MASTER'S DEGREE IN ENERGY ENGINEERING

COURSE OF INNOVATION IN ENERGY PRODUCTION

POLITECNICO DI TORINO

A CRITICAL INQUIRY INTO THE MODELS OF THE FUTURE

BALOCCO ANDREA

ACADEMIC YEAR 2020/2021

INDEX

1 INTRODUCTION

The necessity to achieve a goal, or the will to know how a situation can evolve starting from a defined point, are elements at the basis of model creation: set of actions often, if not always, accompanied by calculations. There are situations describable in a clear and well defined way by a model, while others are not; the interest is going to be focused on the latter. Complex systems, linked to elements changing in time, cannot be rigidly described, but are modified with time, hopefully towards a higher accuracy, but they are inevitably affected by errors: the following pages are developed following this concept.

Is important to underline that this work intention is not to discredit studies made by people working in the developing and improving of models; conversely, they are essential in deciding which path to follow in many fields.

When a model produces negative results for future, such a constant increase in pollution, the objective is to make modifications inside the system behavior to voluntarily get away from these outcomes. In this case, after targeted actions, moving away from made predictions is desirable, not to be seen as a model failure, but its merit. Furthermore, the majority of model developers, propose their work as a possibility, not as a sure evolution of events.

The goal is to understand why we should not have total confidence on model results, particularly when we face quite large systems, with numerous interdependent relations and hardly represented by equations.

A common example is given by weather forecast, which frequently give results different from that one actually found, even in short term periods (few days); moreover, weather predictions made by different agencies tend to provide inhomogeneous forecasts. The difference among models concerning the same subject is due to their structure, that is the actions (algorithm, equations, hypothesis) allowing the passage from input to output data, besides the quality of input data.

Turning back to weather forecast, we can easily point out which could be the “best” model, producing the closest as possible result compared to real ones, merely observe the weather after its predictions. This possibility is precluded for models trying to study medium to long term periods, especially when the supposed effects are negative: in this case would be necessary to act before reaching critical situations, and that is exactly the goal of the model in question: showing an undesired condition and proposing some possibilities to move away from it.

In this paper will often be presented considerations linked to the energy branch because is a field which widely uses models and is a discussed subject even from people not studying/working in it, but all the considerations have a general validity: anytime there is a model, we can use the same approach.

This work is divided in three chapters: the first is of general nature, exposing some common problems in defining a model, with much interest in the portion of them related to future predictions about humans and its interactions with the globe; in the second one is proposed a global model, created in 1970 by a professional of system dynamics, Jay Forrester, and later upgraded by a MIT research group; finally, the last chapter proposes a similar description about the second, with a greater and actual attention about some of the main factors concerning the effect of humans on itself and the surrounding environment.

2 MODELS AND SCENARIOS

A model is a set of actions, instructions or thoughts that allow to get some results (output) processing initially known information (input). The aim of a model is not necessary that of describe in a correct way a phenomenon, but to obtain reactions, as close as possible to what we are analyzing. In the engineering field, there are plenty of empirical formulas that have nothing to do with the real physics of the studied system because they are produced experimentally, but they are used thanks to their results reliability.

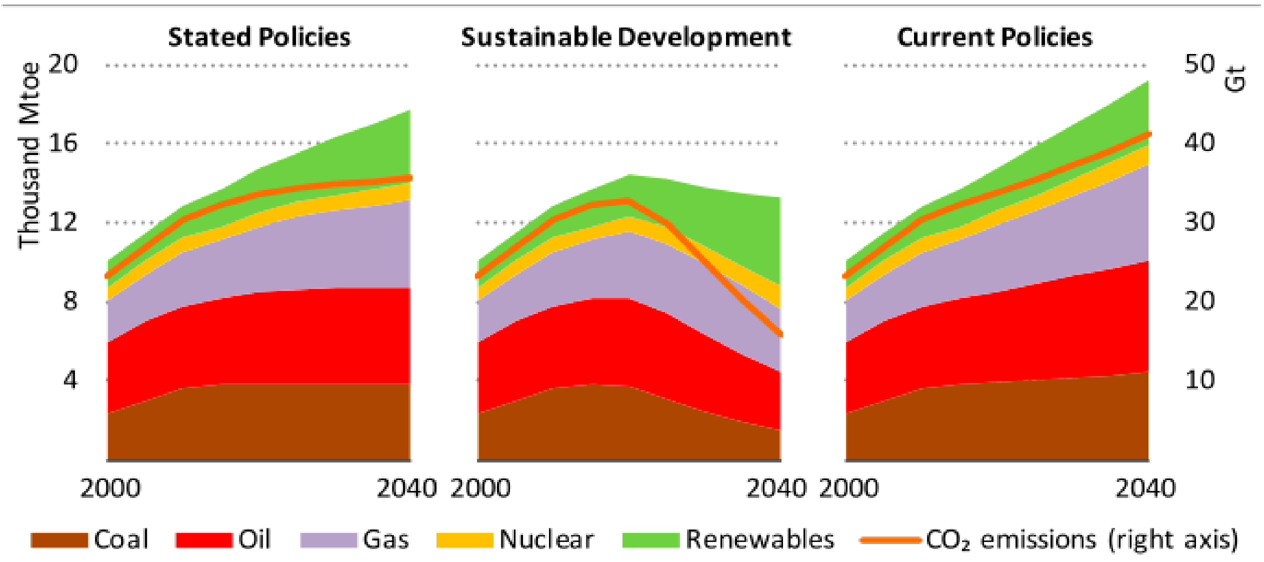
Models can be classified in several ways and, at first, we can divide them in qualitative and quantitative: the first provide a general idea about the outcome, without producing precise values, while the second quantify them numerically. A qualitative model is usually used before of a quantitative one in order to eliminate incompatible possibilities with both the results we are looking for or the input data we own. Once the right pathway to follow is spotted, a quantitative analysis allows us to clearly define our values of interest. Another distinction we can do is between mental models, which do not follow a clearly defined path: they are generally composed by an action and a reaction because our mind is unable to elaborate a lot of information, particularly when they are linked each other, than we have structural models, which are based on distinct steps and reproducible actions (unless the size is too big and the experiment could be simulated scaling down the features).

These are the kind of model we are interested in, where we have to deal with complex and interdependent systems. The situation becomes even more hard when, other than physical characteristics, even the anthropic factor plays a role: economic, political, energy and social decisions made by humanity strongly affect the result of a process. When someone tries to forecast how a system will evolve in the future, several assumptions are included in the model, consequently, it produces the corresponding number of outcomes: these results are called scenarios.

Throughout this paper will be presented some graphs produced by the IEA (International Energy Agency, the most reliable agency concerning energy at global level), extracted from its annual energy report called “World Energy Outlook”, containing lots of information about energy production and consumption worldwide. In order to simulate how the energy consumption will change, the company offers three scenarios:

- "Current policies": it refers to a future trend considering that the increase in energy consumption and energy mix will be similar to the current ones. It is actually the worst scenario, because it is not focused on energy transition and increase in efficiency: it incorporates the present energy policies adopted by countries around the world.
- "Stated Policies": it was previously called "New Policies", and it includes all the expected results concerning energy policies that countries pledged to follow
- "Sustainable development": it is based on the particularly far-sighted hypothesis consequent to a fast energy transition in renewables from conventional resources, besides a global reduction of consumption. This path has been generated starting from the Paris Agreement, in 2015 (COP21).

The following picture shows the CO2 emission and the global primary energy demand (divided in energy resources), that is the total amount of energy from all sources, including losses for transportation and transformation, in the three scenarios until 2040.



1 Three scenarios about energy demand (IEA, WEO 2019)

2.1 A GENERAL VIEW OF THE PROBLEM

To introduce the topic, and to have a first look about the principles of this paper, it is going to be presented a mathematical problem still unsolved: the analytical solution of Navier-Stokes's equations.

$$\rho \frac{du}{dt} = \rho g_x - \frac{\partial p}{\partial x} + \mu \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2} \right) + \mu \frac{\partial}{\partial x} \left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} \right) - \frac{2}{3} \mu \frac{\partial}{\partial x} \left(\vec{\nabla} \cdot \vec{V} \right)$$

$$\rho \frac{dv}{dt} = \rho g_y - \frac{\partial p}{\partial y} + \mu \left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2} \right) + \mu \frac{\partial}{\partial y} \left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} \right) - \frac{2}{3} \mu \frac{\partial}{\partial y} \left(\vec{\nabla} \cdot \vec{V} \right)$$

$$\rho \frac{dw}{dt} = \rho g_z - \frac{\partial p}{\partial z} + \mu \left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2} \right) + \mu \frac{\partial}{\partial z} \left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} \right) - \frac{2}{3} \mu \frac{\partial}{\partial z} \left(\vec{\nabla} \cdot \vec{V} \right)$$

2 Navier-Stokes's equations

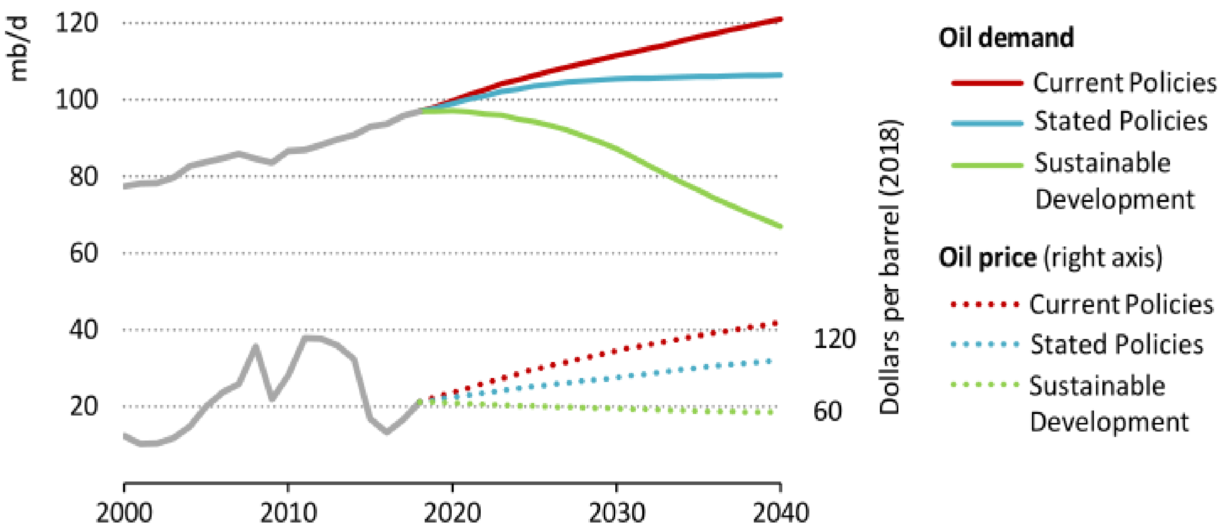
These equations describe the motion of Newtonian viscous fluids, and in 2000 they were introduced into "Millenium Prize Problems", a list of mathematical problems to which a general soliutions has not yet been found: we only have special solutions, where we have a simple geometry or plain physical conditions. The equations are actually correct, except if we get out of the assumptions, but the intrinsic difficulties compromise the utilization any time we face a real situation. The main problems lie in the complexity of functions composing them: they are interdependent. Fluid speed along the three axis (u,v,w), is a function of space (x,y,z) and time (t), furthermore, density (ρ) and pressure (p) are in turn functions of space and time, and if we are dealing with compressible fluids, other interactions arise between the characteristics already mentioned (for example the ideal or real gas laws). Another player is the temperature, not explicitly present in the equations, but influential on density through the thermal expansion coefficient and, consequently, affecting the other parameters.

The geometry is crucial in these problems: a fluid has null speed in contact with a wall, whatever the shape, and keep it in consideration in a formal way is easy but extremely complex, if not impossible, to make it explicit in a general equation, considering the endless possible geometries (pipes, fittings, valves, tanks, channels).

Numerical analysis allows to skip most troubles: we can generate an algorithm simulating the system under study, fitting it for the situation of interest (geometry, physic features and boundary conditions), achieving the desired accuracy, influenced by computational time availability and algorithm reliability.

If we consider a model built to forecast the behavior of a system where we do not only have difficulties related to the mathematical complexity, as the previous example of Navier-Stokes, but we also have boundary conditions dependent on choices taken by people (mainly government policies), a reliable solution is even further away from being reached.

It is shown the oil price and demand as an example, that will be deepened in the next paragraph, which is strongly influenced by human factor:



3 Forecast in oil price and demand to 2040, expressed in millions barrel per day (1 barrel is about 6.12 GJ) (IEA, WEO 2019)

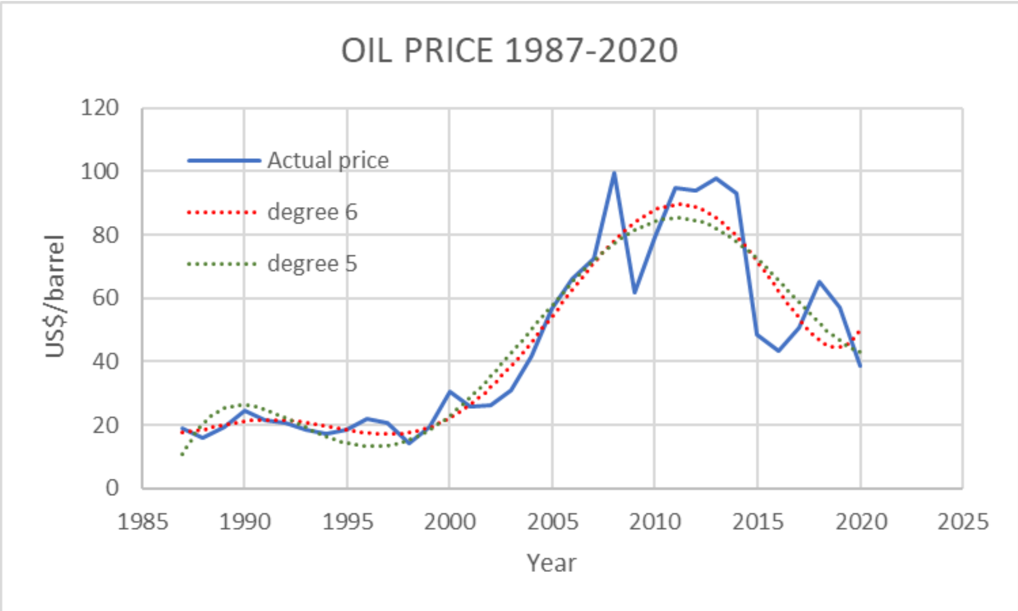
The assumptions made for different scenarios produce quite different results. At first sight, the outcomes of Sustainable Development are unlikely to happen, but at the same time we can be confident that the real trend will match to the Current Policy scenario: Stated policy, or an interval of it, is more likely to be achieved. Obviously, this condition, or any other, is possible only if we fit the corresponding hypothesis, or if a change is balanced by another opposite and similar change, as in any physical problem. Unlike mathematical issues, our parameters must take into account several subjects, as geopolitics, economy, national politics and social matters, other than unexpected factors, less controllable at larger scale.

2.2 A PRACTICAL CASE: THE OIL PRICE

In this paragraph we are going to analyze the trend in oil price in the last 35 years, a relatively short period in which, however, we can see great changes.

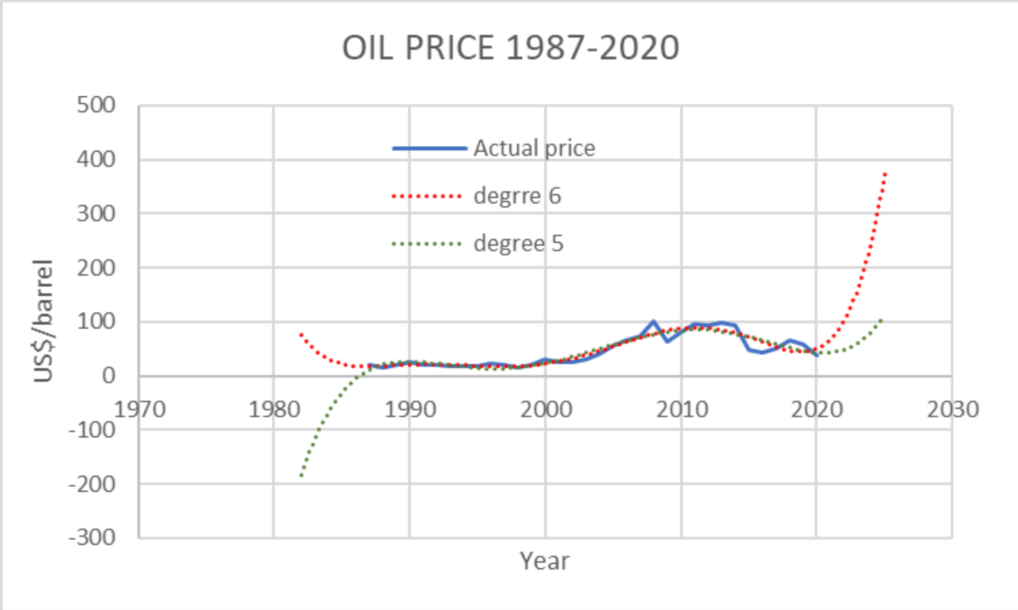
All data are kept from macrotrends.net website, dealing with collection of data and information about several economic issues, and they refer to the average yearly values. It is possible to examine them, and other values including maxima and minima in larger intervals or daily prices, but it is not necessary to provide a lot of information for thus analysis.

The first graph shows the oil price from 1987 up today (solid line), and two trend lines, approximated by a fifth and sixth order polynomial (dashed lines, green and red respectively), processing data on excel.



