reverse the goal of general growth that any company or country has always pursued but, of course, this is not a plausible scenario: if it is possible to imagine a modest de-growth for rich and developed countries, it becomes impossible for developing ones. The duty of each country (or company) should be to pursue its economic goals and at the same time to implement changes of different nature able to compensate the negative impact of the Scale effect (the impact of these changes is measured by the Composition and Technique effects explained in the next sub-chapters).

Obviously, this is a general overview from a global perspective but when analyzing a particular event, it is possible to observe the scale effect having a positive impact on that ecological footprint. A very intuitive example is the measure of the human population: while it is constantly growing globally, there are also limited areas like towns, or sometimes even countries, in which it is possible to observe the opposite trend.

1.3.2. Composition effect

"The composition effect measures the change in pollution due to a change in the range of goods produced by a country." (Copeland, Taylor. 1994)

This is the very most concise definition possible of the Composition effect, it does not emphasize a positive or negative scenario but only define the link between a change in what is produced and the following change in pollution. When Grossman and Kruger introduced this concept three years before, they gave it a negative connotation through the example of trade liberalization among countries with different environmental restrictions: they explained at the same time the idea that *"if competitive advantage derives largely from differences in environmental regulation, then the composition effect of trade liberalization will be damaging to the environment. Each country then will tend to specialize more completely in the activities that its government does not regulate strictly."* This hypothesis will be explained better in the following chapters but for the moment it is important to underline that if it is possible to explain the Composition effect with a negative example, it is also possible to do it with a positive one. Like, for example, G. Liobikienė and M. Butkus did in 2018 in their paper entitled "Scale, composition, and technique effects through which the economic growth, foreign direct investment, urbanization, and trade affect greenhouse gas emissions". They chose to cite the positive transition towards less polluting economic activities which happens, normally, during a country development, shifting from primary and secondary sectors towards the service sector.

"The composition effect states that the economic growth causes structural transformation, as national production grows the structure of economy changes towards less polluting economic activities. Moreover, an economy experiences a transition from intensive industrial sectors to service sector" (Liobikienė, Butkus. 2018)

Of course, this transition lowers the emissions for the developed country but globally this effect could be compensated if the production is simply shifted in another country. Again, it is necessary to analyze case by case in details to really understand the impact on the environment of each event.

1.3.3. Technique effect

"The technique effect measures the change in aggregate pollution arising from a switch to less pollution-intensive production techniques, holding constant income and the range of goods produced" (Copeland, Taylor, 1994)

If the Scale effect is considered to represent a general negative effect, the Technique effect could be viewed as the opposite and represent a reduction of emission thanks to the development of better technologies. For example, more efficient technologies able to consume fewer polluting resources or completely different technologies able to exploit cleaner energy sources. The investments necessary for research and development are usually driven by the growing awareness related the environment, which translates in new policy or even public expenses, and at the same time the possibility of cost abatement pursued by companies. This general positive image is only typical of the last few decades, since when the environment awareness became a topic of interest in the social debate. Before that, especially during the industrial revolution and the World Wars, it is natural to imagine the opposite scenario.

Even today there could be negative cases in which a step-back is unavoidable: just think at the energetic crisis triggered by the war between Russia and Ukraine in 2022. In that case the Italian government assessed the possibility to re-open old coal plants to quickly compensate the rapid growth of Russian gas price.

1.3.4. Pollution decomposition at industry level

This sub-chapter and the next one, are based on the work of Cherniwchan, Copeland and Taylor of 2016 entitled "Trade and the Environment: New Methods, Measurements, and Results", which defines the three effects previously explained, mathematically.

Consider an environment with the following parameters:

- N, number of industries
- Z_i, pollution generated by the industry i
- S_i, the scale of production in industry i

It is possible to define the polluting intensity of industry i as:

$$E_i = \frac{Z_i}{S_i}$$

The system's aggregate pollution as:

$$Z = \sum_{i=1}^{N} Z_i \qquad \rightarrow \qquad Z = \sum_{i=1}^{N} S_i \frac{Z_i}{S_i} \qquad \rightarrow \qquad Z = \sum_{i=1}^{N} S_i \, E_i$$

Then, taking logs and differentiating,

$$\frac{dZ}{Z} = \frac{dS}{S} + \sum_{i=1}^{N} \frac{Z_i}{Z} \frac{d\left(\frac{S_i}{S}\right)}{\frac{S_i}{S}} + \sum_{i=1}^{N} \frac{Z_i}{Z} \frac{dE_i}{E_i}$$

Where $S = \sum_{i=1}^{N} S_i$

Defining:

$\Theta_i = \frac{Z_i}{Z}$, the fraction of overall pollution Z coming from industry i.

$\Phi_i = \frac{S_i}{S}$, industry i's share of the economy's final output.

$\hat{Z} = \frac{dZ}{Z}$, $\hat{S} = \frac{dS}{S}$, $\widehat{\Phi_i} = \frac{d(S_i/S)}{S_i/S}$, $\widehat{E_i} = \frac{dE_i}{E_i}$

The final, reduced, formula can be written as:

$$\boldsymbol{\hat{Z} = \hat{S} + \sum_{i=1}^{N} \Theta_i \widehat{\Phi_i} + \sum_{i=1}^{N} \Theta_i \widehat{E_i}}$$

This formula represents the decomposition of pollution changes explained until now, indeed the three terms of the right side are, respectively, the Scale, Composition and Technique effect.

It is important to underline that this is an industry-level decomposition, and it does not show any changes inside an industry nor inside a single firm. This level of detail is well-known in the literature and at the base of several studies and analysis performed in the last 30 years, but it often turned out to be not enough detailed to describe the relationship between economy and pollution. This is the reason why it is necessary to talk about a deeper decomposition.

1.3.5. Further decompositions

"While the industry-level decomposition has been influential in shaping our understanding of what drives changes in aggregate pollution emission levels, it tells us little about the microlevel adjustments generating change at the industry level." (Cherniwchan et al, 2016)

Starting from this statement, the work of Cherniwchan, Copeland and Taylor continue developing calculations and equations to show new decompositions. For simplicity in this sub-chapter the key concepts are extracted, omitting the whole mathematic path at the base.

To begin, it is possible to look inside the pollution intensity of an industry i, previously called as E_i. A change of this parameter reflects three possible variations inside the industry itself:

- A change of the pollution intensity of one or more firms composing the industry, this parameter can be defined as "e_j" (instead of "E_i") for each firm j.
- A composition effect inside the industry, for example if the market share of a high pollution intensity rises.
- The impact of entry and exit, so how a firm impacts the average pollution intensity joining or leaving the industry.

This decomposition could be not enough, so it is possible to look inside the pollution intensity of a single firm (e_j) too. A change of this parameter depends on four different aspects:

- Again, the pollution intensity can be observed at a deeper detail, in this case at the level of each task in each plant. "*This term is the firm's true technique effect*".
- A Composition effect between the different tasks performed, it is also called *"reorganization effect"*.
- The third aspect concern about changes about the outsourced part of production to other domestic firms and/or to foreign producers also called, respectively, *"domestic outsourcing effect"* and *"offshoring effect"*.
- Finally, a change in the firm's markup.

These two analyses directly lead to the Technique effect decomposition, which (as previously said) can be expressed as:

$$Technique\ effect = \sum_{i=1}^{N} \Theta_i \widehat{E_i}$$

Hence, this single summation can be divided in several terms, for each industry:

1) Effect of changes in firm market shares
2) Effect of entry and exit, in and out from the industry
3) Reorganization effect inside a firm
4) Domestic outsourcing effect
5) Offshoring effect
6) True technique effect
7) Effect of changes in firm-level markups

As stated in the paper: *"If we do not account for these channels, then we may misidentify the way that abatement and emission intensities adjust to policy changes and other shocks."* (Cherniwchan et al, 2016). This the first limit of a lot of analysis performed in the last decades, able to show strong correlation between the evolution of pollution and the Technique effect but not able to identify the precise causes.

2. Environment quality and economic development

This chapter's goal is to introduce the complex relationship between two main entities: environment and economy. This link is represented by the Environmental Kuznets Curve theory which represents a fundamental milestone to eviscerate the topic.

2.1. Kuznets Curve

In 1955 Simon Kuznets published the paper "Economic growth and income inequality", one of the first studies (if not the first) trying to analyze the evolution of income inequality among a population, along the economic development of its country. The data available at the time were scarce and he could only use a sample of three countries (USA, England and Germany) so Kuznets itself was cautious in drawing conclusions. Despite this, he noted an improvement in income equality sufficient to formulate a hypothesis: the suggested idea is that, following the economic growth of a country, after a period of increasing inequality there should be a turning point in which the inequality starts to decrease. This trend can be plotted with a Cartesian graph in which the x-axis represents the per capita income while the y-axis the economic inequality. The drawn curve, with its characteristic inverted U shape, is the Kuznets curve.