4 Trend lines (5 and 6 degrees) for oil price 1987-2020 (Macrotrends crude oil prices, 2020)

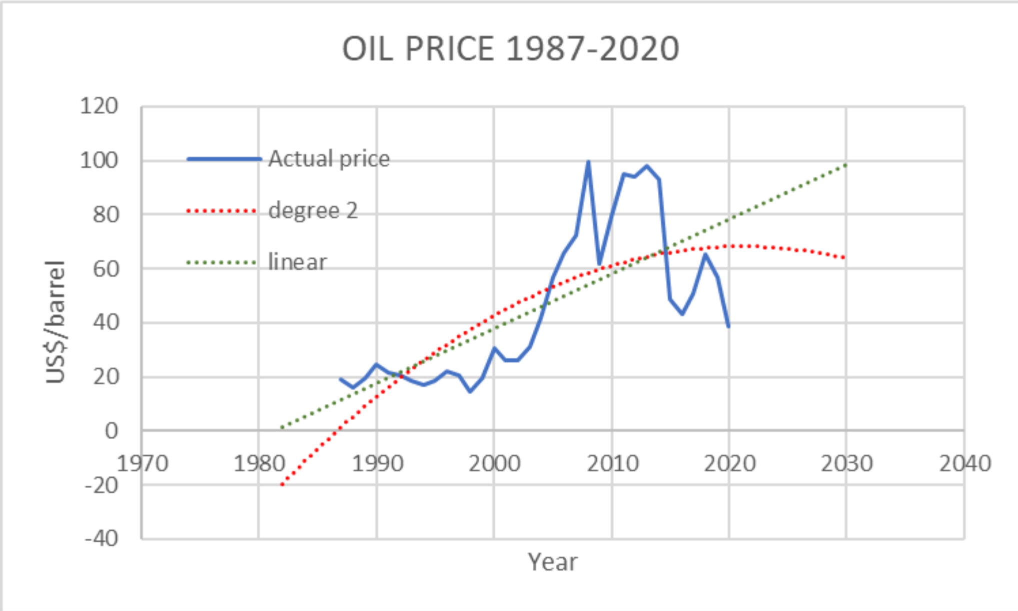
Both the approximations give very similar trends than the real one, but expanding these curves, we obtain unrealistic outcomes.



5 Trend lines (5 and 6 degrees) for oil price 1987-2020 and extrapolation (Macrotrends crude oil prices, 2020)

Both forward and backward extrapolations are of 5 years, quite a short period. Looking at the sixth order approximation, the oil price undergoes a rapid and unlikely increase, while the fifth order seems to get reasonable values, but a further increase in interval extrapolation, just a couple of years, produces the same sudden rise. The backward forecast is not particularly useful, but it could be used to see if, out of the known range, the approximation fits the real past prices; the fifth degree goes below zero (meaningless), while the sixth tends to quickly diverge to infinite.

The fifth and sixth grade polynomials, clearly tend to diverge as the odd and even ones do respectively, but in this case they do it so quickly that the extrapolation becomes unsuitable even in the very short term: they are not able to give useful information about the forecast.

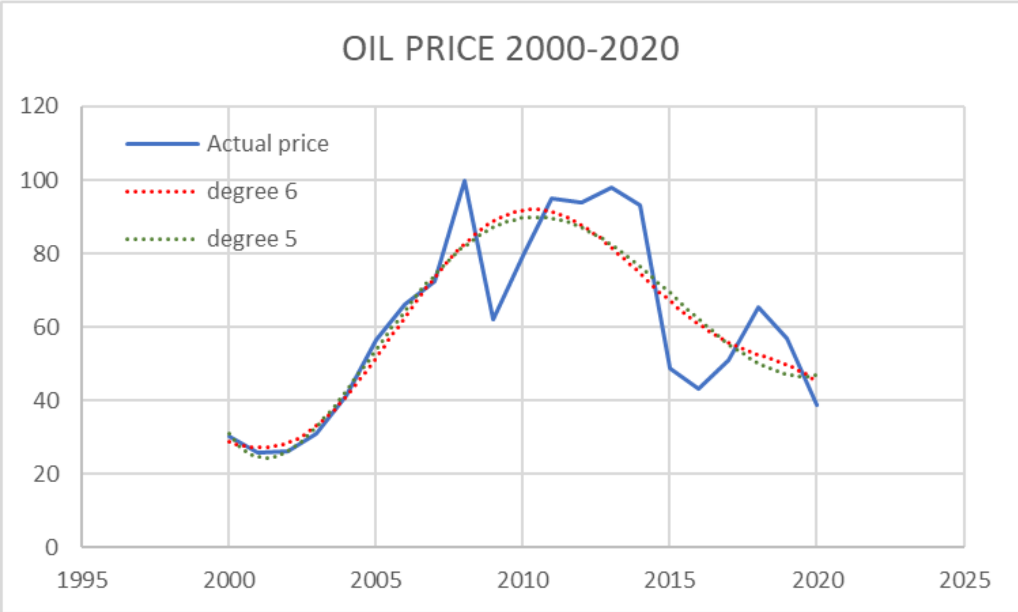


6 Trend lines (1 and 2 degrees) for oil price 1987-2020 (Macrotrends crude oil prices, 2020)

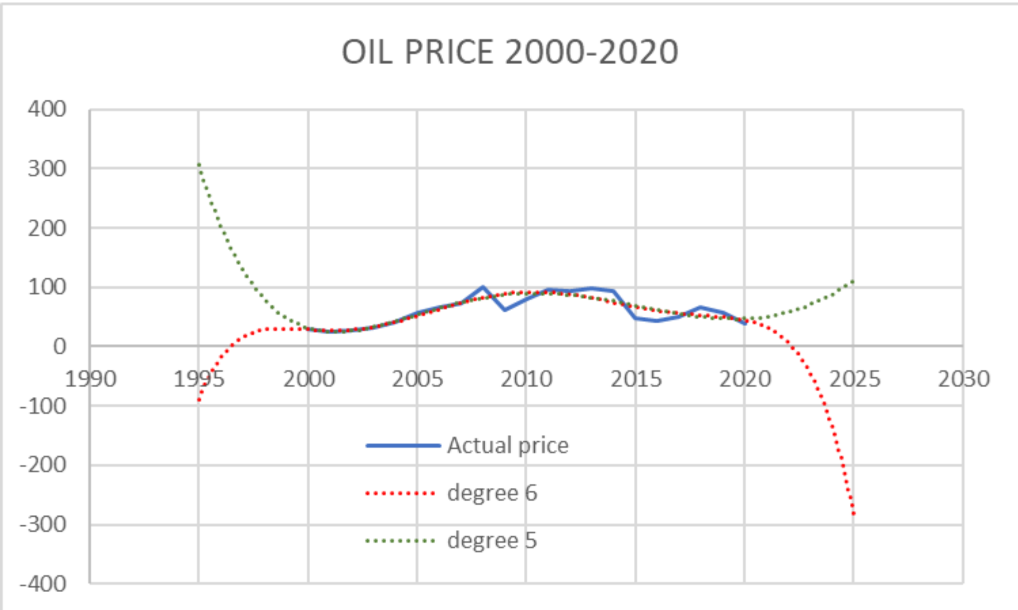
In the graph above the trend curves approximating the results are of first (linear) and second (parabolic) grade: there is no correspondence with the real values, that differ in a significant way. Despite we obtain reasonable outcomes (in absolute values) in the next years, they could be quite different from the future ones just because the low correspondence.

In practice, these graphs show how it is possible that a model (trend line), can represent extremely well a known trend (actual oil price), producing unrealistic values outside of the interval (fifth and sixth order); on the other side, the model can produce reasonable value for the prediction, accompanied by poor quality due to inconsistency of the approximation itself (first and second order).

The time interval shown has not been chosen for a precise reason, and utilizing historical data comprising larger or shorter period, the overall argument is the same: if we only use a mathematical/statistical approach to describe a complex phenomenon, linked with human activity, we are likely to get wrong results. Next charts provide the same process as the previous one, with a different interval: from 2000 to 2020.



7 Trend lines (5 and 6 degrees) for oil price 2000-2020 (Macrotrends crude oil prices, 2020)

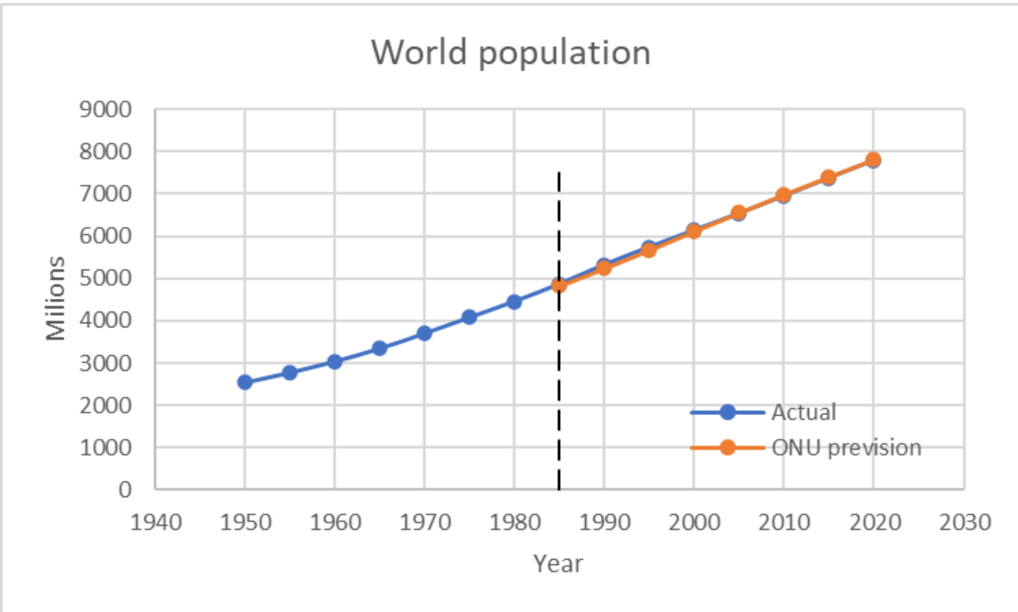


8 Trend lines (5 and 6 degrees) for oil price 2000-2020 and extrapolation (Macrotrends crude oil prices, 2020)

Trend lines for fifth and sixth order change as expected if we use a different period: taking a larger or shorter period has this effect and, comparing the forecast obtained by both graphs for the next 5 years, two observation arise.

The first one is that the trends are quite different, not only about the divergence speed, but also its direction: in the shorter period the sixth order tends to negative infinite, while in the larger interval to positive infinite. The second remark is, as already seen, even obtaining sensible outcomes, as the last one of fifth order, they can be a randomness, considering we get completely different trends with other approximations.

These two aspects would not be a problem just in case, for a short/medium future period, the various predictions produce similar outcomes, so the speech made so far is not always valid and it is possible a trend is durably increasing or decreasing by itself: several models concerning the population growth have been producing very close results to the reality; it is shown the ONU prediction in their 1980 World Population Prospect.



9 ONU prediction for human population (World Population Prospect, 1980)

The assumptions used by the model (annual change in growth rate) almost perfectly match the actual trend, and so, this indicates how a change resistant system, regardless of the reasons for this resistance, could be well represented by a model, while changing features in a system influenced by human choices (as the oil price), are hardly reliably described by simple equations. For these problems we have to create assumptions led by experience and all the past and current observations; in the case of oil price, we must deal with geopolitics issues, competition with other sources, chemical development and the presence of incentives and disincentives.

2.3 COMPARING FORECASTS

As anticipated in the introduction, different models produce different scenarios, mainly because of assumptions implemented; some of them can take into account a determined factor while others can omit it, or again, the hypothesis could be quite different and the results too.

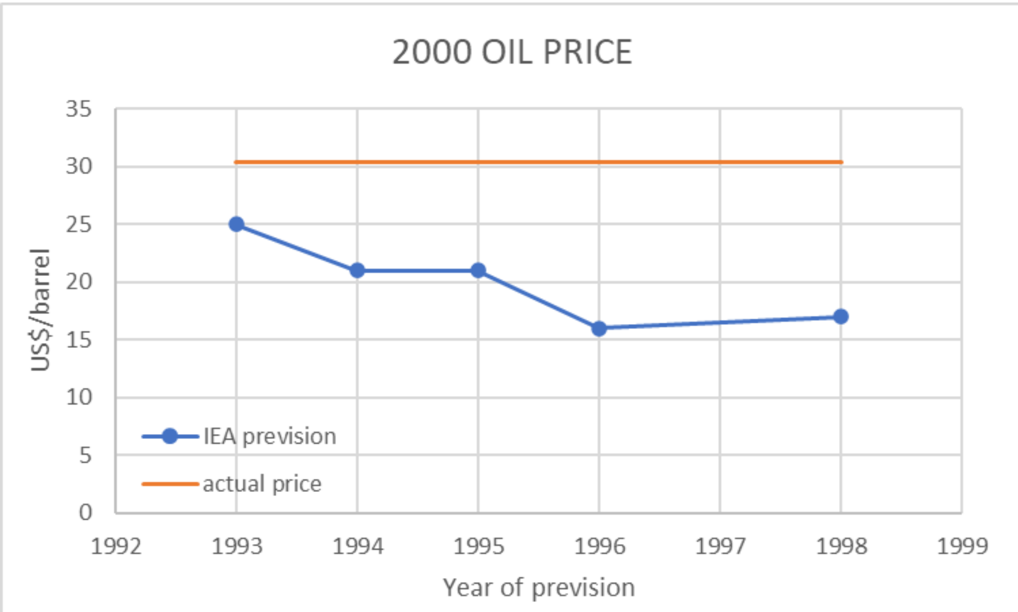
Remaining on the previous subject, there will be proposed several previsions about oil price made by different agencies.

IEA: the aforementioned International Energy Agency (World Energy Outlooks).

PIRA Energy Group: organization committed in the energetic market analysis.

DOE: Department of Energy of the United States.

Before comparing the various predictions, it is interesting to analyze how they are changed the ones of IEA during few consequent years, relating them with the actual oil price.

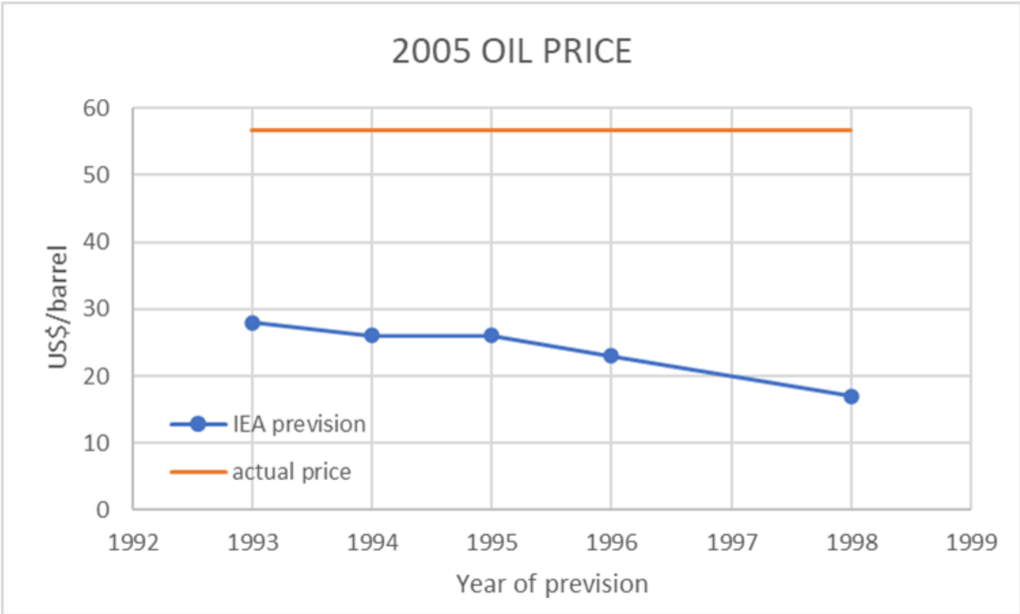


10 IEA oil price prediction for 2000 (World Energy Outlook 1993-1998)

Blue curve shows the prevision for the 2000, yearly proposed in the World Energy Outlook, while the orange curve shows the actual price of 2000.

The first thing we notice is that, despite the period in which these scenarios has been generated is pretty close to the year of interest (less than a decade), the difference is consistent; in 1993 it was expected an oil price of 25 US$/barrel, with a relative error of 17.7% compared to the real one, in 1996 the estimation changed to 16 US$/barrel, with a relative error of 47.3%. A significant aspect to consider is that approaching 2000, the results of forecasts tend to get away from the real values; this is an unexpected outcome, because in general, closer we are to the year of interest, closest should be the prediction: in this case we are clearly moving towards the opposite direction.

Now it is shown the same graph for the year 2005, five years later.



11 IEA oil price prediction for 2005 2000 (World Energy Outlook 1993-1998)

The difference between curves is even bigger: in 1993 oil price forecast was 28 US$/barrel rather than the actual value of 56.6 US$/barrel, with a relative error of 50.6%, in 1998 the estimation is equal to 17 US$/barrel and the error rises to 70%. We can, again, observe a decreasing trend during time.

Now that we have seen how expectations could be quite different from measured values, and how these expectations can change in a short time, the predictions of already mentioned agencies will be compared.

PREVISION FOR 2000 OIL COST (US$/barrel)						
	1993	**1994**	**1995**	**1996**	**1997**	**1998**
WEO	25	21	21	16	-	17
PIRA	18	19	14	15	-	14
DOE	22	19	16	-	16	-

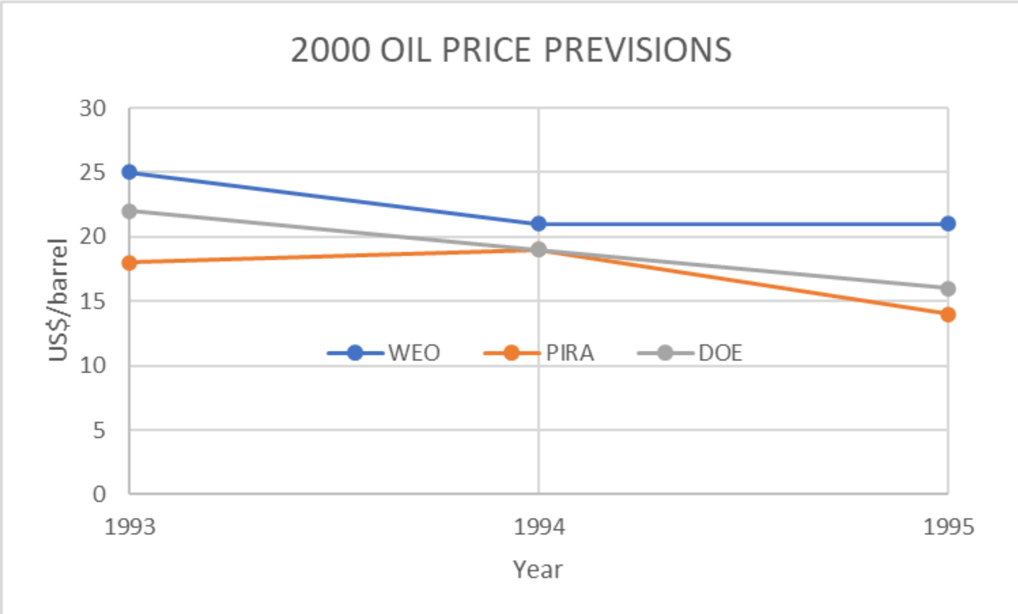
12 Different agencies prediction for 2000 oil price (IEA, World Energy Outlook 2000)

Unfortunately, not all data in this time interval have been found, but looking at the tables we can see a moderate discrepancy between different predictions: concerning the hypothesis for 2000, this fluctuation is more contained, likely because the year of interest is closer, but it tends to increase for 2010: PIRA predictions underrate the price with respect to the others organizations, which provide similar values.