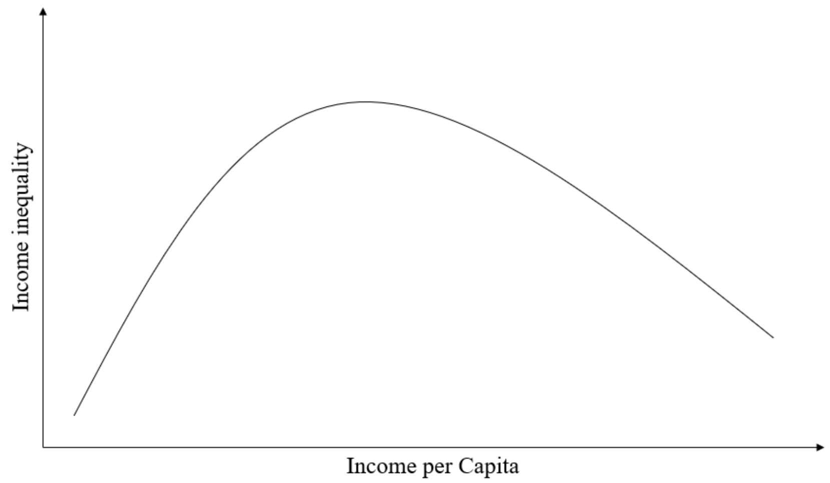

Fig. 2.1: Kuznets Curve

"The paper is perhaps 5 per cent empirical information and 95 per cent speculation, some of it possibly tainted by wishful thinking" (Kuznets. 1955)

With more data available in the following years the theory was quickly abandoned, but the underlying idea survived. It is possible that along a country economic development some aspects, probably considered secondary, worsen during the first phases and at a certain turning-point start to improve.

2.2. Environmental Kuznets Curve

The Environmental Kuznets Curve (or simply EKC) is not related to Simon Kuznets, but it could be quickly defined as a variant of his theory where "income inequality" is substituted with "environmental degradation".

2.2.1. The Theory

At the base of the theory there is the idea that attention towards the environment changes along a country's development through three phases:

1) Initially the level of pollution increases very quickly, there is no consideration for the environment because there are other priorities to fulfill before.
2) In the middle phase the environmental care starts to grow and at the same time the increment of pollution begins to slow down.
3) Finally, the relationship reaches a turning point, and the country can continue its growth while at the same time decreases its environmental impact.

This behaviour can be represented as an inverted-U shaped curve as for the Kuznets one, it maintains the optimistic view but this time the theory obtained great support by the community and after thirty years it is still topic of debate.

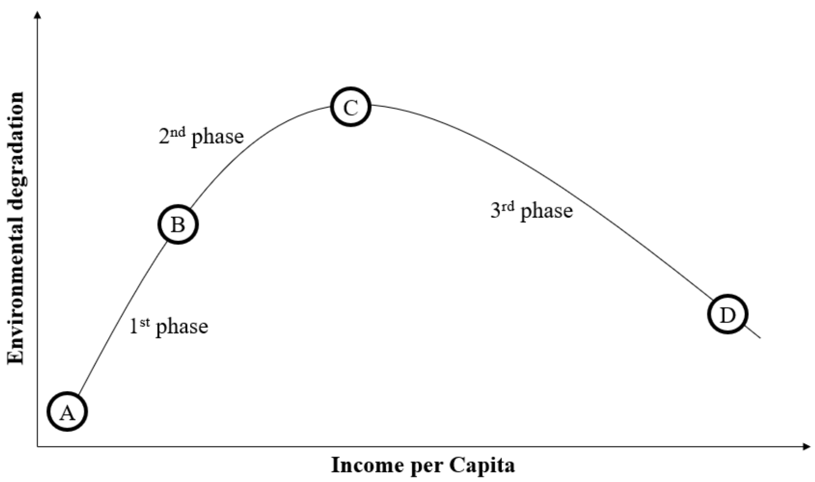

Fig. 2.2: Environmental Kuznets Curve

The idea was introduced, again, by Grossman and Kruger in 1991, they didn't formulate the precise theory but started to notice a certain behaviour: *"we find that ambient levels of both Sulphur dioxide and dark matter suspended in the air increase with per capita GDP at low levels of national income but decrease with per capita GDP at higher levels of income".* In their paper first graphs representing the EKC are plotted, figure 2.3 represents the relationship between SO_2 and GDP per capita (expressed in 1985 US Dollars):

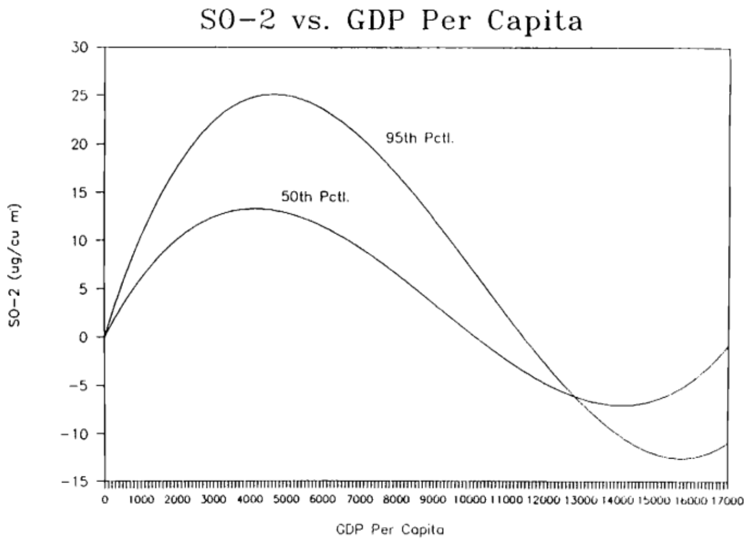

Fig. 2.3: EKC for SO2 – GDP per capita. (Source: Grossman and Krueger, 1991)

As it is possible to notice, they estimated a turning-point around 5000$ of GDP per capita, this value is not important alone, but it represent the starting point of the research and become more interesting once compared with the following studies.

According to Stern (2015), the concept was made popular by the World Bank's 1992 World Development stating: *"as the incomes rise, the demand for improvements in environmental quality will increase, as will the resources available for investment"* but it is in 1994 that this relationship obtained its name thanks to Selden and Song with their study "Environmental Quality and Development: is there a Kuznets Curve for Air Pollution Emissions?". They took in consideration data about some gases such as SO_2 (Sulphur Dioxide), like Grossman and Kruger, which is a gas usually generated by the combustion of coal/petroleum and can be the cause of acid rains. They tried a slightly different approach: their goal was to make forecasts about the evolution of the emission levels through the decades using estimates of economic growth at global level. Figure 2.4, extracted from their paper, represents four different forecasts based on different models and possible scenarios.

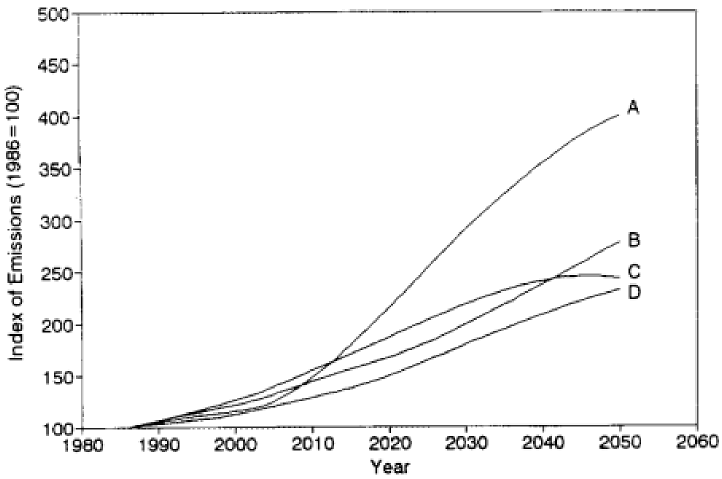

Fig. 2.4: EKC for SO2 – time (Source: Selden and Song, 1994)

The paper is closed in support of the theory but it underlines that, according to their models, the world is expected to reach the turning point not before year 2040 (or even later). This means that humanity should expect levels of SO_2 emissions to increase for numerous decades before reaching the peak and it is difficult to imagine when those emissions could go back at the 1994 level. Gangadharan and Valenzuela in 2001 compared the environment to a luxury good to explain the EKC and the idea that even if initially a population does not care about the environment, once citizens reach a certain threshold of income they start to demand for environmental policy. At the same time, they wanted to underline that *"this argument has been used to justify the pursuit of growth strategies that do not give due consideration to their effect on the environment"*.

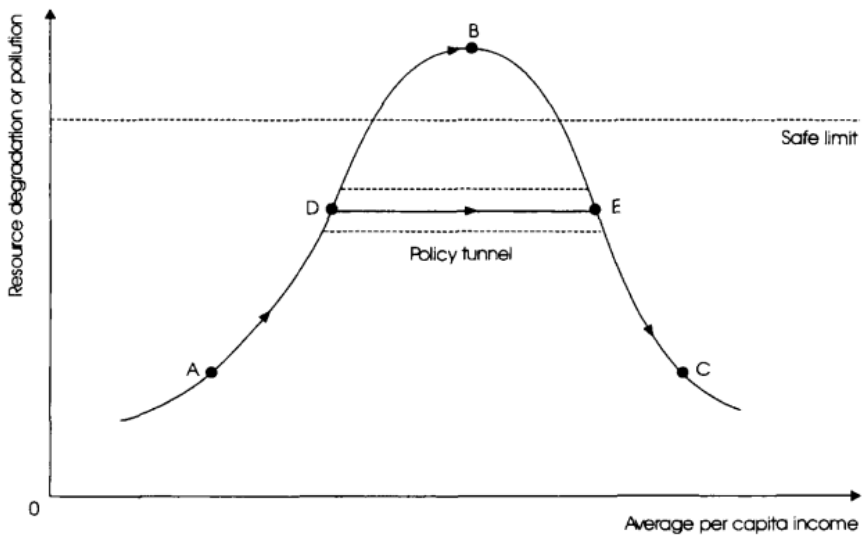

Fig. 2.5: EKC policy tunnel (Source: Munasinghe, 1995)

It is important to understand that even if this behaviour was confirmed, the time horizon could be too far for the planet health, this is the reason why Munasinghe in his paper “Making economic growth more sustainable” (1995) does not share the optimistic view. He suggests to not wait for the “natural” turning point but to take measure in order to maintain pollution under a safe limit: *“lower income countries could learn from the experience of wealthier nations and adopt policies that permitted them to "tunnel" through the curve”* (figure 2.5).