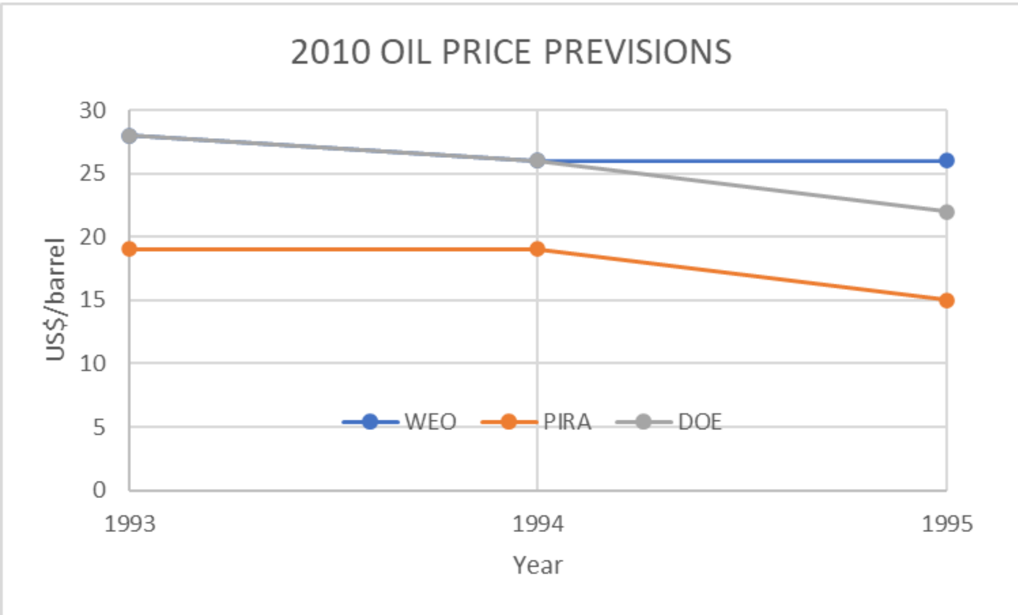
PREVISION FOR 2010 OIL COST (US$/barrel)						
	1993	**1994**	**1995**	**1996**	**1997**	**1998**
WEO	28	26	26	23	-	17
PIRA	19	19	15	14	-	15
DOE	28	26	22	-	18	-

13 Different agencies prediction for 2010 oil price (IEA, World Energy Outlook 2000)

In the following graphs it is proposed the estimation of three years to whom there are data, taken from previous tables, for any agency. Even if there are no sufficient data to obtain an accurate statistic, we have the opportunity to visually compare the oil price range in this period.



14 Comparison of three agencies prediction for 2000 (IEA, World Energy Outlook 2000)



15 Comparison of three agencies prediction for 2010 (IEA, World Energy Outlook 2000)

It must be pointed out that the real oil price in 2010 was equal to 79.48 US$/barrel, therefore more than the highest prediction (WEO 1993 and DOE 1993, 28 US$/barrel), and five times the lowest prediction (PIRA 1998, 15 US$/barrel): in this case the difference between various forecasts takes second place with the overall inaccuracy common to anyone.

2.4 THE INFLUENCE OF DIMENSION IN SYSTEM ANALYSIS

The system dimension strongly influences predictions: imaging to make an energy audit of a building, it is necessary to get a lot of information linked to the fabric (opaque and transparent features), climatic data in the analyzed zone, intended use of the building and its occupation, desired indoor conditions. At the end of data collection, many of which are approximated consulting tables, it is used a model that, manipulating them, produces several outcomes such as energy consumptions (and quality), efficiencies, temperature, moisture. Current regulation (the most important in energy audit is UNI EN ISO 52000), even if they have improved with time, offer results with no negligible difference whit respect to measure data. Enlarging this kind of study to a national, community or global level, it would be impossible to keep in consideration the endless, and diversified, input data, so it is necessary to simplify the system, eliminating many of the characteristics describing it, losing its dynamicity. A daily or monthly average temperature will be used instead of an hourly one, furthermore, it will be averaged on a larger territory, depending on the total size (a region or even a nation).

Models describing the behavior of a relatively large system, as the one of energy consumption or population increase prediction, lose a lot of information about the subsystems involved.

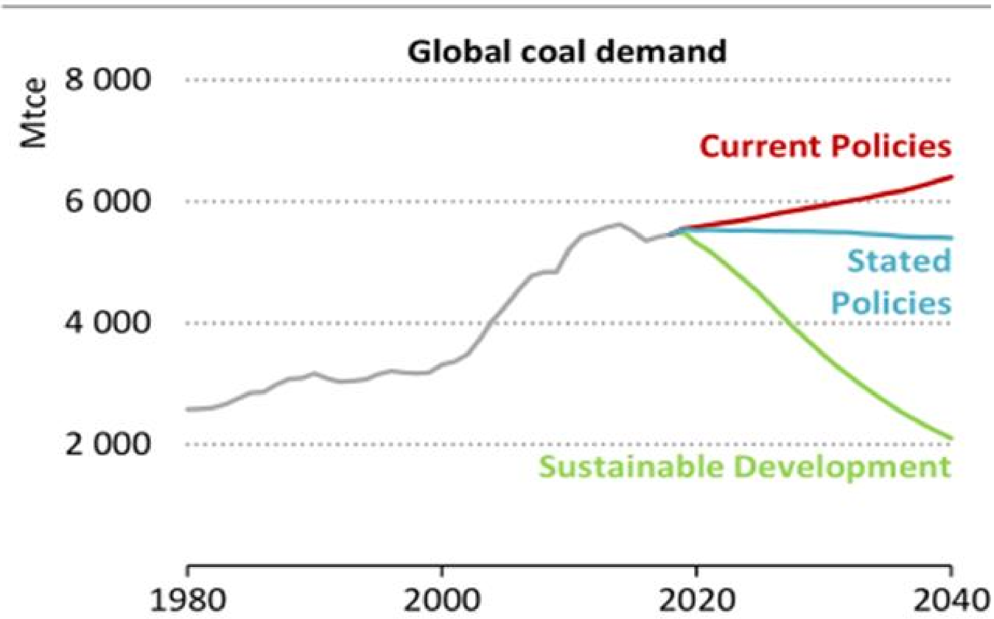
			Stated Policies				Sustainable Development	
	2000	2018	2025	2030	2035	2040	2030	2040
North America	818	492	369	328	304	285	81	50
United States	763	451	350	314	291	272	71	41
Central and South America	29	46	48	47	47	49	30	23
Brazil	19	24	23	23	23	23	14	12
Europe	578	447	314	263	219	203	129	84
European Union	459	319	204	157	113	87	84	59
Africa	129	159	165	160	160	161	113	92
South Africa	117	142	133	117	107	97	92	56
Middle East	2	6	9	10	12	14	7	6
Eurasia	202	229	225	212	203	199	136	74
Russia	171	166	160	144	136	129	88	50
Asia Pacific	1 551	4 079	4 385	4 476	4 502	4 487	2 976	1 771
China	955	2 834	2 934	2 845	2 710	2 568	2 065	1 154
India	208	586	771	938	1 063	1 157	546	395
Indonesia	17	72	97	114	130	148	67	39
Japan	139	165	141	124	115	107	70	43
Rest of Southeast Asia	28	132	172	194	219	241	91	38
World	**3 309**	**5 458**	**5 515**	**5 498**	**5 446**	**5 398**	**3 471**	**2 101**

16 Coal consumption per area and predictions based on three scenarios proposed by IEA (IEA, WEO 2019) measured in Mtce

In the table is represented the coal consumption per world regions, expressed in Mtce (million ton of coal equivalent=0.7 million ton of oil equivalent). It is also represented the prediction until 2040 for Current Scenario and Sustainable Development, other than the real consumption in 2000 and 2018.

Our interest is focused on 2018 data: if a new energy policy forces to halve coal consumption in China in a relatively short time, the global use will change from 5458 Mtce to 4041 Mtce, with a relative global reduction equal to 26%, this is because China is the major coal consumer (slightly more than 50% of the total in 2018). If this policy would be adopted by the EU, new consumption will drop to 5298.5 Mtce with a reduction of 2.92%.

International agreements move towards a reduction in coal use, and looking at the picture below, the only way to reach this goal is to undertake more restrictive measure than the Stated Policy scenario, where the consumption is almost constant.



17 Graphical representation of coal consumption prediction (IEA, WEO 2019)

The Stated Policy could be reached by a relatively small effort by all nations (whole system); on the other hand, the closer we move towards Sustainable Development, the higher would be the effort of big consumers (subsystems), mainly China. When a model performs an average analysis, it does not take in consideration situations like this one: assumptions made for the whole system can be really different among the subsystems, and if a subsystem of primary importance decides to behave in a significantly different way than expected, both in a positive or negative way, the outcomes will be quite different one another.

2.5 EVENTS NOT FORESEEABLE OR REPRODUCIBLE

In this paragraph it will be presented some large topics with the aim to illustrate events that have not the possibility to be forecasted or reproduced.

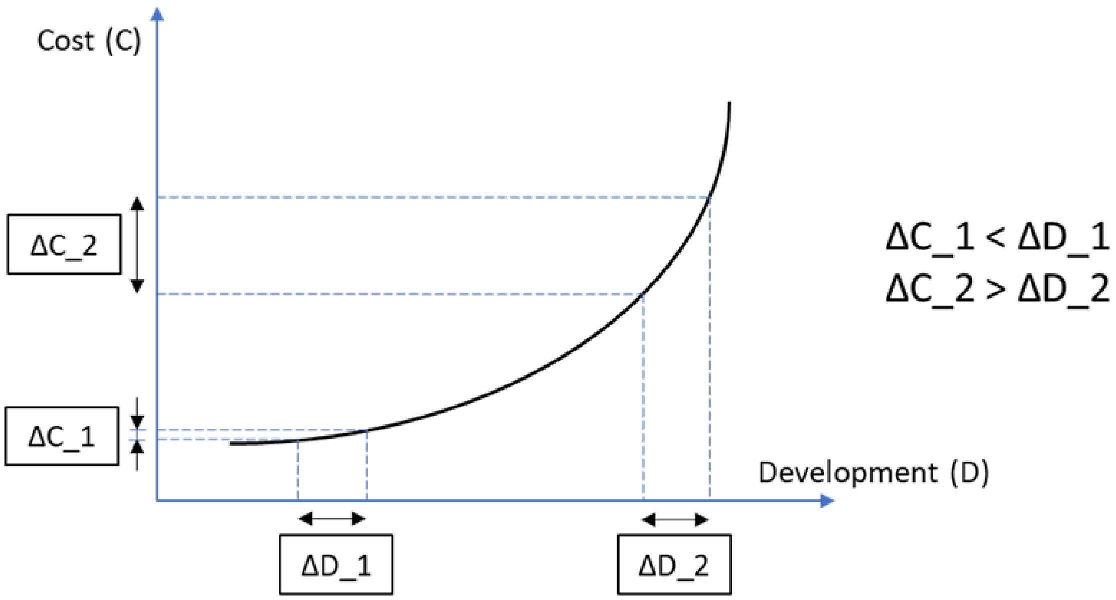
The speech is focused on large scale, if not even global, problems and considerations, because on them we can see the biggest deviation from reality.

Supposing to make predictions about human population, energy demand, economic developments or other topic, for a single nation of average size, the outcomes will be more reliable due to the highest homogeneity of input data: we can include quite close assumptions to the reality, focusing on important aspects and neglecting those not particularly influent in that country, beside being able to outline reasonable policies.

2.5.1 TECHNOLOGICAL DEVELOPMENT

Technological development is an element almost always present inside a model for the future: analyzing a determined context, we try to turn the thought "A technological development will improve the current situation" in a quantitative way, assigning some indicators able to represent it. Technological development has several meanings: in the branch of energy, it refers to an increase in efficiency both in production and utilization; in environment field it could be referred to a reduction of pollution in the biosphere thanks to capture systems or less impactful processes; in industrial manufacturing a development can aim at processes associated to a lower waste production.

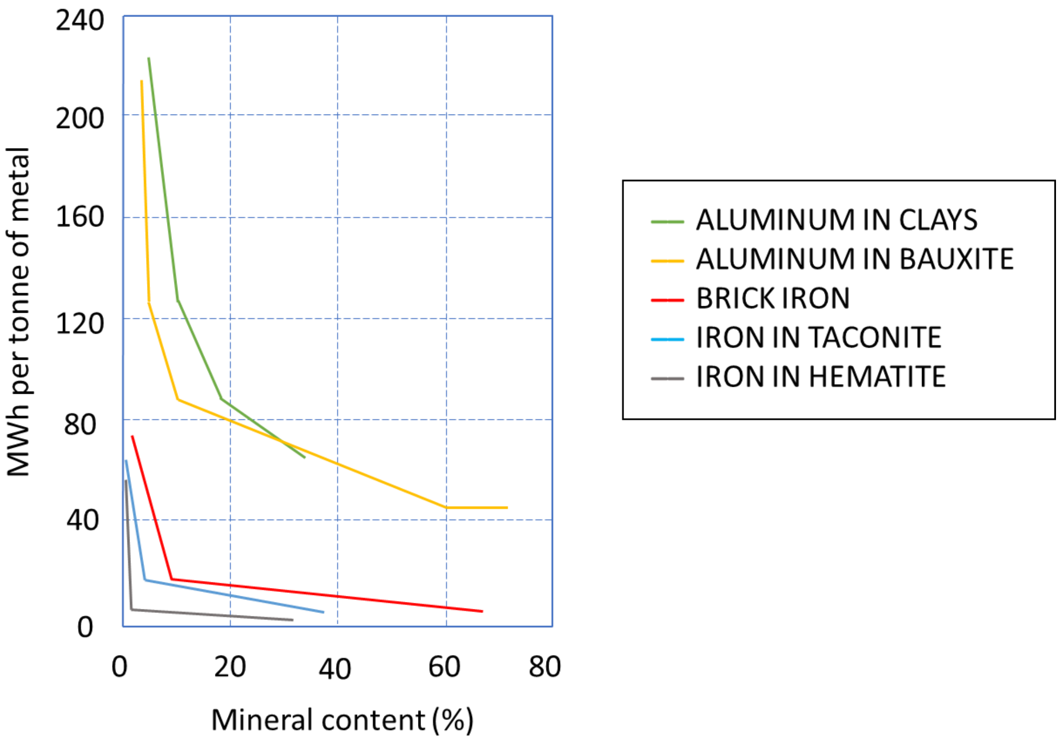
In general, inside a model, the common way to take into considerations these effects is to modify the parameters describing it: referring to the example mentioned above, we can quote an increasing rate of efficiency, or a decreasing rate of pollutant emissions.



18 Qualitative relation between a technological development and the associated cost

This picture shows how a technology improves as function of the cost: at the beginning of diffusion, a technology can be sensibly improved with a small investment, that is our increase in development (ΔD) is higher than the expenditure needed to obtain it (ΔC); the development is profitable. When we c the maximum development of the technology (it can be known or not), global costs tend to overcome the positive effect of development (ΔC> ΔD): a further development is no more economically convenient, or its upgrade need too much effort, making an improvement pointless, where the overall disadvantages are higher than advantages.

There are many examples of processes following this statement, not necessarily linked to cost and development, among which the amount of energy needed to extract metals (aluminum and iron in this case) from the mineral containing them as function of the mineral content itself.



19 Energy needed in mineral extraction as function of its content (Limits to Growth: The 30-Year Update, Meadows)

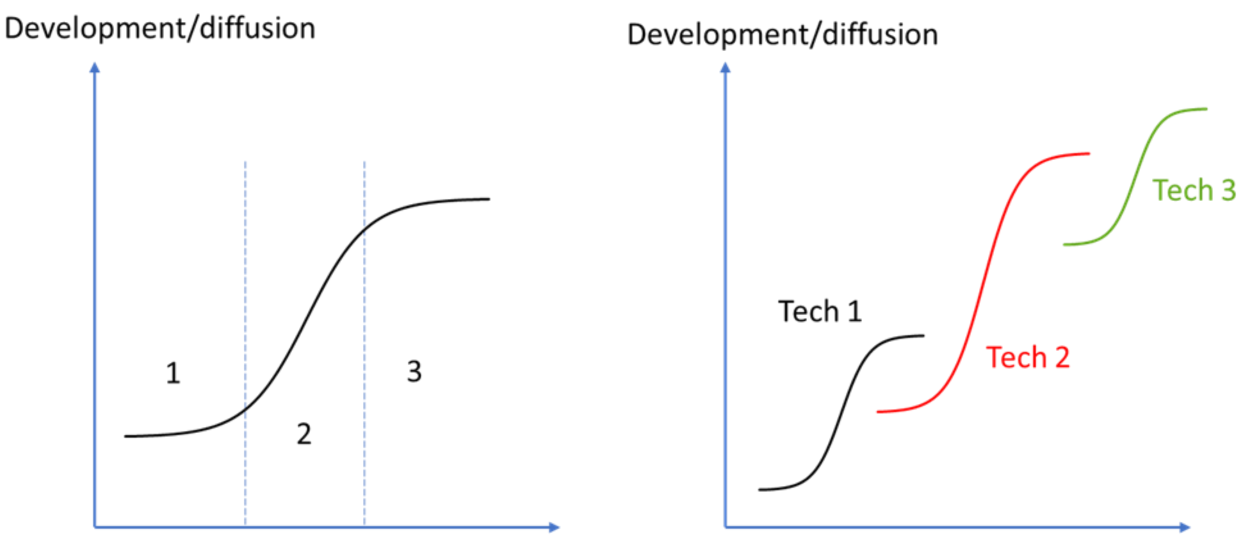
Lower is the amount of metal of mineral, more energetically expensive (and so economically), is the extraction, considering we have to reach less approachable areas, other than treating an increasing amount of processing material and waste per final product. Depending on the process and material, there is a point where no further extraction is reasonable due to too small amount of mineral extracted considering the energy expenditure.