Numerous papers followed in the next years: Miah et al. (2010) recall other nine studies supporting the EKC theory for SO_2 (or similar pollutants) emissions published before 2002 (even if estimated turning points were different). As explained in chapter one, there is a large amount of possible environmental indicators and, obviously, SO_2 emissions level is only one of them. In addition, the chosen environmental indicators set chosen is just the first variable which could differ from each research, other examples are countries or period covered. The great variability is caused first by the lack of details of the theory, which try to describe the relationship between two very generic entities: “environment” and “economy”, in second place it depends on data available to the researchers. To understand the interest of the community toward the Environmental Kuznets Curve, the bibliometric review performed by Anwar et al. in 2021 is really useful: thanks to figure 2.6 it is possible to easily understand the growing popularity of the theory until 2020.

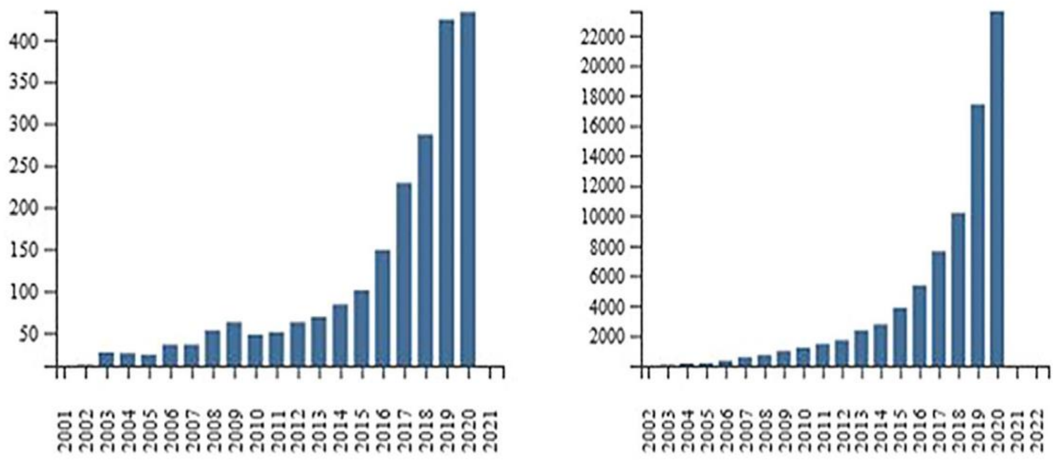

Fig. 2.6: Number of EKC Publications (left) and Citations (right) per year. (Source: Anwar et al., 2021)

As we can see, the number of publications (on the left) and citations (on the right) about the EKC theory has followed an exponential growth reaching more than four-hundred publications in 2019.

2.2.2. EKC through Scale, Composition and Technique effects

In chapter one concepts of Scale, Composition and Technique effects have been introduced, they refer to the relationship between changes in the economy structure and environmental degradation. Just recall that the first one takes in consideration changes about the volume of the economy, the second one looks at the composition of the economy in terms of sectors and industries while the third one is focused on the technology used. Thanks to these effects is possible to have a deeper view of the Environmental Kuznets Curve phases:

1) We can think about a country in the early stages of its development, mainly based on rural economy with a very little impact on the environment. The first sign of growth is represented by the population growth which directly increases the amount of resource needed to survive. Even if the economy doesn't change its composition or the technology used, the dominant Scale effect will start the rise of environmental degradation. In addition, we can expect a population not to rely on farming activities only but to develop a secondary sector introducing technologies without caring about their environmental impact. A simple example could be coal extraction and burning and this means that Composition and Technique effects will contribute to increasing polluting emissions too, this is the first phase of the curve.
2) In the second phase the negative Scale effect is still present, if not in form of population growth it can be represented by the increased per capita income and the new needs which can be fulfilled now. The difference is mainly caused by the switch of impact caused by the other two effects: for example, represented by the development of the tertiary sector and the shift toward cleaner technologies (maybe due to the born of environmental policy). Composition and techniques effects start balancing the Scale one, slowing down the increasing pollution and leading toward the turning-point.
3) Once the negative changes are balanced by the positive ones the curve reaches its peak and for the first-time environmental quality increases, the curve changes its slope and starts drawing the final-part of the inverted-U shape, typical of the theory. The Scale effect is still present because the average income is still growing but at this moment the Technique effect prevails.

2.2.3. EKC basic model

EKC research is usually based on panel data: datasets composed by observations collected for *i* different entities and *t* different time periods. The observations are measures of pollution indicators, while the different entities are often different countries (but the literature contains also studies focused on a single country and its sub-regions). The timeframe is usually in the range between one and two decades, with a measurement frequency which can vary to one per day to one per month.

The theory itself does not include a precise model to define the curve, it is up to each study to propose and test one. Stern (2004, 2015) and Shahbaz, Sinha (2018), generalized the basic common characteristics found in their literature reviews and proposed very similar quadratic/cubic fixed effects models as the basic EKC model. Starting from a multiple regression model based on the unique variable per-capita income, the choice of a fixed effect model is based on the need for controlling omitted variables. In particular, it is necessary to introduce parameters to control factors that may vary across countries and over time, respectively called country effect and time effect.

Hence, an example of a basic Environmental Kuznets Curve model could be:

$$\boldsymbol{Z_{it} = \alpha_i + \gamma_t + \beta_1 Y_{it} + \beta_2 Y_{it}^2 + \beta_3 Y_{it}^3 + \varepsilon_{it}}$$

Where:

- i indexes the country,
- t indexes the time,
- Z represents pollution,
- Y represents the economic growth,
- $\beta 1, \beta 2, \beta 3$ are the coefficients,
- α represents the country fixed effect,
- γ represents the time fixed effect,
- ε is the error term.

Being a variant of the multiple regression model, the most common method used to estimate the coefficients is the Ordinary Least Squares (OLS). This method works looking at the sum of squared differences between the predicted values and the observed values, the coefficients estimated by the method define the curve where the sum of those squared residuals is minimized.

In general, given a set of *n* input points $(x_j\ ,\ y_j)\ with\ j = 1, 2, \dots, n$

The OLS method finds the parameters defining the curve *f(x)* able to minimize S:

$$S = \sum_{j=1}^{n} (y_j\ - f(x_j))^2$$

The sign of the coefficients found define the curve's shape, considering three possibilities for each parameter (positive, negative, or equal to zero) the basic model of the EKC can show seven different types of curves:

Case	Coefficients	Curve shape
a	β1 = β2 = β3 = 0	Constant
b	β1 > 0, β2 = β3 = 0	Linearly increasing
c	β1 < 0, β2 = β3 = 0	Linearly decreasing
d	**β1 > 0, β2 < 0, β3 = 0**	**Inverted U-shaped**
e	β1 < 0, β2 > 0, β3 = 0	U-shaped
f	**β1 > 0, β2 < 0, β3 > 0**	**N-shaped**
g	β1 > 0, β2 < 0, β3 > 0	Inverted N-shaped

According to the theory, the expected scenario should be the *d* one, where the first-grade coefficient has positive sign, the quadratic coefficient is negative, and the cubic coefficient is equal to zero. In this case the model could be reduced to a second-grade polynomial:

$$Z_{it} = \alpha_i + \gamma_t + \beta_1 Y_{it} + \beta_2 Y_{it}^2 + \varepsilon_{it}$$

And the level of income at the pollution peak (the turning point) can be calculated as:

$$Y^* = -\beta_1 / (2 * \beta_2)$$

According to Stern (2004), *"regressions that allow levels of indicators to become zero or negative are inappropriate except in the case of deforestation where afforestation can occur. A logarithmic dependent variable will impose this restriction"*. Hence, he prefers to express the model like:

$$\ln(Z_{it}) = \alpha_i + \gamma_t + \beta_1 \ln(Y_{it}) + \beta_2 \ln(Y_{it})^2 + \varepsilon_{it}$$

And calculate the peak as:

$$Y^* = \exp(-\beta_1 / (2 * \beta_2))$$

If the scenario described by theory does not require the β3 coefficient, why is it present in the basic model proposed? Recalling figure 2.3, it is possible to notice that in the graph proposed by Grossman and Krueger in 1991 the curve has not a perfect inverted-U shape. Moving towards high level of per-capita GDP (and at the same time low level of pollution), the curve reach another turning point and start to grow again. This behaviour transforms the shape of the curve from an inverted-U to something similar the letter N. The so-called N-shaped curve does not contradict the original theory, which foresee an upward trajectory, a turning point and finally a downward trajectory, but it could be considered as an addition.