The approach of changing the rates of development in a model can have acceptable results as long as we define reasonable increase or decrease considering available data and the possibility of development.

While this method suits an existing technology, in evolution, it does not work for a new different technology which replaces the previous one. Human history is characterized by a continuous technological renewal, and from the industrial revolution, its speed has constantly increased.

The study of technology evolution was studied in the second half of the XX century (Roger Law, 1962), and can be qualitatively described in three phases: origin, expansion, end of development, but it is also possible that a technology stops at the first phase if does not results interesting.

1. Origin: the technology is in its infancy, generally not yet marketed or present in the market as a prototype, expensive and unreliable; technical knowledge is limited.
2. Expansion: we observe a sensible improvement and an increase in diffusion thanks to the higher reliability and decrease in price.
3. End of development: the technology is now mature, widely marketed and relatively cheap: the growth proceeds more and more slowly, until it stops completely.



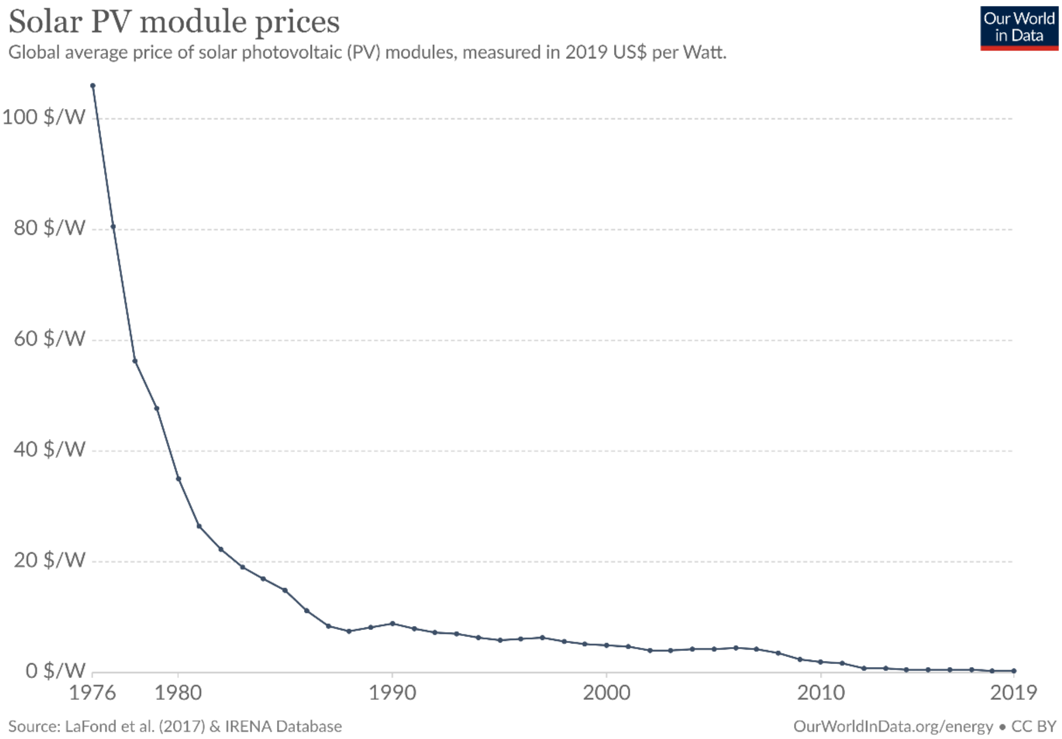
20 Technology evolution and transition

A behavior such the one described can be seen, for instance, in storage devices of digital data: in the last decades of XX century floppy disk were used, then substituted with CD and DVD, while now the main device is USB sticks, microSD and external Hard Disk. There is always more interest in online Storage (Cloud), which can become the most used device in the close future. We can observe a very quick development in computer technology: it can hardly be represented by increasing indices of “technological development”, as we can partially do with existent improving processes.

Furthermore, the difference of some characteristics between subsequent technology can be quite wide, even order of magnitude; in the previous example, the floppy disk capacity was between some hundreds of kB to few MB, DVDs reach some GB of data while current external Hard Disk exceed TB. These devices show a difference of almost three orders of magnitude one following the other; it is unusual to see an index change by 100000%.

We can make other considerations, not strictly related to the technological development, affecting the evolution of a device, for instance the amount of material, energy and so, pollutants, needed to build a system able to store a fixed amount of data. We have also to keep in mind an opposite effect, that is the negative feedback concerning the use of technology: the data we store now has incredibly increased in last decades together with the storage capacity, and the positive effect already described is partially balanced.

In the energy field, industrialized countries are currently in the situation where the traditional sources are at their maximum, or close to it, and the alternative ones are expanding: thermoelectric plants undergo modernization, moving from single cycles to combined cycle plants and cogeneration (CHP). We know the thermodynamic limits of these process and Countries interested in sustainability are moving towards them. At the same time renewable energy (mainly photovoltaic and wind power) get out years ago from the origin phase and they are now in expansion and, most likely, they will continue to do. Here the price of photovoltaic in the last 40 years.



21 Change in solar PV price (Our World in Data, 2020)

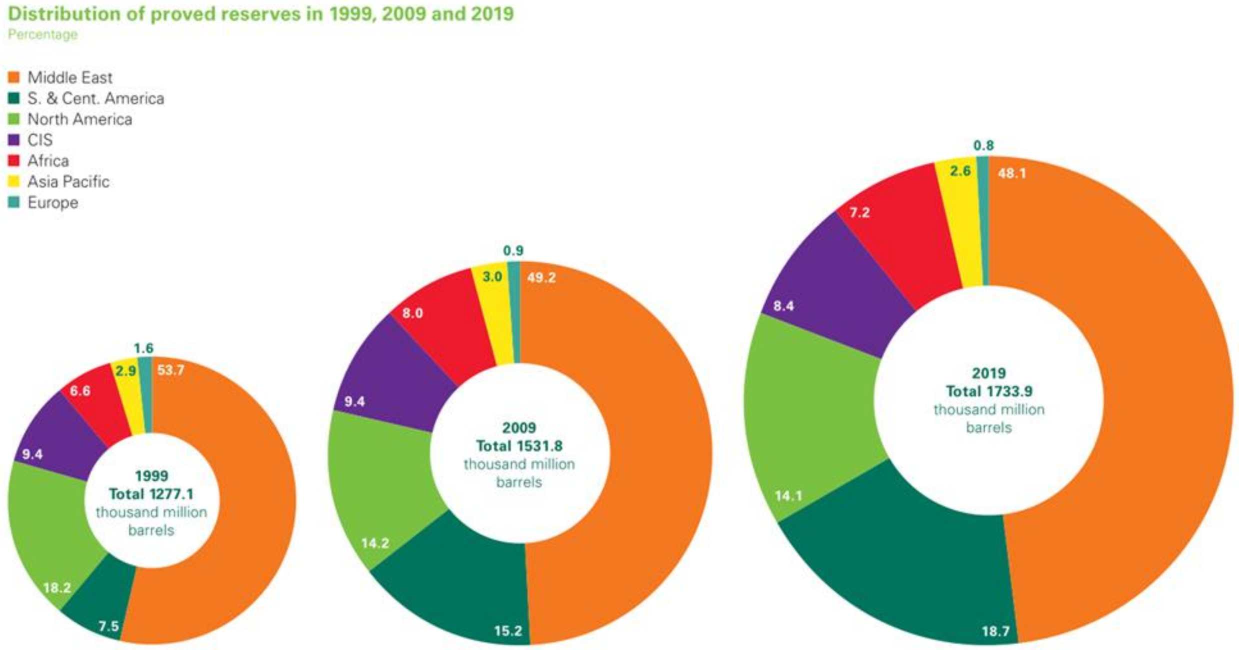
These two facts could be included into a model, trying to use indexes able to represent the changing situation, as the IEA does, but the introduction of a new technology (as the uncertain development of nuclear fusion) could modify the scene, and it is not easy to be predicted.

In essence, when a model makes considerations about a technological development, the first thing to know is the corresponding limit, in order to avoid the under or overestimation of the outcomes, but at the same time a too static description, unable to implement new possibilities, does not correspond to the changing anthropogenic nature.

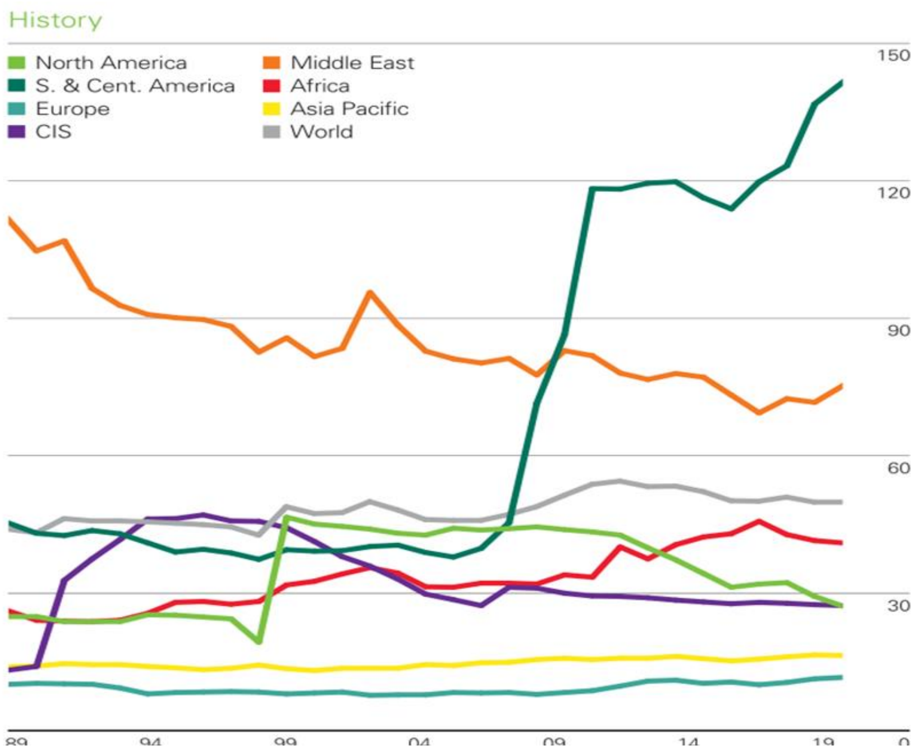
2.5.2 LIMITS OF THE SYSTEM

The presence of limits is probably the main reason for which models are generated trying to forecast the future behavior of a system, because if the planet resources would be unlimited, we will not worry about their shortage, or if the global ecosystem would be able to dispose any amount of anthropic pollution, we would not be interested in more sustainable processes.

In a physical model, we often know the limit under investigation: a thermal machine has a maximum efficiency equal to the Carnot one, materials can endure forces up to the yield stress before a deformation or rupture, but when we face a chaotic phenomenon, related to a lot of aspects or changing with time, generally unpredictable, defining a clear limit is everything but easy.



23 Increasing oil reserves during time, and their location (British Petroleum, Annual report 2020)



22 The dynamic oil time of exhaustion per area (British Petroleum, Annual report2020)

An example of changing limit is given by the confirmed reserves of oil shown in the picture, which increase despite there is also an increase of its extraction and consumption; the prediction about oil shortage is determined dividing the current reserve by the current extraction rate, on yearly basis: as we can see in the chart below, in the last 20 years this limit has been moving forward (from about 45 years in 1989 to more than 50 years in 2019). This means that the discovery of new reservoir has, by far, overcame the increasing utilization rate, furthermore, considering that intentions for future are focused on a reduction of fossil fuels exploitation, we can expect similar trends.

There is no doubt that, as many other planet resources, it is finite, but past concerns about its fast shortage are loosening, firstly because new availability, secondarily thanks a smarter, and in the future, lower use.

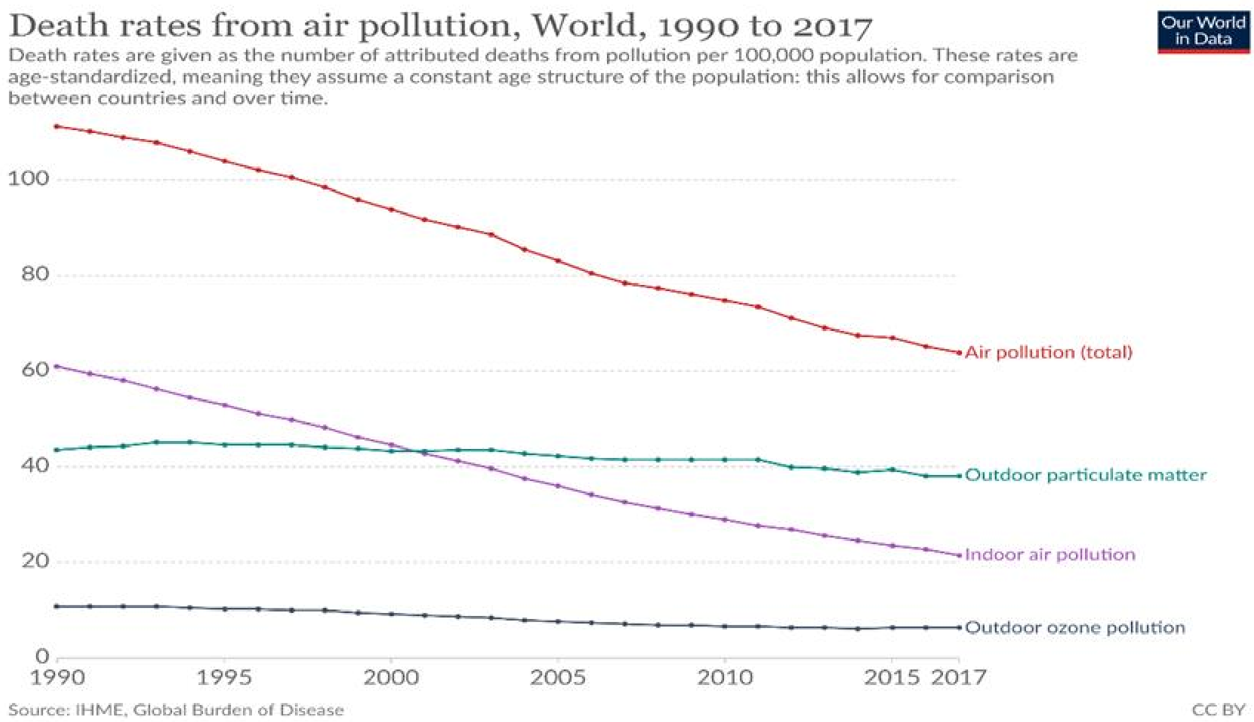
Natural gas is in a slightly more unfavorable condition: in the same period its exhaustion has changed from 60 to 50 years, while there are no worries about coal shortage, for which current estimations exceed 130 years, and keeping in mind we are no longer searching for new reservoir (due to its abundance) other than the reduction of coal utilization is the main objective to sustainability, the situation is even less alarming than other energy sources.

Another issue to be considered is the reliability of values given by Oil producers: several members of OPEC (Organization of the Petroleum Exporting Countries) have been accused of having provided values related to their reservoirs quite higher than the reality. If this is true, considering that current oil stocks of this organization overcome 75% of the overall one (source OPEC, 2019), the difference could not be negligible.

Once we have seen this data, the problem of fossil fuel shortage is not the main worry in the energy field, and it takes second place, still remaining an important issue, to limits of the planet to match the always increasing pollution produced by humans and released in the ecosystem, with a massive focus on greenhouse gas emission, CO2 in first place. The major of scientific community, but not totally, agrees human activities are the bigger contributors to global warming: this concept is generally accepted, and if we are facing a big challenge in emission reduction, it would be appropriate to know the limits within which we can alter the natural equilibrium, because lots of negative effects such as ice melting, enlarging of arid areas, extreme weather conditions, seem caused by our pollution.

Finding accurate numbers concerning these limits is not easy at all because of mutual interactions between global spheres; current estimation supposes that an average increase of 1,5°C will produce massive consequences, indeed, it is one of the parameters used inside energy models as the ones proposed by IEA. Regarding pollution there are other issues to consider such as their danger at a global level: a global model containing the effect of pollution (as the global model of chapter 2), is not able to differentiate between the various substances (NOx, SOx, heavy metals, ozone) nor their cycle, that is the pathway they follow passing from the source of emission to the accumulation site. Permanence time in water, air, ground or living being changes for any substance and at the same time the maximum amount of tolerated pollutant by the system where they diffuse, and the speed of their absorption: these features are dependent on weather, chemical, physical and biological characteristics, changing from place to place.

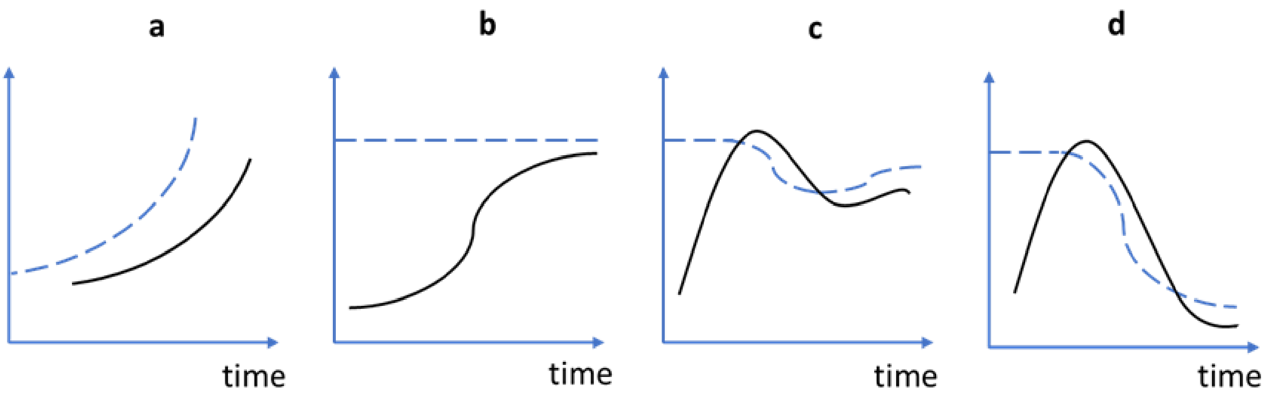
Due to this complexity, cycle assessment of substances inside a system is generally locally performed, or choosing the path of a single substance, while the global effect is built on the overall consequences on human, or other life forms, health: it is not a prediction, but a constatation.



24 Evolution of deaths from air pollution (Our World in Data, 2020)

Luckily, as we can see from the graph, the negative effects due to atmospheric pollution are decreasing, as opposed to many predictions made in the past decades, where the increase was also thought to be exponential. Among the reasons for this discrepancy, we find that in past models were not taken into consideration occurrences such the elimination of some polluting substances, as the Pb in gasoline, and the development of less impactful processes: burners of old energy plant did not favor complete fuel combustion, nor they implemented adequate thermochemical transformation to destroy pollutants.

Imaging to know, and consequently reach a limit, we can ask what are the consequences on the limit itself, and so, how the system reacts at his overcome. Four possibilities are going to be proposed, coming from the studies of a MIT research group in 1972; dashed line indicates the limit, while the solid one the event tending to it.



25 Different ways to approach and overcome a limit content (Limits to Growth: The 30-Year Update, Meadows)

a) The limit growths to infinity and so, even the variable in exam: if I have a deposit with an endless amount of material, I can extract as much as I want, even with an increasing rate, without touching the limit, this is clearly an impossible situation in a finite world.
b) In this situation we tend to the limit, without touching it if not at an infinite time. The way in which we close it (so the curve shape), is not important, it could be sigmoidal as in this case or exponential with negative exponent, or something different: important thing Is to stay below the limit.

This condition guarantees the equilibrium as long as we have a not decreasing limit: if a cultivation has a yearly yield, we can gather up to the maximum production for an indefinite time or until we observe a degradation of the soil. An example of decreasing limit, where we do not have an equilibrium but a consumption, is an oil field: the more I extract today, the less I have tomorrow, and at one point in the future the field will run out (limit equals zero). This is the best condition in a finite world.

c) In this case the limit is overcame for a short period, which tends to slightly decrease, producing a small overexploitation of the resource. When the exploitation returns below the new limit, the latter can rise again. As an example, we can imagine a fish farming when we draw out faster than the reproduction rate, causing a reduction in population. Deciding to decrease the fishing activity, we give time to repopulate in a reasonable time.
d) Even in this case we overcome the limit, but its lowering is quite fast: we refer to it as a collapse, and our possibility to take advantage of a resource drops as well. This is the worst condition and can happen if the system undergoes a large degradation once we reach the limit: when a chemical catalyst is poisoned by too much substance, it stops working. This reaction could also happen when a resource is far overexploited, as in the previous case: without decreasing the fishing activity, the population will drop so fast that it will need a lot of time to be restored, or at worst, it can disappear.

Sometimes it is possible to artificially increase a limit, and in this case we should not consider it as a constant: farmland can be fertilized with substances increasing its normal productivity, or we can use high yield vegetables. Whenever we face global limit, the smartest way, and often the most affordable in long term, is to make a rational use of the resource/process rather than modify it to allow us an overexploitation: costs to restore or take advantage of a problem, hidden by an apparent improvement are generally higher.

A concrete example is given by the increasing interest in Carbon Capture and Storage (CCS), a methodology aiming at avoiding the CO2 emission in atmosphere, intercepting and storing it after combustion. This practice is debated: capture, storage (mainly by gas compression), transport and other contingencies, are accompanied with sensible energetic and economic demand: technical community still does not agree if pros overcome cons, specially because renewable technologies are more and more economically competitive. Despite these worries, if this process will become economically and energetically competitive, CCS would allow the utilization of fossil fuels in future, being able to capture up to 90% of CO_2, and if coupled with biomass, we can see a net carbon absorption.

A common thought is that we can overcome many limits thanks to technological development, but actually, we can't: maybe we can increase them, but not endlessly; we may not know the maximum, but it exists, and as previously seen, even if we rise a limit, the expenditure to increase it again is higher and higher, and at a certain point it becomes counterproductive due to externalities. This concept is strongly supported by the already mentioned team of MIT and not only for technology: most governments believe or sustain a continuous economic development, but if at first sight an increase in life quality seems positive, it produces lots of secondary negative aspects, turning a development into a regress.

This is not always true, as in the last years there is an increasing interest in the rehabilitation of some environmental sectors that have suffered a degradation, such as some open cycle geothermal plants which purify the water from a polluted aquifer before returning it, even if it is a process fluid (it does not necessarily have to be cleaned), or the expansion of communities committed to waste elimination from ecosystem, not for commercial purposes. These are ways to increase, or better, restore, the limits that have been modified by human activity.

2.5.3 POLITICAL DECISIONS

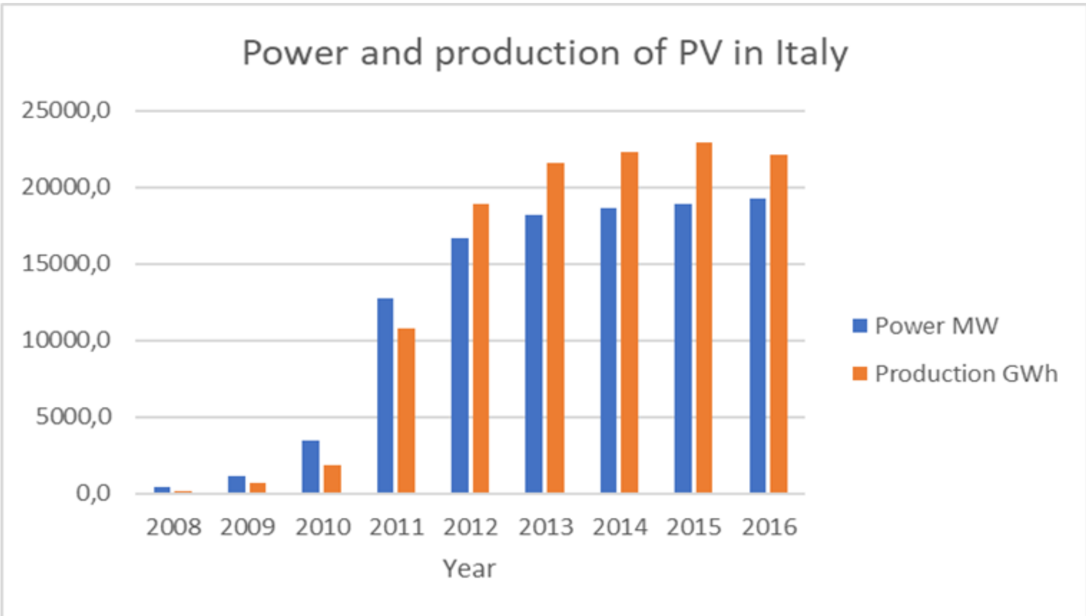
Government policies are probably the most incident factor on models for the future creation and, in the other hand, quite hard to be implemented both for the complexity and slowness of determination, and because the commitments made are not always respected.

The decision of single countries is usually a consequence of treaty at community or global level; there exist many associations of countries, any of which has a higher or lower influence on members, such as UE, OECD, OPEC, ONU, WHO; each organization has different goals, from health to tourism to energy, and lots of countries belong to more than one association. Decision made by these organizations can have strong effect in the global system, and a striking example is the "United Nations Framework Convention on Climate Change" (UNFCCC), of which most countries all over the world adhere, which scope is to contrast the climate change. Governments belonging to it meet yearly in the Conference Of the Parties (COP), where progresses and changes are discussed, as long as new policies to be adopted. Several models adopt their results or expectations inside model assumptions, such the Sustainable Development scenario produced by IEA, which simulates how the energy sector has to change in order to respect the global heating below 1.5°C with respect to preindustrial period, limit suggested by COP21 (Paris agreement).

It could happen that a country decides to not respect a predetermined policy, as happened in the USA, when government in charge up to 2017 invested towards energy efficiency, but the next administration decided to change in favour of fossil, coal in particular, besides an exit from Paris Agreement. Being one of the main global CO2 producers per capita (about 16 tonnes/year, against 8 for China and 6.5 of UE, 2019) and a relatively large population, this country has a sensible impact at global level: an increase in emission will negatively counterbalance the effort of other nations.

To really promote a change is necessary to operate at least one of the two following actions: make the new initiative economically interesting, or make the old state of the art uneconomical, or even illegal.

Incentives are the favourable way to proceed: people prefer to be awarded to change something in their life rather than be penalized to maintain a habit, for instance, following a directive from European community (2001/77/CE), regarding a higher diffusion of renewable sources in member countries, Italy made a series of incentives called "Conto Energia", aiming at increasing photovoltaic installed capacity.



26 Increase in PV power and production after incentives on renewables "Conto Energia", Italian transposition of European Directive 2001/77/CE about renewable energy.

As shown in the picture, the photovoltaic was almost absent up to 2008, and thanks to these incentives, PV had been able to cover 7% of total electrical demand of Italy in few years, that is 22,1 TWh out of 314,3 In 2016 (GSE, 2017). A peculiarity is that several users observed a positive economical balance during the whole life cycle: installation of modules had not reduced the overall expenditure, but it made it profitable, which is quite uncommon considering that energy is a service which requires an expense.

Currently, at community level, many efforts have been spent in building energy efficiency, and several members are adopting incentives measures; UE estimates indicate that modernization of existing buildings can reduce 5-6% the total energy consumption.

The two previous examples are types of the first action already stated, that is make economical interesting an energy upgrade, while some examples of disincentive are the imposition of fees in imported or exported products or banish an activity, such as nuclear energy in several countries around the world, among which Italy. Despite this source has undergone a drop, we can not exclude a future interest in this technology to speed up a low-carbon society: it will depend on policies undertaken by countries.

In conclusion, policies have a huge impact on most outcomes of a global model, and a long-term prediction is quite unreliable: we can make reasonable forecast up to deadlines of regional international agreements, but plans can even change before that time.

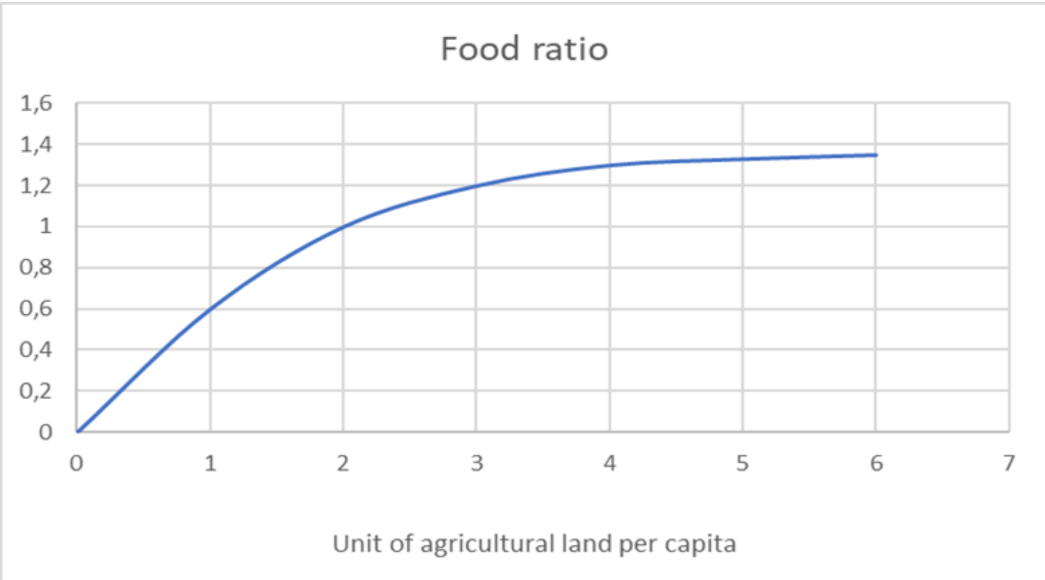
2.5.4 INTERDEPENDENT EVENTS

When the outcome of an event depends by a single action, it is easy enough to describe the relation between them, both under rational and mathematic point of view, as an object left from a certain height, following the same physical rules independently from cause or place of the earth where this action happens, and the only trick to pay attention at, is the right determination of present forces, other than correct boundaries condition. Even people who are not practical about dynamic equations know that the body falls until it reaches a surface able to sustain it, like the ground.

When we build a model having to do with situation where an effect could be produced starting from several causes, or an action could produce several effects, or both, there is a complication in the understand of the phenomenon, and an even bigger difficulty in the development of its systematic description. Models describing future scenarios contain lots of situations like these: in the case of oil price already discussed, its variation could be produced by energetic or environmental issues, both raised by producer or users, in order to favor or not its exploitation; geopolitical issues, which can be carried out lowering the price by a country producing it, to break the competition at global level or to equilibrate the market, or again, because of military conflicts, often broken out for the control of energetic reservoirs during contemporary history. As we can see, there are many elements, and all of them can potentially happen together in a chaotic way: making a prediction is extremely hard.

To explain more in depth the concept of interdependence, it is proposed a description about the surface land utilized for agricultural activity, closely linked to population: following numbers are purely illustrative and do not indicate a precise physical quantity (it is quite common to use fictitious values in complex system, as it will be shown in the next chapter).

The first consideration is that global surface is finite, and we assume it equal to 24000 million territorial units, then, each person needs 1 territorial unit related to buildings, streets, services, and various infrastructures. At this use we have to sum the ones related to agricultural activities which can not be higher than the



27 Food ratio as function of land per capita (World dynamics, J.Forrester)

difference between total available units (24000 million) and the ones needed for the population. It is finally introduced the Food Ratio, a parameter keeping in consideration the food quality as function of the amount of land used for agricultural purpose.

A food ratio value of 1.35 ensures a correct and healthy nutrition, and it needs about 5 territorial unit per capita; the lower is the units available per capita, the lower is the food ratio. If we have a land availability higher than a correct nutrition, we keep the food ratio constant, that is there is no overproduction.

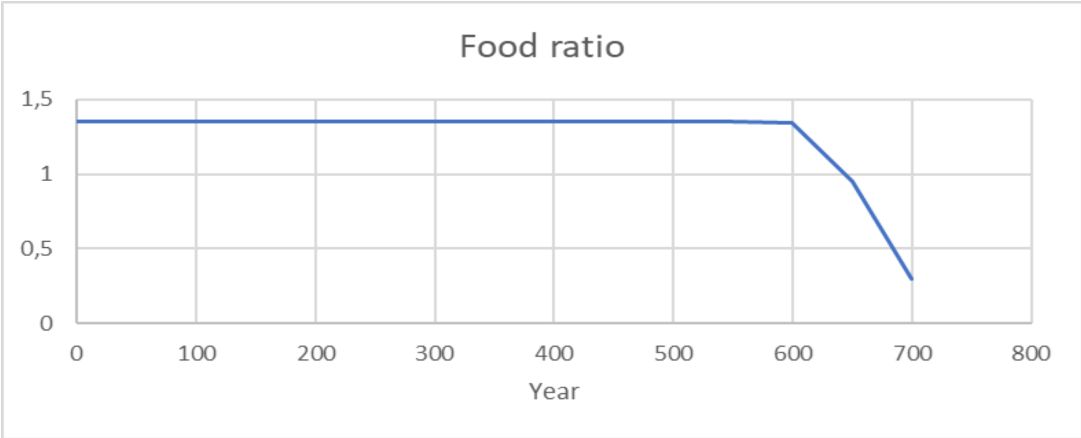
In the following table we can see the trend of food ratio as function of population, supposing the doubling time equal to 50 years (every 50 years the population doubles, typical progress of an exponential function with a yearly increase close to 1.4%), and the relative graph showing the food ratio during time.

YEAR	MILLIONS PEOPLE	MILLIONS OF TERRITORY UNITS OCCUPIED BY POPULATION	MILLIONS OF UNITS AVAILABLE FOR AGRICULTURE	AGRICULTURAL LAND PER CAPITA	FOOD RATIO
0	1	1	23999	23999	1,35
50	2	2	23998	11999	1,35
100	4	4	23996	5999	1,35
150	8	8	23992	2999	1,35
200	16	16	23984	1499	1,35
250	32	32	23968	749	1,35
300	64	64	23936	374	1,35
350	128	128	23872	186,5	1,35
400	256	256	23744	92,8	1,35
450	512	512	23488	45,9	1,35
500	1024	1024	22976	22,4	1,35
550	2048	2048	21952	10,7	1,35
600	4096	4096	19904	4,86	1,34
650	8192	8192	15808	1,93	0,95
700	16384	16384	7616	0,46	0,3

28 Variation of food ratio due to land occupation by population (World dynamics, J.Forrester)

Intuitively, an increase in population produces a decrease in land availability for agricultural use and an increase in food demand, thus, at some point we reach the moment where, in average, the food ratio goes below the correct nutrition value of 1.35. It does not matter the rates and numbers used for this analysis, this is the only possible scenario when we have an increase in population of a finite world: we can use an increasing rate of 1%, similar to the one of 2020, and we can consider a lower food ratio ensuring good nutrition thanks to higher food production per land, but the results are the same, only moved forward.

An element of primary importance is the speed of change of the characteristics of a system when it follows an exponential law (in this case the population): collapse happens in a short time compared to the whole interval considered.