This case is described by scenario *f*, that adds a positive sign to the cubic coefficients compared to the previous described case. In this scenario it is possible to calculate the turning points as:

$$Y_1^* = \left(-\beta_2 - \sqrt{\beta_2^2 - 3\beta_1\beta_3}\right) / 3\beta_3 \qquad Y_2^* = \left(-\beta_2 + \sqrt{\beta_2^2 - 3\beta_1\beta_3}\right) / 3\beta_3$$

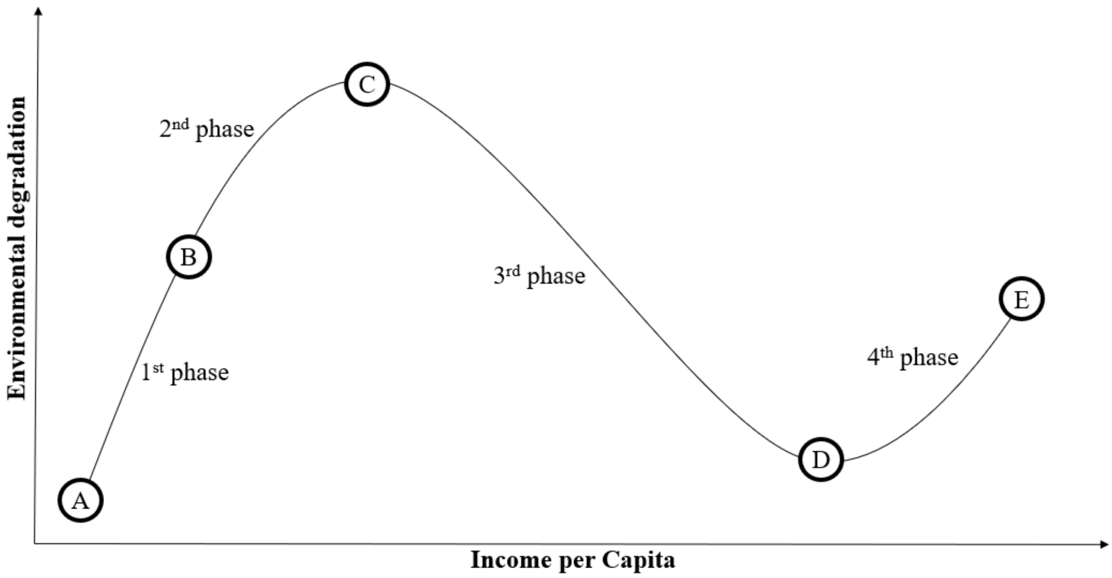

Fig. 2.7: N-shaped Environmental Kuznets Curve

Of course, the model proposed in this paragraph represents a simple possible version even if valid. Numerous lacks could be pointed out about this model but also about the theory itself, next paragraphs will try to cover all the Environmental Kuznets Curve flaws.

2.3. Main critiques to EKC

Even though the theory became so popular, its validity is still far from being proved. During the last three decades, researchers have been sceptical about the existence of the curve and have moved numerous critiques towards the theory. Copeland and Taylor in 2004 wrote: *"What is perhaps most striking about the EKC literature is the limited role that theory has played in its development. This has created difficulties in interpretation since the basic finding is consistent with many possible explanations."*. After almost twenty years these statements seem to be still valid.

2.3.1. Theoretical critiques

To begin, it is important to focus on the theory formulation. As previously written, the theory is not rich on details, it is vague and based on numerous assumptions, even if not explicit.

First, as explained by Stern in 2004, the theory does not take in consideration the possibility for the environmental damage to *"reduce economic activity sufficiently to stop the growth process"*. This means that, according to theory, there is no limit for the curve peak height and no level of pollution will have impacts on the economy growth. This assumption is difficult to be valid in every case, but it is plausible to think that a country will reverse its pollution trend before slowing down its economic growth, being, the latter, the primary and only goal.

Second, paragraph 1.1 tried to introduce the complexity of evaluating "environmental impact", a similar discussion can be opened about the way to measure a country's growth. The most common indicator used is Gross Domestic Product (GDP), it takes in consideration goods and services produced within a country's border. As an alternative it is usually used Gross National Product (GNP), which, instead, considers value produced by a country's citizens and businesses, regardless of the location. Both indicators focus on economic output, while another useful instrument is the Gross National Income (GNI) to measure the income earned by citizens and companies instead. Usually, it is their per-capita value the relevant measure, simply calculated dividing the total value by the population, in order to have a measure comparable among different countries. At the same time, using an average value could not be representative of the real condition of the population's majority: *"income is not however, normally distributed but very skewed, with much larger numbers of people below mean income per capita than above it. Therefore, it is median rather than mean income that is the relevant variable"* (another critique expressed by Stern in 2004 in his paper "The Rise and Fall of the Environmental Kuznets Curve"). In addition, all these indicators focus only on economic aspects, this is the reason why an indicator like the Human Development Index (HDI) could be a more complete choice: it takes in consideration Gross National Income but also life expectancy and education level.

Third, even when a curve with an inverted-U shape is observed, it is difficult to define the precise cause. The basic explanation given by EKC theory is the so-called "Income Effect" where environmental quality is considered a normal good, hence, its demand increases with income. Being environmental quality determined by different factors, *"this explanation suggests that the relationship between pollution and income should vary across pollutants according to their perceived damage"* (Copeland, Taylor. 2004). In every case it is necessary to assert if this is the real explanation or maybe one of a set, other actors could play an important role in drawing such a curve. In particular, it is important to take in consideration two factors: environmental policy and economic openness degree, the first can be really different from a country to another, while the second could lead to misidentify the responsible for pollution. This is a direct recall to the difference between GDP and GNP, because it's true that environmental policy applies inside a county's border for both domestic and foreign companies, but to assign responsibilities to each country correctly, domestic companies located abroad must be calculated too. This topic will be discussed in detail in chapter three, for the moment it is important to underline that according to the classic explanation a country becomes cleaner because companies become cleaner (predominant technique effect) but, introducing the possibility for dirty companies to simply move to another country, draws a completely different scenario where the composition effect could be the predominant one.

2.3.2. Lack of evidence

In support of theory, encouraging results regarding sulphur dioxide have already been cited but they are not sufficient to prove the EKC relationship. Unfortunately, numerous studies have been performed using different pollution measurements and the results are quite different.

For some pollutants partial support is found from the literature, for example it is the case of the N_xO_x family. Nitrous Oxide (N_2O), which is considered the third responsible for global warming, is part of this group. According to Miah et al. (2010) *"it is notable that only the observations in OECD countries yielded results which produced an inverted U-shaped EKC. Data for a panel of 156 countries produced an upward straight line, with a major number of them being developing countries."* This suggests that the actual developed countries' path in terms of environmental impact could be not followed by developing nations.

A section in chapter 1 is dedicated to global warming, the topic is well-known since the second half of twentieth century but at the same time remains unsolved. It seems to be the number one challenge faced by humankind and the main responsible is known to be the level of CO_2 in the atmosphere. Looking at the literature focused on studying the relationship between CO2 emissions and economic growth the results are not optimistic: in 2010 Miah et al. wrote: *"it may easily be observed that the general EKC for CO_2 is a monotonous* *straight line in almost all cases. This indicates that economic growth will not maintain the environment in regard to CO_2".* In 2017 Shabaz and Sinha performed a deep review focused only on carbon dioxide and the conclusions are less defined, which is a better scenario compared to the drastic one cited previously: *"a broad conclusion from the reviewed studies is that there is no consensus regarding the existence or shape of EKC, i.e. for any geographical context, researchers can come up with different and opposing set of results".* Again, the theory seems to be limited.

The different results underline the difficulties in measuring environmental pollution, showing that a single indicator cannot be taken as representative, but it is necessary to consider a complete mix of values. To report an example, Stern in 2004 already pointed out that: *"the mix of residuals has shifted from sulfur and nitrogen oxides to carbon dioxide and solid waste so that aggregate waste is still high and per capita waste may not have declined."*

2.3.3. Econometric critiques

Researchers' community does not agree on the right model to be applied to the EKC relationship, according to Miah et al. 2010, models proposed in the literature are, in general, of two typologies: they could be part of the Fixed Effect family (like the one proposed in paragraph 2.2.3) *"where all other variables remain constant and only the changes in emission are measured with the changing income per capita"* or be Random Effect models *"where other additional variables are calculated as a changing factor".* The direct consequence is a set of different attempts resulting in different conclusion. Results from different papers are not easy to be compared even for papers with the same, or similar, goal because "*the same geographic region can produce opposing arguments on the existence and shape of the EKC, resulting from the data set, the selection of variables, and the choice of methodology.*" *(Anwar et al., 2021).* If no proposed model seems to be shared by the community and to produce convincing results, probably, the reason is the presence of some econometric bias. It is not possible to generalize, and each case should be discussed in detail but there are three main defects diffused among the literature.

An important obstacle to face is the omitted variable bias, the theory defines the economic growth as the only independent variable, but a country is a lot more than its GDP. This is the reason why numerous other parameters of social, political and/or technical nature could be added in the model. Some examples are education level, political freedom, corruption index, trade openness and fossil fuel or renewable energy consumption. This is only a possible list, other variables could play an important role and a model without the right set of variables could generate results where responsibilities are mis-allocated. It is necessary to be careful when evaluating the quality of a certain model and continue the research to define the right indicators. This topic is well-known in the literature, *"many studies extend the basic EKC model by introducing additional explanatory variable intended to model underlying or proximate factors such as political freedom, output structure or trade"* (Stern. 2015) but it is still an open problem.

Different is the situation described by Müller-Fürstenberger and Wagner in 2007, according to their paper "Exploring the environmental Kuznets hypothesis: Theoretical and econometric problems" there are two main aspects not correctly considered by previous studies. *"First, the literature up to now ignores the econometric implications of the fact that Kuznets curve regressions involve nonlinear transformation of integrated regressors (GDP or the logarithm of GDP)"*. Their critical position tries to underline the necessity to not assume linearity as starting point and to approach the problem through the econometric knowledge required in case of nonlinear transformation.

Second, they critique methods used for panel data, suggesting that, in a large part of the literature, these methodologies are chosen based on the wrong assumption of cross–sectionally independent panels. According to their paper, *"hardly any panel of economic data satisfies the cross–sectional independence assumption. This assumption, which requires GDP and emissions series to be independent across countries, is of course highly restrictive and unlikely to hold"*.

2.4. EKC conclusion

More than three decades have passed since the introduction of the Environmental Kuznets Curve concept. Based on the previous idea of Simon Kuznets to link economic inequality and economic growth, the EKC theory tries to define the relationship between pollution and economic growth as an inverted U-shaped curve. This behavior is characterized by a turning point after which economy can continue its development lowering its negative environmental impact. The theory has collected support in the scientific community since the beginning and its popularity never stopped to grow during its life.

At the same time, critiques toward the theory have been moved almost since its born and in 2024 the theory in its original form has not collected sufficient results to be proved. The general idea shared among the researchers' community is that it must be enriched because *"the focus on reduced forms linking only per capita income to pollution is unlikely to be fruitful."* (Copeland, Taylor. 2004)

A particular aspect of the theory is its increasing popularity despite its inconclusiveness, there are few reasons to explain this coexistence. First of all, *"the literature expanded rapidly because of the ease of estimation and the potential relevance of its findings."* (Copeland, Taylor. 2004). A bit of context is needed, for centuries economic growth has been pursued without caring about environment, the topic became relevant only in the second half of twentieth century when scientific research proved the damaged caused by economic activity to the environment and the negative consequences that reflect on human life. The introduction of environmental policy became necessary and, at first sight, economic growth and environmental care didn't seem to be compatible. The Environmental Kuznets Curve would have been the perfect answer: continue to pursue economic growth as always and lower pollution slowly without impacting on the economical path.

Although this optimistic view was quickly criticized, the EKC theory is responsible for two main contributions. To begin, it gave birth to a completely new branch of literature debunking *"the commonly held view that environmental quality must necessarily decrease with economic growth"* (Copeland, Taylor. 2004) and bringing pollution data inside the economic analysis. This literature raised a series of questions with the intent to understand relationships between environmental impact and all the aspect of economy, the next chapter is dedicated, in particular, to the effect of trade openness. In second place, *"it provided highly suggestive evidence of a strong policy response to pollution at higher income levels."* (Copeland, Taylor. 2004)

3. Environment, Trade and Competitiveness

This chapter's goal is to analyze the complex linkages between trade openness, competitiveness and environmental policy. The relationship between the first two entities is studied and theorized since the 18th Century hence, in comparison, the introduction of environmental policy is a very young concept and even younger is the literature studying the impact of this addition on the previous equilibrium.

3.1. Trade and comparative advantage

To begin it is useful to analyze the relationship between trade and comparative advantage to define a context and only later add the environmental policy to this scenario.

The starting point is represented by the Heckscher-Ohlin model developed by Eli Heckscher and Bertil Ohlin in the early 20th century. Also called H-O model, in its original form it describes an abstract scenario where:

- only two factors of production are taken in consideration: labor and capital;
- only two commodities can be produced, one requires a labor-intensive industry while the other a capital-intensive one;
- only two countries are part of the market, which differ only in their availability of the two factors of production, one country is labor-abundant while the other is richer in capital.

In this "two countries – two goods – two factors" framework the H-O theorem states that each country exports the commodity produced with its relative abundant factor and imports the other. It is important to notice that this particular difference between the imaginary countries is usually observed between developed and developing countries, where the first category is more capital-abundant compared to the more labor-abundant second group. Of course, the theorem is valid only in the far-from-reality world describe above but (as written by Deardorff in 1982) it *"has been the mainstay of trade theory for half a century"*. The reason of its popularity is the general idea at the base of the model: a country exports or imports certain goods based on its factors' availability, represented by labor or capital abundancy in the simplest scenario. The limits of the first simplified scenario were clear since the beginning, for example Jones in 1956 pointed some of them: the market in the model is considered to be purely competitive, there are no transfer cost, no differences in technology used, the two factors differ in quantity but not in quality and the commodities are produced under constant return to scale. In addition, neither government interventions are taken in consideration, nor firms' heterogeneity inside each industry.

During decades following the definition of the traditional version, the model has been extended to include new factors/goods and remove assumptions, in order to describe a world closer to the real one. Initially, it is important to cite Samuelson and Vanek's work on this process, which gave birth to the Heckscher-Ohlin-Samuelson (H-O-S), before, and the Heckscher-Ohlin-Vanek (H-O-V) models, later. The latter was still *"unable to explain trade between two countries within the same industry"* (Cole, Elliot. 2003) and in the second half of the 20th century new branch of research became popular, in 1995 Markusen and Venables wrote: *"The industrial-organization approach to trade (the "new trade theory") and the literature on "geography and trade" have enriched our understanding of the causes and consequences of trade by adding elements of increasing returns to scale, imperfect competition and product differentiation to the more traditional comparative-advantage models of international trade"*. Despite the progress, models proposed at that point were still based on the theoretical assumption of industries composed by national firms producing just one product in one location. With the increasing development of multinational firms another step forward were required to extend those models in order to take in consideration also concepts like foreign direct investments (FDIs) and delocalization in trade theory. Concepts strongly connected with the impact on trade caused by the introduction of environmental policies in the framework.

3.2. Green policy as damage for competitiveness

Initially, this section will assume the introduction of environmental policy to have a full negative effect on involved firms' competitiveness. The main theory linking this assumption to trade is the Pollution Haven Hypothesis (PHH), instead in section 3.3. the assumption will be relaxed, and other theories will be discussed.

3.2.1. The Pollution Haven Hypothesis

Following an approach close to the H-O one, it is possible to imagine a scenario composed by two countries which, this time, differ only for the stringency of their environmental policy. This difference, again, is something usually observed between developed and developing countries. If there are no trade barriers between them, the expected conclusion is similar to the Heckscher-Ohlin theorem: the country with the weaker environmental policy will specialize in polluting industries and will export goods produced by those industries, while the opposite behavior is expected for the other country. In this model the combination of trade openness and the introduction of stringent environmental policy leads the developed country to became cleaner because its direct environmental impact decreases. At the same time, if this positive composition effect is simply compensated by a negative one in the developing country, globally, there will be no improvement in term of emissions. This theory is called Pollution Haven Hypothesis (to recall the concept of tax haven) because of the role played by the country with weaker environmental policy.

This hypothesis raises doubts about the effectiveness of environmental policy which could damage some industries without imposing any real technical improvements. The PHH brings into question also the positive results supporting the EKC: is it possible that the real cause of an observed inverted-U curve is simply the changed location of firms causing that environmental impact? If this was true, once the developing countries become wealthy, they will not observe the same result applying the same environmental policy because *"in our finite world the poor countries of today would be unable to find further countries from which to import resource-intensive products"* (Stern, 2004). PHH has two main requirements: differences in environmental policy and open trade, hence, it can be applied to two different scenarios. The first one is the introduction of stronger environmental policy when two countries have no trade barriers between them. The second one, leads to the same results but through the opposite path: trade barriers' removal between two countries with different environmental policy level. In this case the PHH can be formulated as written by Copeland and Taylor in 2004: *"when trade is opened, North will export the clean good (Y) and import the dirty good (X). The polluting industry will contract in the North and expand in the South. The low-income country becomes a pollution haven"*, where "North" and "South" are the two imaginary countries in the model.

Again, the too simplified model cannot be representative of the real world where, as stated before, international trade is affected by a multitude of factors. At the same time, it is important to recall the conclusion of the first chapter of this thesis: it is not easy to understand the real causes of an environmental impact change looking only for an industry-level analysis. That conclusion was based on the already cited work performed by Cherniwchan, Copeland and Taylor, in the same paper they proposed a slightly different theory called Pollution Offshoring Hypothesis (POH) where domestic firms could appear cleaner just shifting their most polluting activities abroad. *"It is reminiscent of the PHH, but in that hypothesis the focus is typically on dirty final good producers moving production or plants to countries with weak environmental policy. The POH is more subtle in that it leads to fragmentation of production in countries with stringent environmental policy."* (Cherniwchan et al. 2016).