29 The effect of exponential increase in population on food ratio (World dynamics, J.Forrester)

The topic just proposed offers some of many different elements in competition: correct nutrition and population are both influenced (or they influence as well, there is a relation) by land occupation. There are other aspects we can add, for instance, after a not sustainable use of land for agricultural purposes, the ground loses nutrients: the consequence is a productivity decrease (the terrain could also become unproductive). Other possible considerations are linked to the effective utilization of the ground; some areas cannot be cultivated or utilized for infrastructures because they have a landscape value, while others are designed as protected areas.

Interdependency can arise from almost any other sector of a global system: another element affecting the land use is the ecosystem pollution: using water for agriculture can reduce the efficacy of dispersion of some substances, with a positive effect for food (irrigation) and a negative effect for the environment; the same could be said for deforestation: it increases the amount of available land, with a negative effect on CO_2 absorption from atmosphere and a loss of quality of the soil nearby (this practice is quite common in South America).

The colloquial description of all possible consequences of an effect is relatively easy when picked alone, however, keeping track of all of them together is definitely more difficult. Trying to define these relations in a formal way, mathematically, is even worse, particularly when we face not quantifiable subjects: mechanization and digitalization tend to produce a negative effect on people occupation, this is a rational common thought, but how can we describe in a solid way this effect, and how can we take into account all the possible consequences such as unrest and social tension? To produce a reliable model, the first thing to do is to define all the relevant qualitative interactions between the element present inside the model, then it is necessary to quantify them, using or creating unique relationships. In the next chapter it will be proposed a global model aiming at this objective.

3 A GLOBAL MODEL

Whenever we deal with a complex system, including several but correlated aspects, the study of a single event goes in the background than the sum of all the ones that have an impact; the branch aiming at the description of these phenomena and the consequent generation of a model is called system dynamics. This subject was born around 1930 and its first applications concerned economic issues of companies, a relatively small system, and subsequently adopted for urban dynamics of cities and, moving towards bigger and bigger systems, it reached the global level.

The reason to produce a systematic global model arose in the second half of 20th century: people coming from different areas of the world started to worry about the human development and its relationship with the environment; in 1968 they give life to the Club of Rome (based in Winterthur, Switzerland). The pioneers of the group were Aurelio Peccei (Italian industrial) and Alexander King (Scottish chemist), followed by professionals working in diversified field: economy, politics, science, business, each of which characterised by concern in the analysis and promotion of a (more) sustainable way to live in this planet. The group strongly tried to cooperate with various government to highlight the problems produced by uncontrolled human activity and exponential growth, with unavoidable clashes with administrations and companies, especially the ones with a capitalistic view. The first important weapon used by Club of Rome was a report called "Limits to Growth", written in 1972 and subsequently improved, by a group of collaborators of the Group at the MIT, leaded by Donella Hager Meadows. Their starting point was the global model produced in 1970 by Jay Wright Forrester, presented at the beginning of this chapter, and then upgraded by the group of researchers, rework that will be presented from paragraph 3.5.

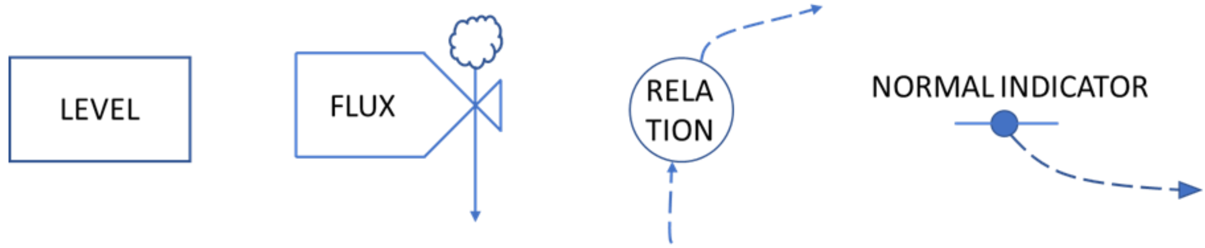
The meaning of global system in this case concern everything that care about human activity, such as social, economic, demography aspects, together with the relation that humanity has with the planet. The goal of those studies was to underline the negative aspects of the human development, which is normally seen as something of positive, towards itself and the environment, if this development is not kept under control. There were presented several scenarios about this model, both to observe what can happen in case the humanity will not take rational decisions to limit its impact, and for the definition of possible pathways to reach an acceptable equilibrium.

Despite this model has been used to describe the global system, it could be restricted to a part of it: a continent or a country, in which case the relations compounding it can be defined in a more precise way considering the inhomogeneity of the world.

3.1 GENERAL STRUCTURE OF THE MODEL

The model is focused on 5 macro features of the system: population, capital investment (excluding agriculture), natural resources, capital for agriculture and pollution, each other linked with numerous relations. The structure is easily representable with a graph thanks to the limited number of elements composing it:

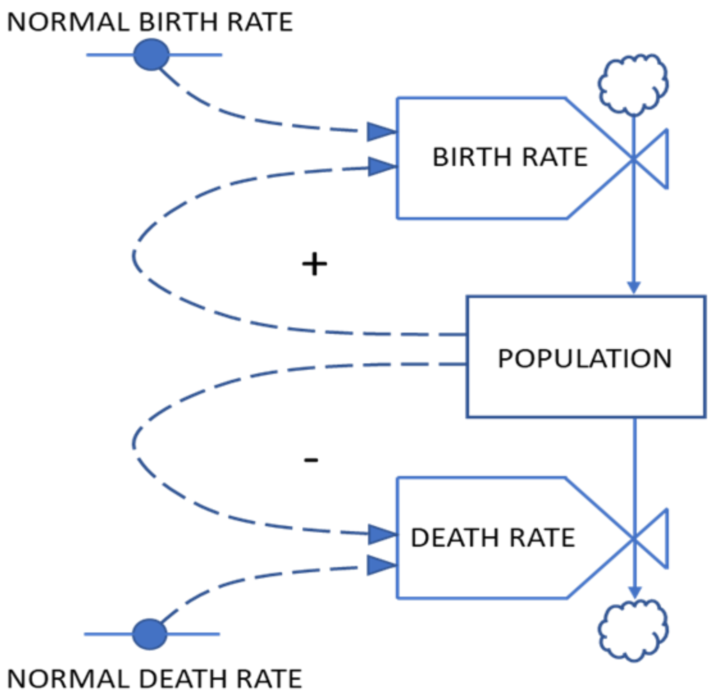
- LEVELS: they are the four macro features abovementioned and represent the net quantities of the subject in question in time, and they are graphically portrayed as rectangles. Making an analogy with a hydroelectric plant, a level is given by the amount of water in the reservoir.
- FLUXES: they are responsible for the level changes and can not being influenced by other fluxes; we represent graphically them as a kind of valve. Taking up the hydroelectric plant, fluxes are the incoming and outcoming flows of water (they change the level).
- RELATIONS: fluxes depend on levels and are linked with them by relations and indices keeping track of global variables; they are shown as circles, and the link between elements is displayed with arrows indicating the logical path to follow. In the hydroelectric plant, what affects the water to be turbined (outcoming flux) is given by the electrical grid request each moment (relation), while water supplies to basin (incoming flux) depends on hydrologic and climatic condition (relations).
- NORMAL INDICATORS: they are input data allowing us to quantify a phenomenon, assigning it a value based on statistical considerations, such as a birth or death rate for the period in exam (these values, as everyone in the model can, and should, change with time). In the plant a normal indicator is the yearly average incoming water flow.



30 Graphical representation of model elements (World dynamics, J.Forrester)

The symbol of fluxes is characterized by an arrow indicating an increase in the level if it enters into the latter, or a decrease if it exits from it; the cloud indicates a source or a sink of the flux and it has not particular interest.

Inside the structure there are many feedback loops, that are pathway composed of several subsequent elements starting in one point and arriving at the same one, closed on themselves. In practice a level is modified by fluxes related to it, and its variation produces another effect on itself caused by the loop. These are the kind of interconnections hard to be quantitatively determined. When a loop produces an increase in the level it is called positive, negative otherwise. It is now proposed a portion of the model including two feedback loops concerning the change of population.



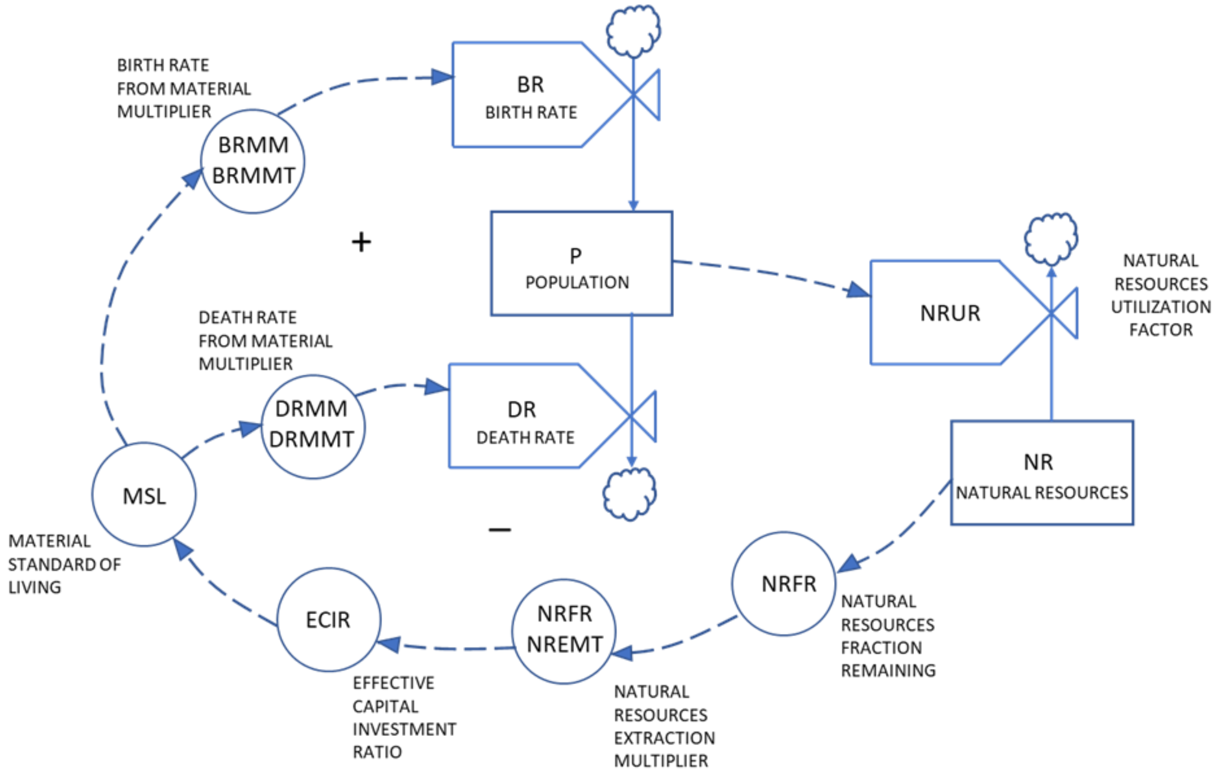
31 A portion of the system, including two feedback loops (World dynamics, J.Forrester)

There is only one level, the population, which can be modified by two fluxes: birth rate is the number of births in a period, generally one year, and it increases the population (arrow directed towards the level), while the death rate is the number of deaths in the same period, and it acts negatively (the arrow points outside the level).

Normal birth and death rate are imposed standard values, and in the year of model development, that is 1970, their values are 40 births for 1000 people, so 0.04, and 28 deceases for 1000 people, and so 0.028. These normal indicators represent births and deaths in normal condition, without taking into account all the possible effects that can affect them; even if reasonable, they are "fictitious", because we cannot actually define a normal situation considering that these values, as any indicator in the model, are intrinsically dependent on several circumstances, not separable from them. It is possible that a change in some indicators produces a modest effect, as for the normal birth rate, but as shown later, this is not true for all of them.

In the picture there are two feedback loops, one positive and one negative, identified by a + a – respectively. Considering the positive one, new births are obtained multiplying the normal birth rate by the population, so an increase in population produces an increase of the flux, that is the number of births, because keeping the rate constant, the product between it and the population increases. The same could be said for the deaths: keeping the death rate constant, an The The same can be said for the negative loop: keeping the rate constant, an increase in population produces an increase in deaths. These opposite effects are not equal because the rates are different: the birth rate is higher and so the population rises; if we want to reach an equilibrium there are two possibilities: weaken the positive loops or strengthen the negative.

As it will be shown later, there are many factors affecting fluxes and, as consequence, several loops will be generated. The purpose of this analysis is not to describe the whole model, but to provide the capacity to focus on any part of it in order to be able to make criticisms. It is important to underline that there is no intention to make a non-constructive criticism about this, or any other model, but to raise awareness about the results, which can be easily unreliable. The structure of this model is quite sophisticated and reasonable, surely incomplete, but effective; problems arise turning a line, a geometric figure representing a clear concept under qualitative point of view, into a series of numbers or equations.



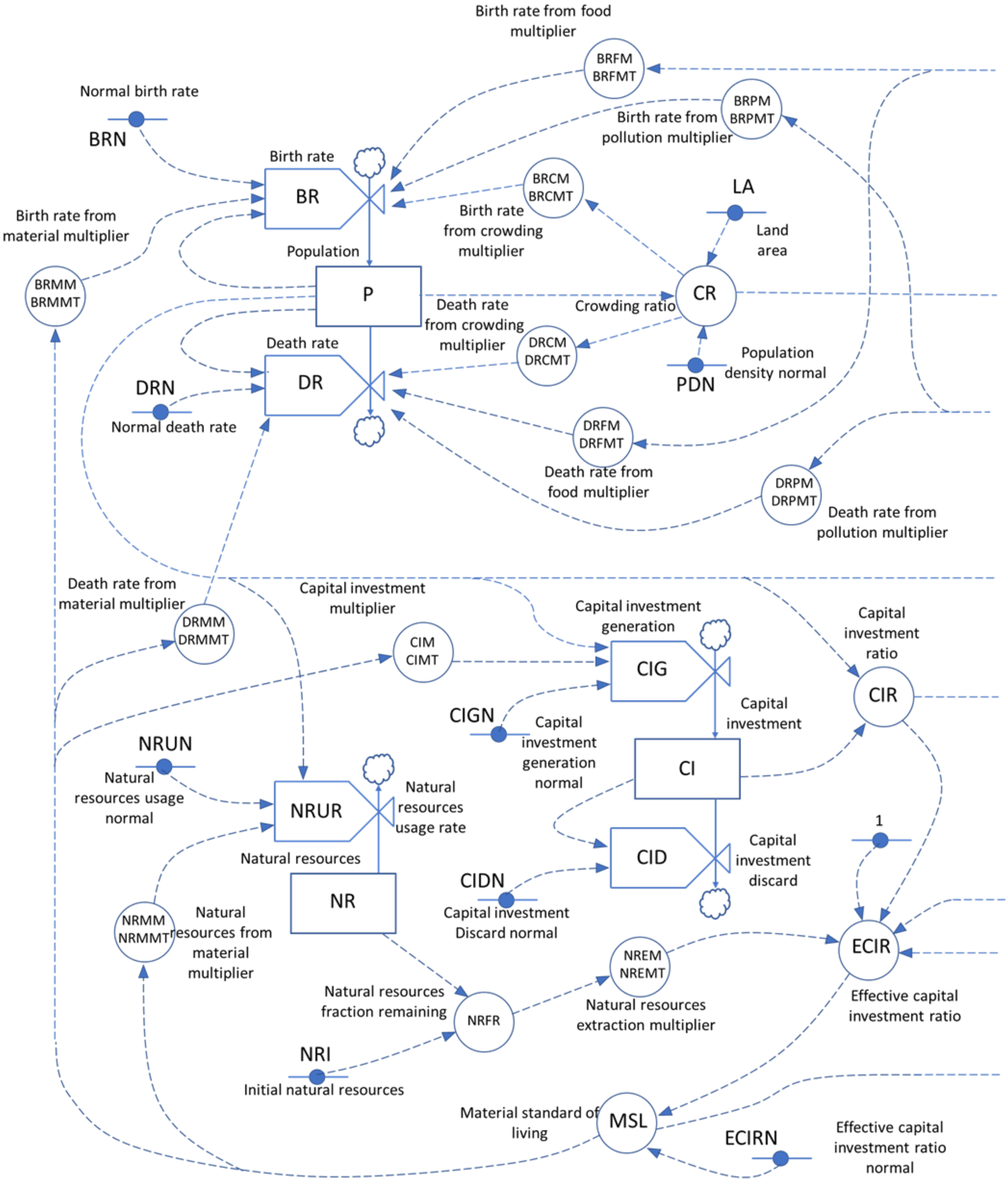
32 A portion of the system, including more levels and fluxes (World dynamics, J.Forrester)

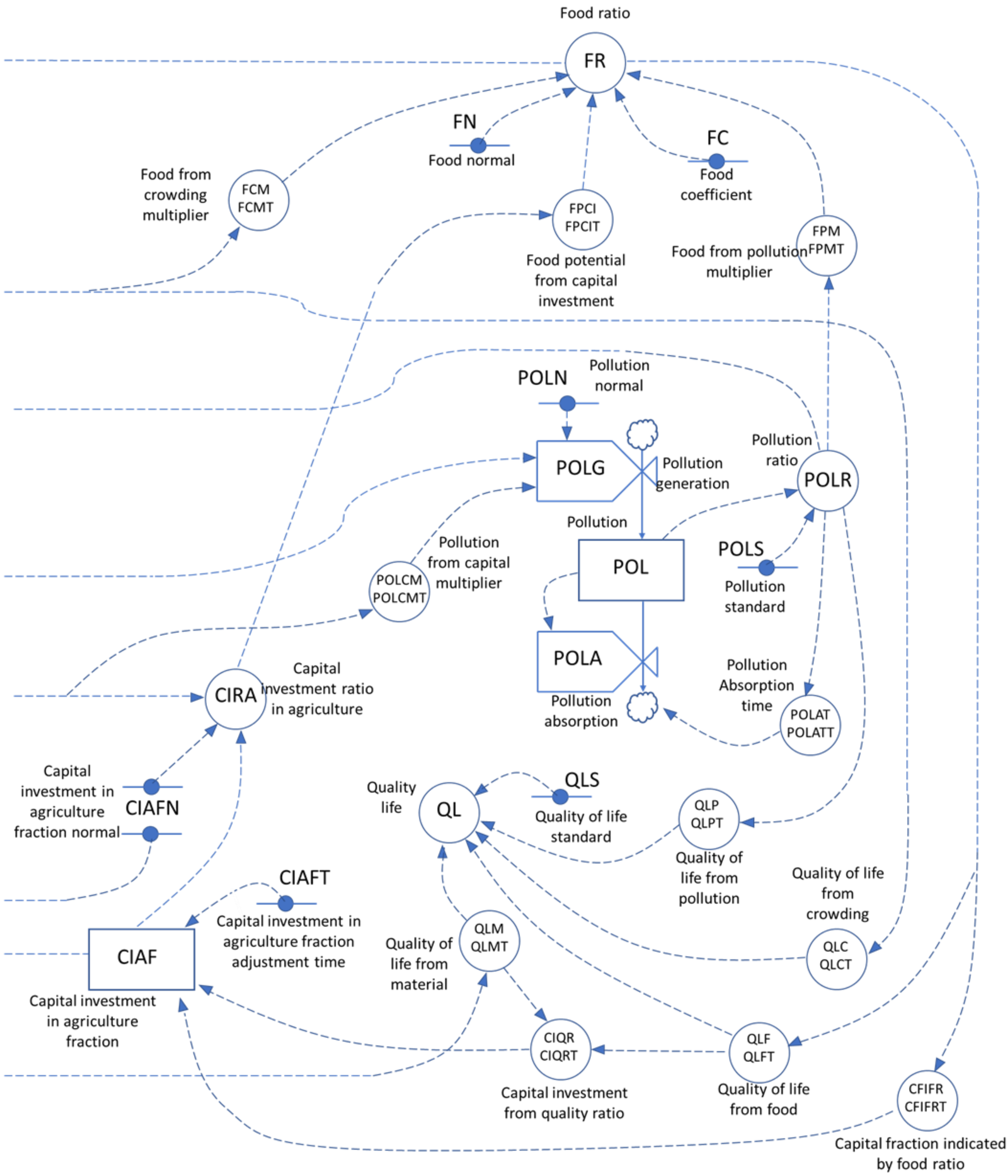
It is proposed a bigger and more articulated portion of the model than the previous one, where appear several relations and another level: natural resources. Each element, other than a name, has a short abbreviation. The abovementioned normal indicators of normal birth and death rate are not present in the picture to keep clearer the new relation but, of course, they are still valid; actually, lots of relation are missing, and they will be all included in the complete diagram, which will be shown later.