The hypothesis can be unbundled and represented as shown by Taylor in 2005 (Figure 3.1)

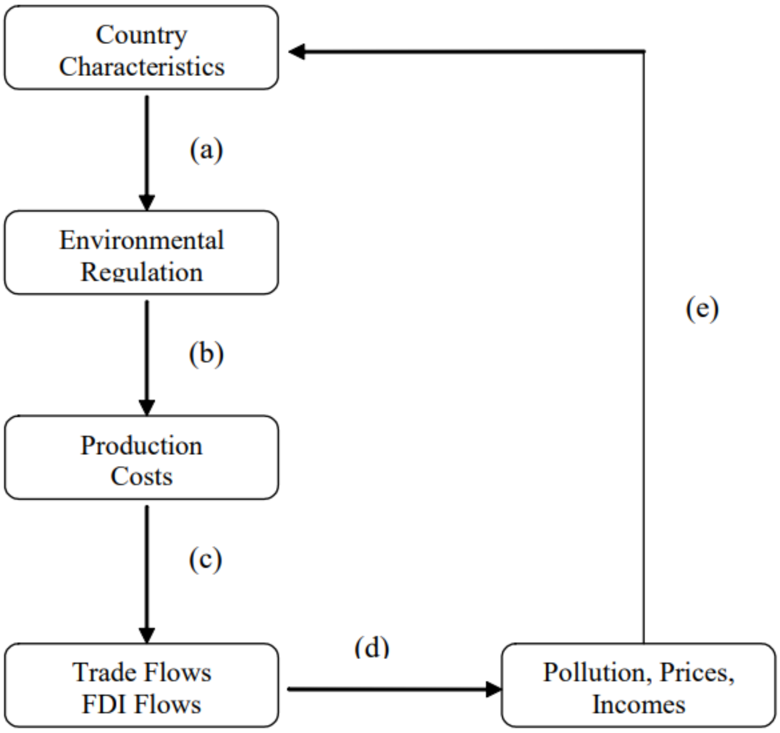

Fig. 3.1: Unbundled PHH *(Source: Taylor, 2005)*

This decomposition helps to look inside the PHH to study each step of its events' chain and it is also useful to understand its cyclical nature. Five steps are defined (from "a" to "e"): initially a certain country introduces environmental regulation based on its own characteristics, this change affects production costs which impact on trade and FDI flows hence, also incomes and pollution are expected to change. Finally, the ring is closed because all these changes modify the initial country's characteristics, but at the same time the other involved countries observe changes in their structure, and this could cause the opening of new cycles too. The PHH assumes that step "b" is negative for competitiveness: new environmental regulation raises the production costs, but relaxing this assumption (and studying different hypothesis) the structure proposed by Taylor remains useful and could be used to draw different conclusions.

3.2.2. PHH and EKC: two case studies

The second chapter showed the simplest model to study the Environmental Kuznets Curve but, at the same time, it tried to explain the EKC theory flaws and the limits of using the basic model. Now, after the PHH introduction, it is possible to move a step forward looking in details at two specific papers and their models.

The first one is a popular study conducted by M. A. Cole: "Trade, the pollution haven hypothesis and the environmental Kuznets curve: examining the linkages". Published in 2004, it represents one of the most popular papers in the literature focused on the relationship between the two theories. Starting from the idea that even if the PHH was plausible evidence in support were not conclusive, he defined the following model:

$$\begin{aligned} ln\, E_{it} = {} & F_i + K_t \\ & + \gamma + \delta\, ln\, Y_{it} + \phi(ln\, Y_{it})^2 + \psi(ln\, Y_{it})^3 \\ & + \sigma\, ln\, M_{it} + \lambda\, ln\, DX_{it} + \theta\, ln\, DM_{it} + \eta \ln T_{it} \\ & + \varepsilon_{it} \end{aligned}$$

(Cole, 2004)

Where:

- *i* indexes the country and *t* indexes the year,
- *E* is the pollutant emissions,
- *F* represents the country fixed effects while *K* the time one,
- *Y* refers to per capita income,
- *M* is the percentage of manufacturing in Gross National Product,
- *DX* is the share of dirty exports to non-OECD countries in total exports,
- *DM* is the share of dirty imports from non-OECD countries in total imports,
- *T* represents the trade intensity (the ratio of the sum of imports and exports to GNP)
- *ε* controls for the error.

The equation was estimated both for a group of pollutants (CO2, NOx, CO and SO2 included) and for a sample of OECD countries. This analysis produced some interesting results: it showed a strong relationship between each pollutant and per capita income, *"DM"* and *"DX"* partially explained emissions and *"M"* showed a positive, statistically relevant relationship with pollution. *"Finally, having controlled for structural change, income and possible pollution haven effects, trade openness still exhibits a negative, statistically significant relationship with pollution"* (Cole, 2004), and he suggests that the causes could be found in greater efficiency in resource consumption (due to increased competitiveness) and/or greater access to cleaner technologies. The results were not conclusive, nor EKC or PHH could be definitely proved, but it showed how each variable plays a role in the scenario and proved the importance to include them in the model.

The second paper proposed is different from the first one: it is a more recent study published by S. A. Solarin and other three authors in 2017, entitled "Investigating the pollution haven hypothesis in Ghana: An empirical investigation". Instead of testing the theory from a general point view it focuses on a single developing country: Ghana. There are three main reasons at the base of this precise choice: firstly, foreign direct investments in this country increased over the years. At the same time, level of CO2 emissions followed the same trend too and finally, country's policymakers are going towards the introduction of CO2 reduction measures to pursue a more sustainable development. Cheap labor and natural resources are typical attractive factors of FDI in developing countries, to understand if less stringent environmental policies can be added to the list in Ghana, the authors developed the following equations to be estimated:

$$\ln TEM_t = \xi_0 \ln FDI_t + \xi_1 \ln GDP_t + \xi_2 \ln ENE_t + \xi_3 Z_t + \xi_4 + \xi_5 T + \xi_6 B + v_t$$

(Solarin et al., 2017)

$$\ln PEM_t = \delta_0 \ln FDI_t + \delta_1 \ln GDP_t + \delta_2 \ln ENE_t + \delta_3 Z_t + \delta_4 + \delta_5 T + \delta_6 B + v_t$$

(Solarin et al., 2017)

Where:

- *TEM* represents total carbon dioxide emissions from the consumption of energy per capita (expressed in oil equivalent?)
- *PEM* represents carbon dioxide from the consumption of petroleum per capita (expressed in oil equivalent?)
- *FDI*, real Foreign Direct Investment per capita (expressed in 2005 US dollars)
- *GDP*, real Gross Domestic Product per capita (expressed in 2005 US dollars)
- *ENE* represents energy use per capita composed by:
    - *FOS* for fossil fuels energy consumption per capita
    - *REN*, same but for renewable energy instead
- *Z* is a vector of control variables composed by:
    - GDP^2, included to test for EKC
    - *INS* for institutional quality
    - *URB* for urbanization population ratio
    - *FIN* for financial development
    - *TRA* for trade openness
- *T* is the trend
- *B* is a control variable for test

Their conclusions are more specific compared to the previous cited paper: first, they showed how the growth of real GDP, urbanization, financial development, and trade is related to increasing emissions while institutional quality contributes to decrease them. According to them, *"the study was able to establish EKC in Ghana"* (Solarin et al., 2017). At the same time, their findings reveals the impact of FDIs on the increasing emissions when looking at pollution produced by petroleum consumption only, but also when all the sources are considered. Again, they, without hesitation, stated: *"Ghana has developed a comparative advantage pollution-intensive industries and become one of the "havens" for the world's polluting industries"* (Solarin et al., 2017).

3.2.3. PHH conclusion: Pollution Haven Effect

In general results are not so conclusive, there are no evidence able to prove the validity of Pollution Haven Hypothesis. Gill et al. in 2018 performed a deep literature review to conclude: *"results are mixed at best, as no conclusive conjecture on the existence of the PHH can be established"*. They showed how the literature is composed by studies supporting each side of the discussion, some of them strongly sustain the hypothesis (like the Ghana paper cited before), some didn't find sufficient evidence, others showed the opposite behavior and observed firms moving towards more stringent policies. These differences raise doubts about the evidence supporting the theory, for example *"most of the analysts ignored the cost of mobility of translocation of these industries in case of the PHH"* (Gill et al. 2018). At the same time other aspects could be taken in consideration: corporate social responsibility and the reputation that a firm could establish or maintain affect certain choices.

The described situation is similar to the Environmental Kuznets Theory: a popular and debated theory without significant evidence to conclude the discussion. The EKC chapter tried to explain that, although the literature is not conclusive, some useful contributions were produced by researchers like the Income Effect. Something similar can be observed for the Pollution Haven Hypothesis too. It is not possible to consider environmental policy differences the main cause of firms' relocation choice, *"it is important to emphasize the evidence found supports the existence of a pollution haven effect only"* (Copeland, Taylor, 2004). The so-called Pollution Haven Effect (PHE) is the impact caused by environmental policy on production and import-exports decision, which is not able to determine delocalization alone but acts as an incentive or a deterrent. "*The pollution haven effect arises when a tightening of environmental regulation deters exports (or stimulates imports) of dirty goods"* (Taylor 2005). The PHE represents a necessary but not sufficient condition for the PHH, its existence does not prove the main hypothesis but at the same time rules out the possibility of a quick denial.

Without sufficient evidence in support of PHH, the hypothesis that environmental policy has no effect on trade should be taken in consideration too. It can be called Factor Endowment Hypothesis, *"environmental policy has little or no effect on the trade pattern: instead standard forces, such as differences in factor endowments or technology, determine trade"* (Copeland, Taylor, 2004). This hypothesis, more than adding something to the literature, would be a confirmation of previous trade model that didn't consider the impact of environmental policy, especially like the H-O models introduced in section 3.1. The evidence in support of the Pollution Haven Effect seems to define an intermediate scenario: differences in environmental policy can have an impact on trade and change some industries composition but not alone, they represent only one parameter to be considered to determine trade patterns. *"Comparative advantage is determined jointly by differences in pollution policy and other influences, such as differences in factor endowments"* (Copeland, Taylor, 2004). Hence, models should include variables to consider these differences, otherwise trade and delocalization causes could be misjudged.

3.2.4. The Pollution Halo Hypothesis

Pollution Haven Hypothesis is considered to be completely negative towards the environment: companies looks for the weakest policy to address their investments in order to face the lowest standards, especially through usage of old technologies or polluting energy sources. What if, instead, foreign direct investments could be beneficial for the environment or, at least, not completing worsening? This could happen when developed firms export technologies and/or skills better than those present in the host countries. In this case, trade openness is consider beneficial for the environment because it supports the spread of cleaner technologies and practices, hence it represents the opposite result of the same basic Pollution Haven scenario. This concept is called Pollution Halo Hypothesis (the two hypothesis share the same initials but only the Pollution Haven Hypothesis will be referred as PHH in this thesis). It describes the perfect scenario for the developing countries because FDIs not only contribute to their economic growth but also help them to support this growth in a sustainable way. *"This is defined as pollution halo hypothesis, when foreign investors use better management practices and advanced technology, resulting in cleaner environment in host countries"* (Liobikiene, Butkus, 2018).

The debate about this other possible scenario is probably more recent than the PHH, in 2005 Taylor introduced the topic without going into detail: *"if the diffusion of clean technologies is accelerating as a result of globalization, this indirect impact of trade may well turn out to the most important for environments in the developing world"*. The precise name and definition were proposed later, he also pointed out the scarcity of evidence linking openness to markets, pollution levels, and technology choice present in the literature at that moment. In the previous paragraph it was described how the results for the PHH are mixed, it is the same also for the Pollution Halo Hypothesis: it is not possible to prove a general rule because each country has its own characteristic and relative findings can be opposite from one to another. At the same time some interesting behavior can be extracted from the literature: *"the pollution haven hypothesis is more strongly supported in low- and middle-income countries, while the pollution halo hypothesis appears more valid in high-income countries"* (Mert, Caglar, 2020). This trend seems to match with the expectation to find stricter environmental policy in high-income countries and FDIs don't seem to be useful in helping developing countries become cleaner but further research is needed. Singania and Saini in 2020 also explained that Pollution Halo Hypothesis considers *"FDI as a tool to develop a mechanism for sustainable development which may be further decomposed into scale, technique and composition effects"*. If we look at the two hypothesis through the three effects they could have the same scale effect, same or similar composition effect but opposite technique effect, this is the key difference. Recalling the Environmental Kuznets Curve, the technique effect change along development is considered the main responsible for the turning point and the characteristic inverted-U shape. It is possible to focus only on the foreign direct investments' impact to imagine that a similar trend could be defined again. In the initial development phases a country could behave like a pollution haven and attract only dirty investments, which contribute to a rapid growth. If the demand for environmental sustainability increases with the per capita income, the country will change the type of attracted investments and use them to pursue development while reducing its environmental impact. In this plausible scenario, the degradation caused by FDIs is expected to follow an inverted-U trajectory meanwhile the country proceed with its development.

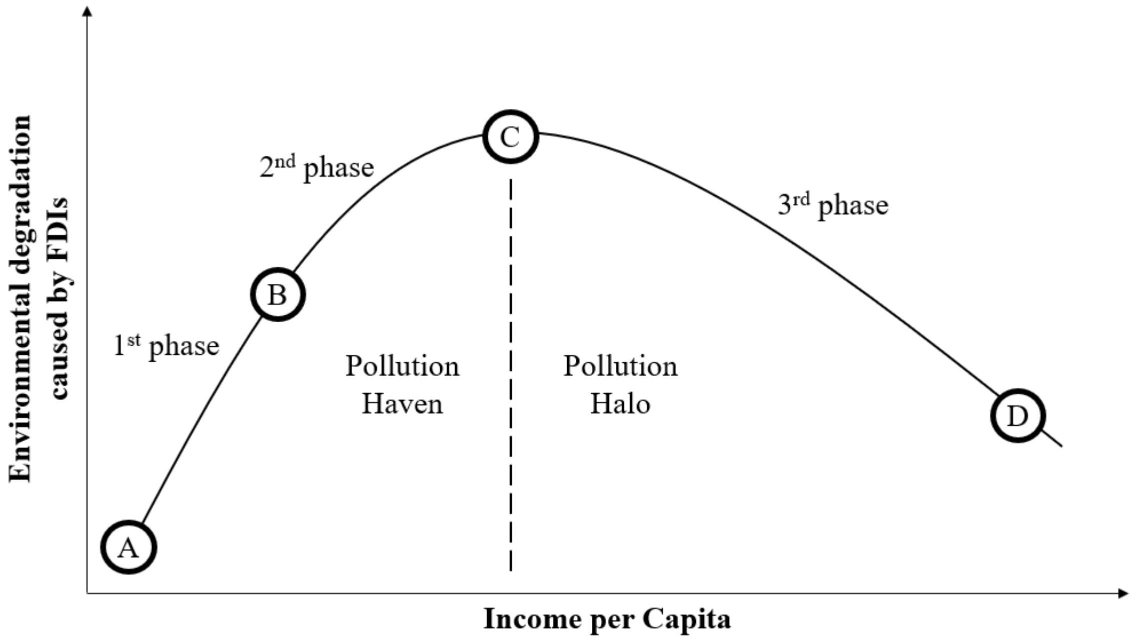

Fig. 3.2: EKC for foreign direct investments

3.3. Green policy as advantage for competitiveness

The previous section is based on a precise assumption: the introduction of stricter environmental policy represents a disadvantage for involved firms compared to companies in countries without the same rigidity. The idea is simple and plausible, if a firm is already maximizing its competitiveness, in the best case the introduction of stricter policy can have a neutral effect because, otherwise, the firm would have already made that improvement. This concept is supported by the traditional literature: *"the traditional view among economists and managers concerning environmental protection is that it comes at an additional cost imposed on firms, which may erode their global competitiveness"* (Ambec et al., 2010), but at the beginning of the 90s Michael Eugene Porter started to consider the possibility to question this assumption. Being the first to produce a relevant contribution in this direction, the result of its work is called Porter Hypothesis (PH) and this sub-chapter will be mainly focused on it.

3.3.1. The Porter Hypothesis

As already suggested, the possibility for an environmental policy to increase firms' competitiveness is strictly linked with their ability to make the best business choices. If firms are perfect entities, i.e. already expressing their complete potential, it will be impossible to increase their competitiveness (compared to not-involved companies) through stricter policies. This leads the focus on the question: are firms already maximizing their profit? *"Porter directly questions the view that firms are profit maximizing entities"* (Ambec et al., 2010). In this scenario, it is possible to imagine a "win-win" situation where a well-designed policy can both enhance environmental quality and competitiveness. It is important to underline the hypothesis does not say that all policies can easily reach this goal but it is the first to introduce the possibility. Indeed, in 1995, Porter and Linde described the general idea on this topic present in that time community: *"economists as a group are resistant to the notion that even well-designed environmental regulations might lead to improved competitiveness"* (Porter, Linde, 1995).

Before proceeding with details about the hypothesis itself, it is useful to underline the importance of this branch of research, because it could be relevant both for managers and legislators. First, because it could show ignored inefficiencies and opportunities, second, because it could guide policymakers to promote environmentalism and industrial competitiveness at the same time. *"No lasting success can come from policies that promise that environmentalism will triumph over industry, nor from policies that promise that industry will triumph over environmentalism"* (Porter, Linde, 1995). This is in total contrast with the Pollution Haven/Halo scenario discussed in the previous chapter because the ideal policy would not push local firms to move outside a country's borders to avoid the new stringency. Hence, evidence in support of the PH are at the same time arguments against the PHH too.

The starting point of the Porter Hypothesis is the simple idea that stricter environmental policies stimulate innovation, which should lead to efficiency improvements able to reduce waste of every type of resources. To improve competitiveness, the benefits obtained from this innovation should overcome all the costs faced to adapt to the new policy, this tradeoff is what determines the main difference at the base of the Pollution Haven and the Porter scenario. In order to study this possibility an understand if Porter's idea has supporting cases in the real world, it should be converted from a general concept to a precise hypothesis before. The main contribution to pass this fundamental step was given by Jaffe and Palmer in 1997: starting from the vague concept introduced by Porter, and highlighting that "*the evidence offered in support of this hypothesis is largely anecdotal"* (Jaffe, Palmer, 1997), they proposed the definition of three distinct variants of the Porter Hypothesis: the "Weak", "Narrow" and "Strong" versions.

The Weak version of Porter Hypothesis (PHW) simply asserts that environmental regulation spurs innovation. It does not include the effects of innovation so it does not tell whether firms gain in any aspects from this introduction nor if it damage them. It is plausible to expect for this version to be generally true, because it should be a goal of introducing stricter policies. To test this hypothesis researchers are looking for a positive link between the intensity of regulations and firm's innovation strategy, measured as investment in R&D, new technologies and successful patent applications. As expected, the Weak version finds support in the empirical literature, "*environmental policy changes the relative price (or opportunity cost) of environmental factors of production, it would be surprising if increased policy stringency did not encourage facilities to identify means of economizing on their use"* (Lanoie et al., 2011). Even if the validity of this version does not surprise, it gives little support to the general concept and makes a point: when evaluating the impact of stricter policies on firms it is not sufficient to look at the short-term costs imposed, but it is necessary to evaluate the results of the induced investments too.