The population P has a direct effect on the natural resource utilization NRUR: an increase in the first produces an increase in the latter, consequently, there is a bigger flux concerning the level of natural resources NR. The quantity of remaining resources NRFR tends to lower and this has a negative effect on the extraction NRFR/NREMT because it is necessary to reach reservoirs more and more difficult to access and of lower quality (accessible and abundant reserves are the first to be exploited), This leads to a weaken of the effectively invested capital ECIR, cause we have to spend more to obtain the same, and a variation on the material standard of living MSL: the bigger expenditures for extraction are, in overall, decurted from what is spent for consumer goods and services if the extraction is made by the nation, or in the case the exploitation is conducted by private company there will probably be an increase in prices. The change in MSL has an effect on both birth and death rates: its reduction tends to increase the birth rate (this concept seems counterintuitive and will be explained), favouring the positive feedback loop, but at the same time it increases the death rate.

In this model is quite common the presence of a relation affecting two opposing fluxes related to the same level, and sometimes it generates two loops with the same sign; an example, not present in the picture, regards the already seen food ratio FR, an index that keep track of the food availability, which when reduced, produces a reduction in natality and an increase in mortality: they are both negative feedback loops.

It is now shown the whole global model.


Birth rate from food multiplier
BRFM BRFMT
Normal birth rate
BRN
BRPM BRPMT
Birth rate from pollution multiplier
Birth rate
BR
BRCM BRCMT
Birth rate from crowding multiplier
LA
Land area
Birth rate from material multiplier
BRMM BRMMT
Population
P
CR
Crowding ratio
Death rate from crowding multiplier
DRCM DRCMT
Death rate
DR
PDN
Population density normal
DRN
Normal death rate
DRFM DRFMT
Death rate from food multiplier
DRPM DRPMT
Death rate from pollution multiplier
Death rate from material multiplier
DRMM DRMMT
Capital investment multiplier
CIM CIMT
Capital investment generation
CIG
Capital investment ratio
CIR
CIGN
Capital investment generation normal
Capital investment
CI
NRUN
Natural resources usage normal
NRUR
Natural resources usage rate
Natural resources
NR
CID
Capital investment discard
1
CIDN
Capital investment Discard normal
NRMM NRMMT
Natural resources from material multiplier
NREM NREMT
ECIR
Natural resources fraction remaining
NRFR
Natural resources extraction multiplier
Effective capital investment ratio
NRI
Initial natural resources
Material standard of living
MSL
ECIRN
Effective capital investment ratio normal

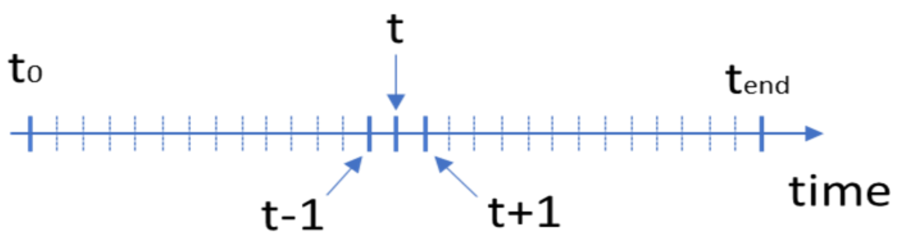


33 Complete model representation (World dynamics, J.Forrester)

3.2 PARTICULAR STRUCTUR OF THE MODEL

After having proposed the model in a general way, we can make specific considerations, analyzing how relations are represented in a quantitative way. Like before, there will not be proposed all the relationships of the system considering that the way they are written is somehow homogeneous; to have a deeper knowledge about them, consult the book World Dynamics by J.Forrester.

For the simulation of the model was chosen the DYNAMO language, but without getting lost into the definition of functions and scripts, it will be proposed the equation in an intelligible way, using the classic concept of numerical analysis time subdivision: current quantities are defined using the subscript "t" while previous and next time interval as "t-1" and "t+1" respectively. Whenever a flux is introduced, it refers to the increase or decrease from time "t-1", so the previous one, and "t", the current. After the determination of all characteristics of the model at time "t", it turns into "t-1" in order to proceed up to the desired point in the future. Timestep used in the model have a length of 1 year.



34 Time discretization (t_0=1900, t_{end}=2100 for simulation in World dynamics, J.Forrester)

Simulations start from 1900, depicted as t_0, and the same subscript is used for any indicator characterizing the system at initial time, and they are generally imposed using likely or measured values for that year; the analysis proceeds until 2100 and, in some cases to 2300.

In the previous paragraph had been proposed some subjects related to the level population, so there are going to be analyzed some of the already seen relations, together with the other 4 elements present in the following scenarios (pollution, natural resources, capital investment and life quality).

The easiest parameters to be calculated are the levels: we take the value corresponding to the previous timestep and we add or subtract the relevant fluxes associated to it.

3.2.1 CALCULATION OF POPULATION (PEOPLE)

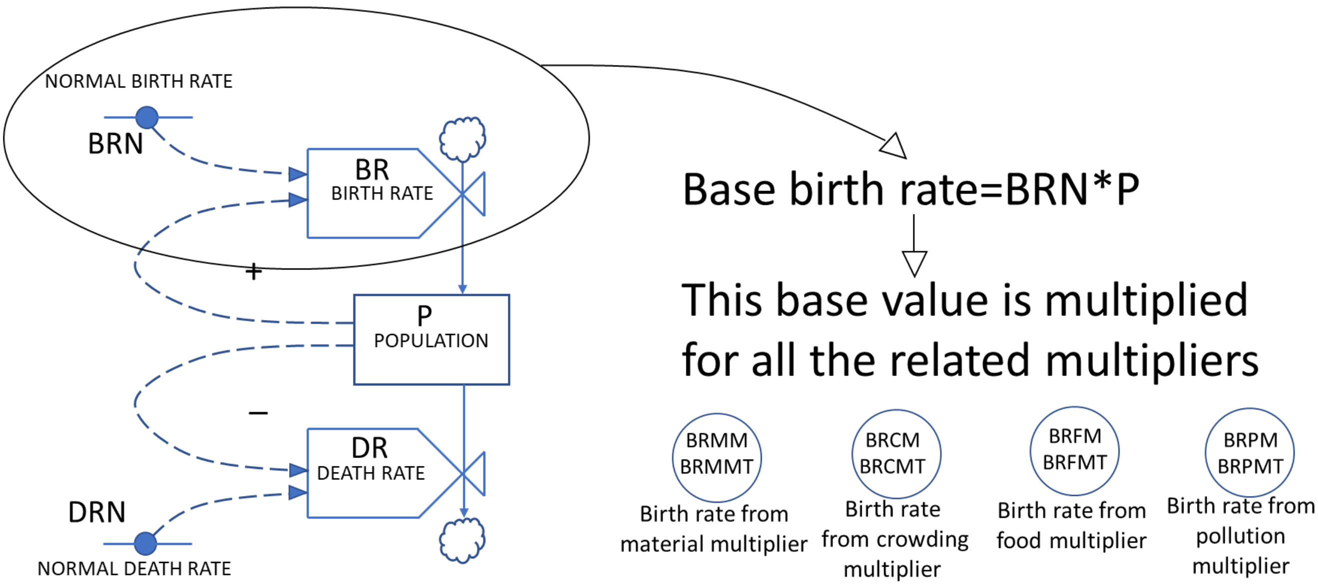
Population is determined summing the new births and subtracting the deceases whit respect to the former level.

$$P_t = P_{t-1} + BR - DR$$

P=population BR=birth rate DR=death rate P_0=1,65*10^9

3.2.2 CALCULATION OF BIRTH RATE FLUX (PEOPLE/YEAR)

Fluxes are more articulated to be qualitatively determined because it is necessary to understand which parameters affect them, but once this is done (so when the graphical representation is complete), to calculate their value, it proceeds in two phases as shown in the example of the picture.



35 Steps to calculate a flux (World dynamics, J.Forrester)

At first the base rate of flux it is calculated, which is given by the product between normal rate and the associated level. The second step is to multiply this value for all the related dimensionless multipliers, which are indices affecting the flux, coming from different branches of the model. In this example the flux is the birth rate, and besides the normal birth rate, it is dependent on material, crowding, food and pollution issues.

Each multiplier is set to 1 for the conditions of 1970, which is a sort of reference year: when a multiplier moves away from this number, the condition is getting

better or worse depending on the issue considered (a decrease of birth rate due to food shortage is negative). Multipliers interval is between 0 and some units, and it is clear they have a comparing meaning: their values have a meaning when compared each other.

$$BR = P_t * BRN * BRFM * BRMM * BRCM * BRPM$$

P=population   BR=birth rate   BRN=birth rate normal=0.04

BRFM=birth rate from food multiplier

BRMM=birth rate from material multiplier

BRCM=birth rate from crowding multiplier

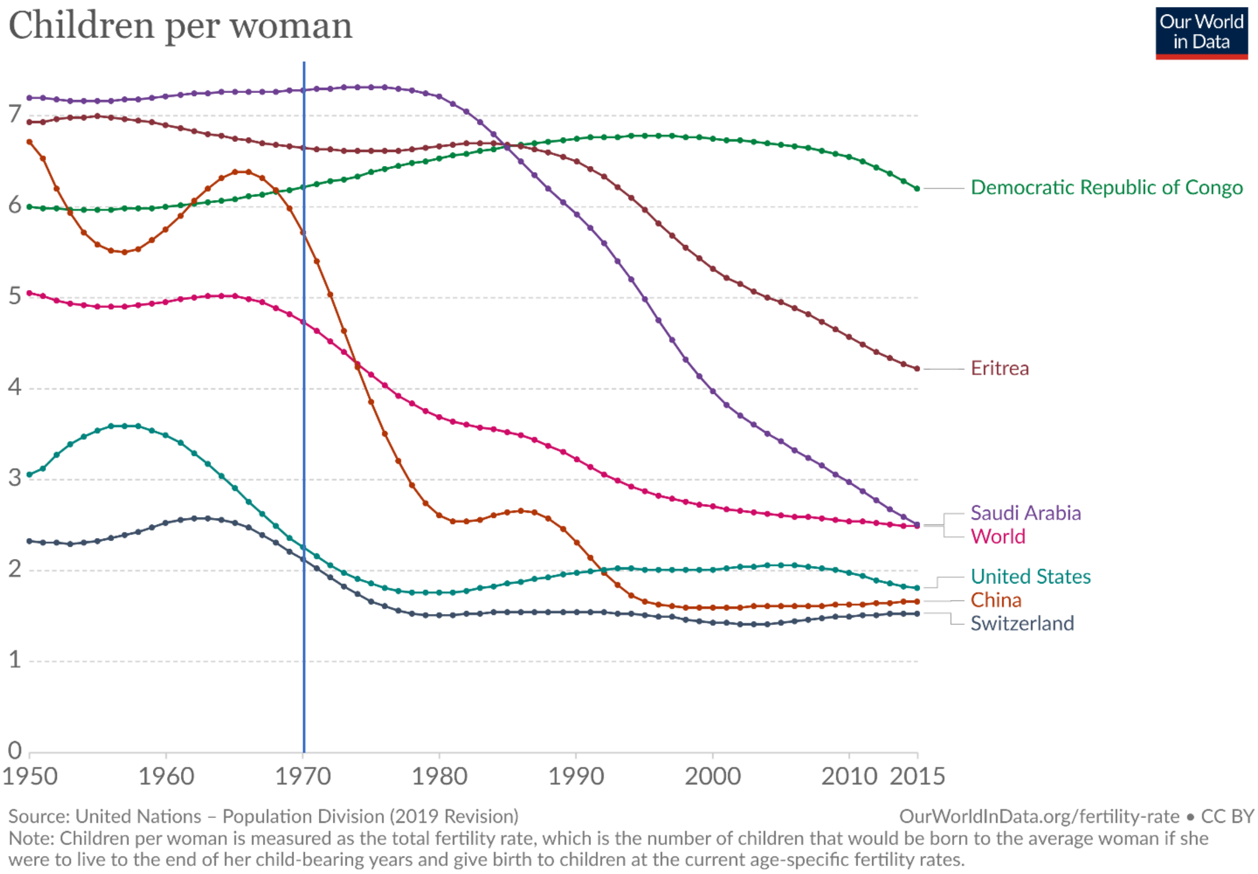
BRPM=birth rate from pollution multiplier

The most sensitive points are precisely the multipliers because they are characterized by a series of values dependent on the causes generating them, trying to estimate each of them without the influence of the others (which is actually impossible), such as the BRFM (birth rate from material), only dependent on MSL (material standard of living). This procedure is substantially correct, but the quantitatively established relations have a “logic” origin, they come from observations and situations occurred in past, and they often have not a mathematical description at their base: in practice these relations are built from experience, so they are easily affected by errors.

3.2.3 CALCULATION OF BRRM (BIRTH RATE FROM MATERIAL MULTIPLIER)

This multiplier modifies the birth rate keeping track of material condition of life, that is goods and services (among which healthy ones), present in the society. It is clearly an average value and it is underestimated for developed countries and overestimated for developing countries. Before showing this relation, is necessary to understand the reason for giving some values as function of material standard: the base logic comes from observation concerning the richness of a country with the natality.

In the following graph it is shown the number of children per woman, starting from 1950 to 2015 for six countries and the global average, values strictly linked with birth rate. To properly use these numbers, we should verify that the ratio between men and women is almost the same for any country to avoid over or underestimations. After a quick look at this ratio for several countries, it seems that the values are quite homogeneous, with some unavoidable oscillation and not particularly influential.

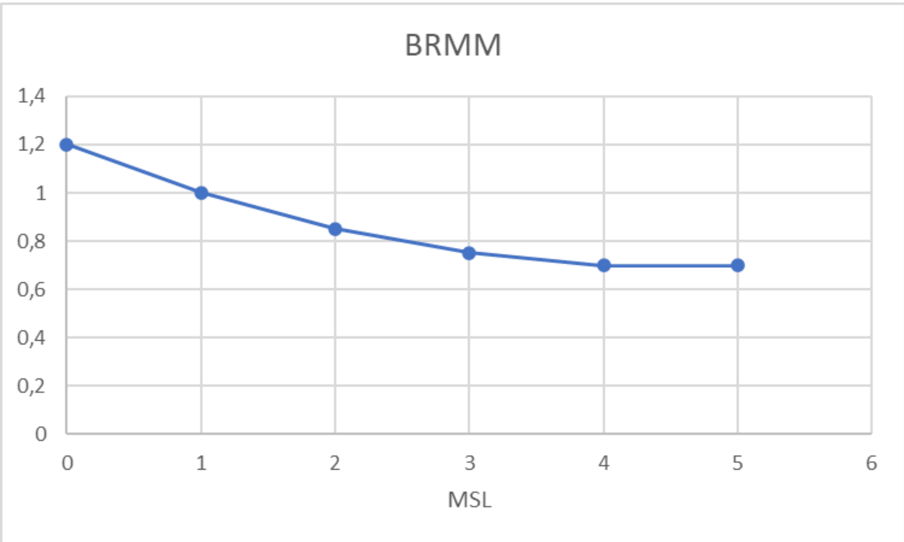


36 Children per woman, a value strictly linked to birth rate (Our World In Data)

The majority of countries with a low PIL (directly related with material standard of living) among which Eritrea and Democratic Republic of Congo, have birth rate sensibly higher than richer countries such USA and Switzerland. There are some exceptions, for instance in Saudi Arabia, where in 1970 it shown quite high natality despite it was not a poor country.

The reason behind difference in birth rate against richness is that poor countries do not pay attention to birth control, nor at personal level and at social one, furthermore, children actively contribute to family sustenance: they can work or take care of smaller children, allowing parents to work. In industrialized countries instead, children need a lot of attention and require an important expenditure to grow up; in the second half of 1900 schooling used to elongate rather than previous decades, where working before the age of majority was common: in that period, in industrialized countries, children stopped to be seen as a help for the family, but as an affectionate desire. Summing this fact to the high cost to maintain children, the result is a decrease in birth rate.