In its work, Porter himself suggested that policymakers should focus on outcomes instead of processes while designing an environmental policy, if they want to spur innovation. The Narrow version (PHN) add something to the Weak one: not all policies are equal, some of them are better in stimulating innovation. In particular, it states that flexible regulations represent grater incentives to innovate for companies compared to traditional, prescriptive form of policies. It is not easy to empirically test this hypothesis, in 2011 Lanoie et al. reported that *"because market instruments have not been widely used so far, no study has been able to conduct a direct test of the "narrow" version of PH"*. According to them, at the time, it was not possible to prove that *"market-based instruments"* were actually better than *"command-and-control measures"*, but at the same time they pointed out the presence of indirect support in the literature.

Finally, the Strong Porter hypothesis (PHS) includes the overall impact of introducing better environmental regulation and express Porter's idea completely. This version states that stricter policies does not limit to induce innovation (as for the Weak version), but this innovation is sufficient to offset the other negative effects. The final result would be an increase in competitiveness for involved firms, which will be proof of their imperfections too. To test this version it is necessary to search for a positive linkage between the regulation level and firms' business financial performance (compared to competitors in other countries). "*The effect of environmental policy on business financial performance may be direct (e.g., in terms of compliance costs), or indirect (e.g., through the impact on innovation and thus production costs)"* (Lanoie et al., 2011). Although the Weak version seems to be valid, and increasing innovation is observed where stringent laws are imposed, there are no final evidence for the tradeoff to be commercially beneficial. Findings in literature are mixed, different studies produced opposite results, but this is not a surprise. As already explained, Porter didn't try to state that new environmental policies were improving firm's competitiveness, he wanted to break the general idea that this scenario was impossible. In this term, each paper in support should indicate well-designed policy while papers denying the hypothesis, the opposite.

3.3.2. PH conclusion

Two different discussions should be opened regarding the Porter Hypothesis: one about its Weak version and one about the other two. The Weak version finds strong support in the literature, it is not too difficult to test and the results are not surprising. Even if it is not enough to prove the full-optimistic Porter's view, it shows how environmental laws are not completely negative for firm's competitiveness, stimulating research and development of new technologies or processes. It also represents a starting and necessary point to proceed with the analysis of the other two versions: without support for this basic one, the others could be quickly abandoned.

The situation regarding the Narrow and Strong versions is different: they are more difficult to test and results in the literature are not clear. While for the Narrow Porter Hypothesis the main obstacle is the absence of an adequate amount of cases to observe, for the Strong version the required analysis is complex. The general approach is to look for a link between the stringency of regulation and firm's business performance or competition among nations. It is difficult to isolate the effects caused by a certain policy in mid-long term from all the other actors involved and analysis could be easily biased. An interesting work to cite is the study performed by Costantini and Mazzanti in 2012, regarding the EU15 countries during the period 1996-2007. Their analysis supports both the Strong and the Narrow PH: *"environmental policy actions seem to foster export dynamics rather than undermine EU competitiveness in international markets"* (Costantini, Mazzanti, 2012), but they specify how the PH cannot be taken for granted because findings in support are related to that specific sector or policy instrument. As already said, different studies report different conclusions, this uncertainty is well-described by the meta-analysis performed by Cohen and Tubb in 2017. This method is used to aggregate results from papers investigating the same relationship, treating each study as a single observation, with the same weight but opposite sign if in support of the hypothesis or not. So divided, the two groups seems about equal but there is also one interesting point: *"once disaggregated, there appears to be a higher chance of finding a negative finding at the facility, firm or industry level, and a higher chance of a positive finding at the state, regional or country level"* (Cohen, Tubb, 2017).

Although the literature is not able to provide conclusive results, it represents a breaking point compared to the general belief initially shared by economists and it can be useful both for businesses and policymakers. Firms should follow literature findings for three main reasons: first, they would be stimulated to look for internal inefficiencies or possible improvements. As already said, treating firms as perfect maximizing-profit entities is a strong assumption that cannot be taken for granted. Second, firms would have an additional instrument to address their R&D activities, in order to intercept the increasing demand for environmental quality and be more prepared. Finally, lobbying efforts could focus on supporting the best type of environmental regulation instead on fighting the change. Obviously, a certain policy cannot be introduced ignoring the economic impact, hence, the benefits are directly shared with policymakers because the less local firm competitiveness is harmed, the more can be achieved in terms of environmental quality.

4. Conclusions

4.1. Literature review outcome

With this thesis I wanted to describe the relationship between human development and environment but this so-popular concept is at the same time so wide that a thesis is not sufficient to eviscerate it. Through three chapters, I tried to organize the related literature in order to decompose the general concept, analyze its different aspects and focus on the main hypothesis. The idea behind the chosen path was to add different topics and actors one at a time, to build the final complex relationship starting from the simplest scenario, without taking anything for granted.

To begin, the first chapter explained the relevance of the topic and introduced the complexity of defining and measuring environmental health alone before investigating about links with external factors. With this context, it was possible to introduce the chapter main concept: Scale, Technique and Composition effects. These effects represent how a certain change in human activities reflects on the environment, defining three typologies. Respectively, they intercept variation in industries' size, technological level and composition. This industry-level decomposition is well-known in the literature since the last decade of the 20th century and it is useful to describe general causes of increasing or decreasing pollution. Despite the popularity, limiting the analysis at a macro-level could be too generic and lead to misunderstanding. More recently, a deeper firm-level decomposition has been proposed, in particular to show how non-technological changes inside an industry fall into the general Technique effect. At the moment, it's easy to find environmental analysis addressing responsibilities to the Technique effect without being able to look inside it, hence, further research is needed and it is plausible to expect that, using the firm-level decomposition, higher quality analysis could be performed.

The second chapter is dedicated to the Environmental Kuznets Curve, inspired by the previous Kuznets Curve hypothesis. This theory is a milestone in the literature, it links environmental degradation with economic development suggesting a particular behavior: along a country's development, its environmental impact increases until a turning-point where begin to decrease without interrupting the economic growth. This relationship can be represented in a graph with an inverted-U shaped curve which is the Environmental Kuznets Curve itself. The theory found great interest in the literature but not the same support, despite this, it has some relevant merits: first, it introduced the possibility to decrease human environmental impact without giving up the economic growth, a concept not taken in consideration before. Second, it gave birth to a related branch of literature, which produced other interesting hypothesis but also results, like the observed tendency for environmental quality demand to increase together with population income (also called Income effect).

Finally, the third chapter introduced trade and firms' competitiveness in the equation. Starting from the assumption that a stricter environmental policy is only a disadvantage for the involved firms (compared to the others), there are two main hypothesis discussed in the literature. Both consider the introduction of new regulation an incentive to move outside the country's borders to avoid it. The first, called Pollution Haven Hypothesis, is completely pessimistic: in this scenario the permissive country welcomes foreign companies for an economic gain in exchange of worsening its environmental health because firms simply shift the pollution sources. Hence, the stricter country is damaging its industries in exchange of a local environment improvement, which, globally, is useless. The other hypothesis, instead, is called Pollution Halo Hypothesis, it is a bit more optimistic because defines a scenario where the weakest countries can gain also from an environmental point of view due to the acquisition of better technologies or production processes. From the other side, a literature branch is open to the optimistic possibility of environmental policies able to increase involved firm's competitiveness while decreasing pollution. This branch is based on the Porter Hypothesis, formulated in the Weak, Narrow and Strong versions. The first one simply states that green policies stimulate innovation, the second one considers flexible policies better compared to classic ones and finally the Strong version talks about win-win policies where both firms and environment can benefit from. All these hypothesis find great interest in the literature and each of them has both support and critiques, this reflects the complexity of the topic. All the scenarios are plausible and it does not seem possible to express a generic rule to define how human actions are and are going to impact on the environment. Each case is different, depending on characteristic of countries, industries and policies involved, a solid amount of variables should be taken in consideration to correctly link causes with effects.

4.2. Final considerations

At this moment, the research could appear inconclusive: no hypothesis proposed have been proved and the most important ones (discussed in this thesis' third chapter) cannot even be rejected. Despite this, researchers have been able to reject the general beliefs regarding this topic: first, the idea under which it is not possible to decrease pollution without arresting economic growth, second, the idea under which the introduction of environmental policy can only harm domestic industries.

The global warming debate followed a particular behavior: from one side, there is no doubt regarding the emissions caused by human activities and the expected consequences if no radical change is implemented. From the other, no significant steps ahead have been made in decades. The main reason behind this inconsistency is the expected economic shock required to abate and/or offset greenhouse emissions. The results explained in this thesis round about that: from one side, the rejection of the EKC theory proved that the problem will not solve itself "naturally". It is not possible to expect that focusing only on the economic and technological development will lead also to pollution abatement in a properly period of time. From the other side, findings against the PHH and in support of the Strong Porter Hypothesis show how designing the right environmental policies could minimize the economic damage. In my opinion, policymakers should exploit actual literature while at the same time supporting its development because further research is needed. It is also plausible to expect relevant results in the early future: the literature is still relatively young due to its recent exploit in the public debate and, most important, the data availability for the analysis will increase both in quantity and in quality.

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