The author of the model, basing on data available at that time, tried to quantify the link between birth rate and material creating a table of BRMM as function of the MSL.



MSL	BRMM
0	1,2
1	1
2	0,85
3	0,75
4	0,7
5	0,7

37 Imposition of birth rate from material multiplier, as function of material standard of living (World dynamics, J.Forrester)

A higher material quality of life tends to decrease the birth rate up to reach a stable value. The first uncertainty from this multiplier, and for anyone present in the model, is that we are trying to turn a clear situation under logic point of view in something that does not exist, or better, which is not reproducible: we cannot analytically demonstrate this relation and, at the same time, we cannot impose inside the whole model to keep all the others parameters to verify if it is actually valid, as often happens in the engineering field when an experimental model is built.

It is clear that the commendable goal of the author was to create a formulation not yet existing, but we must pay attention to take the values as a representation: they are not real characteristics of nature.

Another consideration is that the value of BRN previously used is kept constant at. In reality the model is able to changes many variables, but the author decided to maintain it the same for the whole simulation. As we can see in the graph containing the number of children per woman during time, the global trend has moved from about 4.8 in 1970 to 2.5 in 2015: it almost suffered a halving. There could be several causes to this change, and one of them is surely a change of the normal birth rate.

The last consideration is linked to the fact that, imagining a future with a lower quality of life in general (as many scenarios propose), among which the material standard of living, most affected countries will likely be the industrialized ones because in the developing or undeveloped countries these standards are currently low, and the society proceeds in an almost autonomous way, without being particularly affected by a global change. As a consequence, following the trend of graph about the multiplier, the birth rate should increase, but industrialized countries have, as previously seen, a relatively good education ant the culture of birth control, and the probable effect of a decrease in quality life is not an increase in births, but a decrease, caused by lack of confidence for future conditions the children will face.

3.2.4 CALCULATION OF POL (POLLUTION)

This level indicates in a quantitative way the global pollution, but unlike the population, which is described by the effective number of people, POL is an index that does not represent a real and well defined quantity. As happen in the variables of state of thermodynamics (as entropy or enthalpy), the proposal of the author is to model the pollution in a way in which, what really matters, is not the punctual value of a parameter, but the comparison between two or more of them. POL does not represent the physical amount in terms of tonnes of pollutants into the environment, and it is not able to differentiate between different substances, or again it cannot keep track of the path they follow (biosphere, hydrosphere, atmosphere or anthroposphere), how they accumulate or how they are absorbed: it tries to figure out the global pollution as a whole.

Another issue about the model is that it does not take into account possible correction actions, of any type (economical, demographical, linked to pollution), and together with the previous simplification, make it impossible to implement the reduction of one specific pollutant. Many elements of the model are characterized by these limitations.

Being a level, pollution is determined summing and subtracting fluxes related to it from the previous one; the initial value in 1900 is set to 2*e8, equal to 1/8 of the standard in 1970.

$$POL_t = POL_{t-1} + POLG - POLA$$

POL=pollution POLG=pollution generation POLA=pollution absorption

POL_0=2e8

3.2.5 CALCULATION OF NR (NATURAL RESOURCES)

Natural resources is a level and we have only one flux; it includes all the non-renewable resources.

$$NR_t = NR_{t-1} - NRUR$$

NR=natural resources NRUR=natural resources usage rate NR_0=9e11

The level NR, as for pollution, does not provide the real reserves, but simulates a global average composed by all finite resources: metals, fuels, minerals. To determine its amount, we impose a per capita resource consumption, equal to 1 in 1970, in order to have a total consumption NRUR (natural resources usage rate) of 3,6*e9, determined multiplying the population for the per capita value. In the previous and following years, this index is modified depending on the prediction about change in consumption.

We can already identify two forcings about the way we calculate this level: firstly, we have only one exiting flux, while as we have seen in chapter 1 for oil reserves, the amount of a resource can increase when new stocks are found. Secondly, there is not a differentiation between several resources; it is like any of them is used with a rate dependent on the total reserve, and they will all run out at the same time. In reality many mechanisms are triggered aiming at the exploitation reduction of resources moving to the shortage, in favor of a more abundant one. Among these mechanisms we can point out an increase in price, a sticking to processes with lower waste, a change in material towards a resource more accessible with similar, or better, characteristics, or even by recycling.

One of the biggest assumptions made regards the availability of resources, which is set at 250 years at the consumption rate of 1970, creating the NR_0, In the table below is shown the life of some resources, considering the rates and known reserves of 1970, in years.

Aluminium	100		**Iron**	240		**Nickel**	150
Chrome	420		**Lead**	26		**Oil**	31
Coal	2300		**Manganese**	97		**Silver**	16
Cobalt	110		**Mercury**	13		**Tin**	17
Copper	36		**Molybdenum**	79		**Tungsten**	40
Gold	11		**Natural gas**	38		**Zinc**	23

38 Some resources reserve in 1970 (Limits to growth, Meadows)

We can see many inconsistencies between real values and the ones proposed by the table, where several resources should be already run out; these numbers confirm both the variability of known reserves and their utilization rates. Any prediction about an average total year duration, as 250 years in the global model, is quite risky: we cannot make a precise evaluation of this number.

3.2.6 CALCULATION OF CI (CAPITAL INVESTMENT)

For the year 1900, it was chosen as a reference, a per capita value equal to 0.25 (that, as many indicators, has not a real economical meaning), and multiplying it by the population, 1.6 billion in the same year, we have the initial condition CI_0.

$$CI_t = CI_{t-1} + CIG - CID$$

CI= capital investment   CIG=capital investment generation

CID=capital investment discard CI_0=4e8

3.2.7 CALCULATION OF QL (LIFE QUALITY)

Life quality is an index which has not an effect on other elements of the model; looking at the graphical representation, we can see only arrows pointing at it, without exits, but it is an important parameter to describe the human condition. To determine it, the standard quality of life, equal to 1, is multiplied by 4 multipliers coming from different part of the model.

$$QL_t = QLS * QLM_t * QLC_t * QLF_t * QLP_t$$

QL= life quality QLS=standard quality of life=1

QLM=quality of life from material QLC=quality of life from crowding

QLF=quality of life from food QLP=quality of life from pollution

3.3 SCENARIOS GENERATED BY THE ORIGINAL MODEL

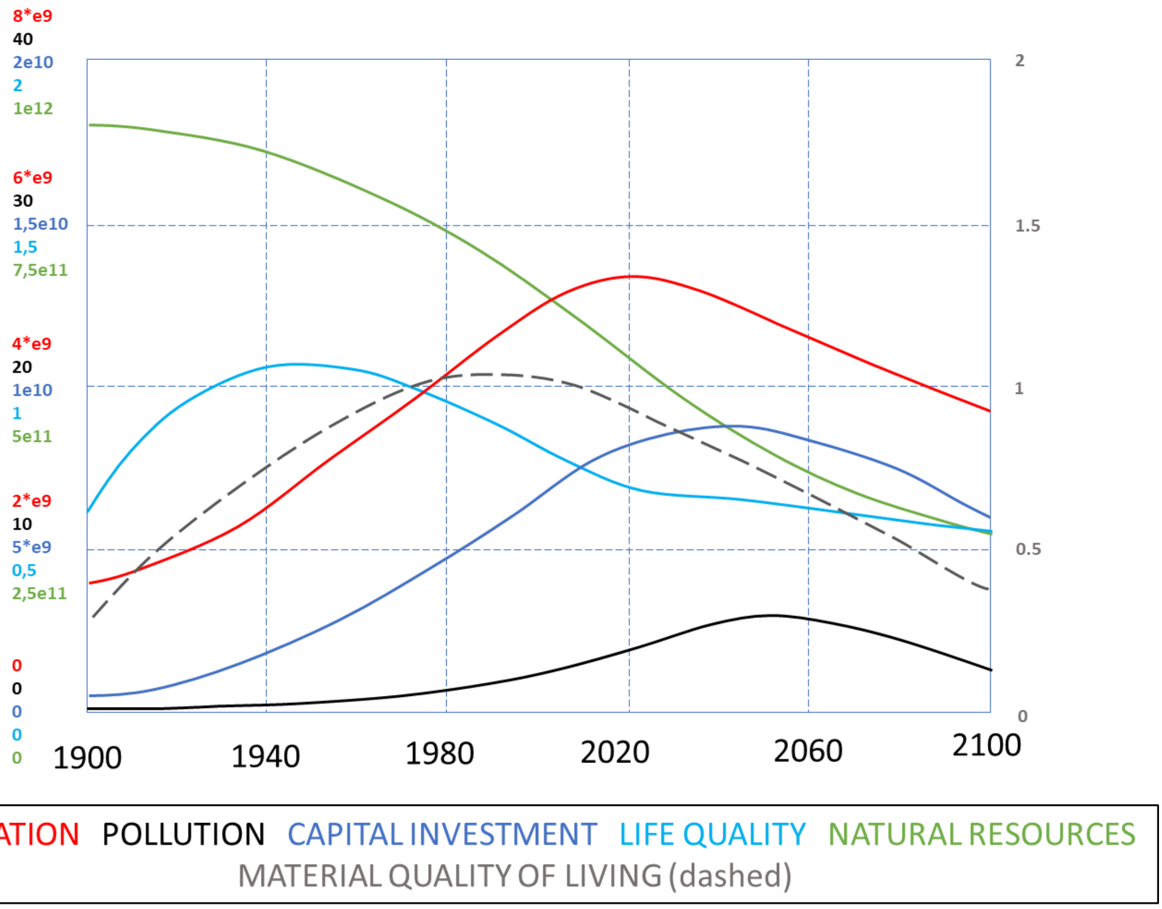
In this paragraph it is going to be presented some of the scenarios simulated in 1970 (all the scenarios generated in that year, together with deeper descriptions, are available in the book World Dynamics), and it will present how the outcomes differ from the measured from reality, other than the unreliability of some assumptions implemented in the model.

Scenarios are proposed using a graph containing 5 fundamental factors of the system: 4 levels (population, natural resources, capital investment and pollution) and the life quality; we can also find some interesting indices for particular cases.

These 5 characteristics has been presented in the previous paragraphs, and their values are shown in the left margin of graphs, while the peculiar characteristics are represented with a dashed line in the right margin.

3.3.1 STANDARD SCENARIO

This is the scenario generated when the global factors and trends of 1970 are maintained stable; its aim is to provide a prediction of future events without applying changes in the global system of that year.



39 Standard scenario (World dynamics, J.Forrester)

In this scenario we face a crisis due to natural resources shortage: between 1970 and 2000 it is expected an increase in utilization factor of 50%, and after this period the capital investment drops because of a lower resource availability and a larger and larger difficulty of extraction; the population rises up to a peak in 2020, than it will reduce as consequence of the decline in life quality, started years before. Pollution does not affect strongly the global behavior: it increases sensibly with respect to 1970 (almost 6 times), but without becoming an issue for the other elements of the model, it mostly suffers from them. It is also shown the material quality of living, reaching a peak some years after the life quality.

We can observe a decline in human condition, but unlike other scenarios, it happens in a soft way, without quick changes, but in 2020, if not before, we can exclude a trend like this one.

A questionable element is given by both the life quality and the material standard of living. Starting from the first, it is quite risky to say the life condition is now worse than between the first postwar period to today. Life quality is a parameter extremely hard to be determined; a way to estimate it is making surveys regarding people satisfaction about a sample of population, or measuring life expectation or indices related do it, or again comparing economical parameters or linked to individual freedom. Practice like these are useful to have a general idea about cannot be considered reliable as a whole, furthermore, they are not made systematically for each country and the current administration could modify the answers, or the population is not in the condition to freely answer. Consulting some graphs of the website Our World In Data, it seems that in last 20-25 years, several countries has been experimenting a constant personal satisfaction, with a slight increase for undeveloped or developing ones, while developed countries we can sometimes look at a decrease, such as in USA; looking back to the scenario, it presents a strong decrease in life quality.

There is no doubt that the material standard of living of today is surely higher than any period before now, while the scenario gives value similar to those of the first years of 1900. From the pure material point of view, today in industrialized countries there is access to any product we desire, and even in less developed parts of the world is found an average improvement. Technologies and practices used for getting life better and facilitate heavy work, tend to be adopted by developing countries later than industrialized ones, where they become obsolete over the time.

The latter concept is valid for material goods, and we can think at how cars are no longer a luxury item, or at instruments that in past were used almost only by professionals, such as cameras and photographic development chambers, today easily accessible. Even services, health and school infrastructures or public administration are part of the material standard of living; like what already exposed, there is a general increase in their efficiencies, mainly as a consequence of the always and always diffused digitalization: many operations could be done online, saving time rather than moving to offices.

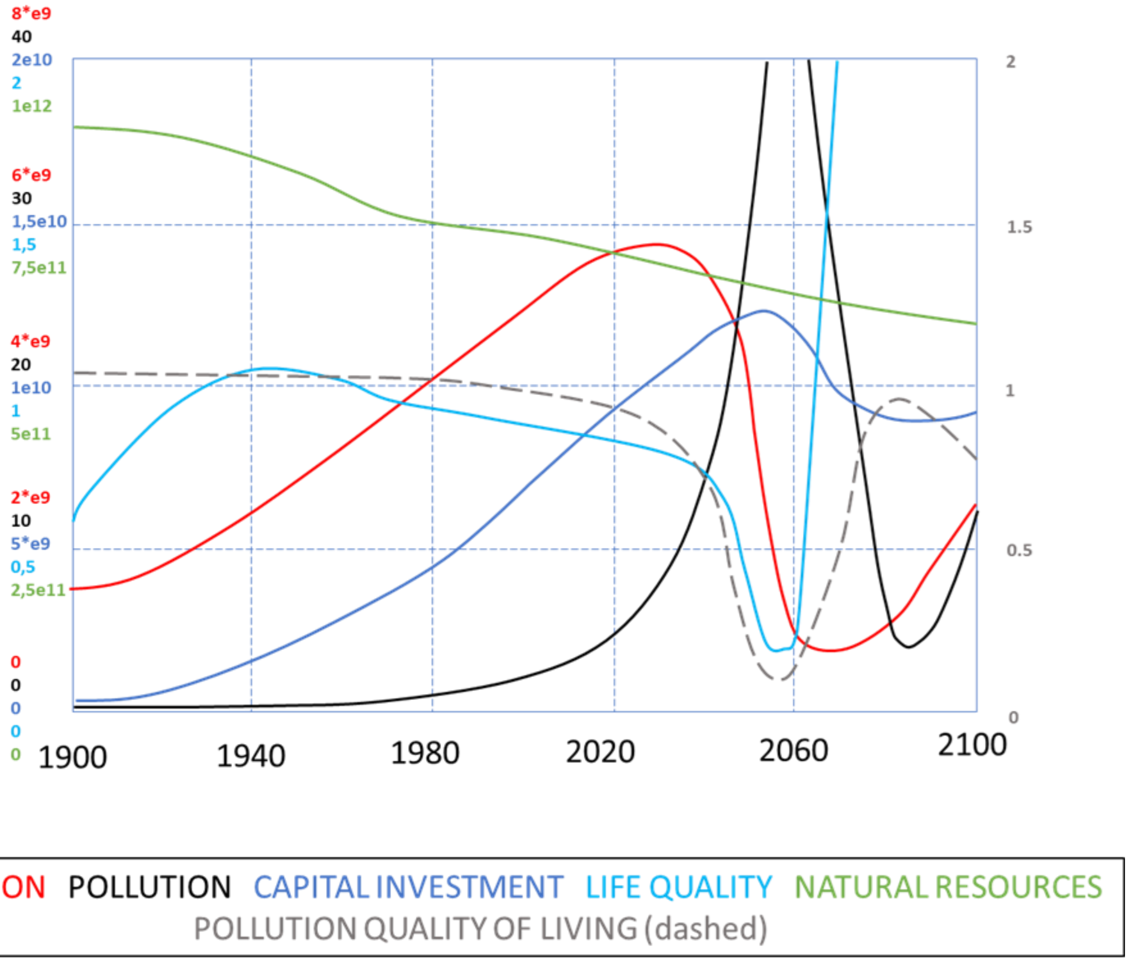
Among those proposed in the graph, the more discordant one is population, reaching a peak of about 5.5 billion in 2020, when we have actually overcome 7.5 billion, almost 8, and we are following a reduction in birth rate but still not a negative rate, so we are not at the peak. This data is of outmost importance to understand the unreliability of the scenario, because demographic growth is the easiest parameter to predict and, as shown in a picture of a previous chapter, ONU's estimations in 1980 trace extremely well the real growth, such as several other predictions of different agencies.

If the outcome for a “easy to determine” element such population is quite far from the measurements, it is legit to doubt of other indices like pollution or capital investment, which are not described by a concrete and real parameter. Anyway, the author itself thought this is not the most likely scenario.

3.3.2 SCENARIO WITH REDUCTION OF RESOURCES UTILIZATION

In standard scenario the decline takes place by natural resources run out, consequently the author decided to modify the normal rate of resource utilization NRUR from 1 to 0.75, keeping all the other parameters constant. The trend of main characteristics of the system after the change is shown in the following picture.

In this scenario we observe again a decline, but it takes now place by a strong increase in pollution and, unlike the first case, it happens rather quickly. Natural resources reduce without raising worries, promoting an increase in capital investment for a prolonged time; this effect together with the increase in population, generates an exponential and uncontrolled rise in pollution between 2030-2040. Pollution tends to sensibly decrease birth rate and increase deceases, causing a drop of population and life quality, but due to delays of the system, there is a continuous pollutants accumulation even after a reduction in their production (pollutant life cycle is strongly dependent on substances, but it can last decades or more). Once the pollution absorption takes the upper hand with respect to production, the life quality undergoes a great rise, followed by a slower increase in population. An important issue is the similarity between curves of life quality and life quality due to pollution: the other effects related to the first index are almost negligible.



40 Scenario with reduction of natural resources utilization (World dynamics, J.Forrester)

We notice again an underestimation of population than the reality, and the peak is some years late rather than the first scenario.

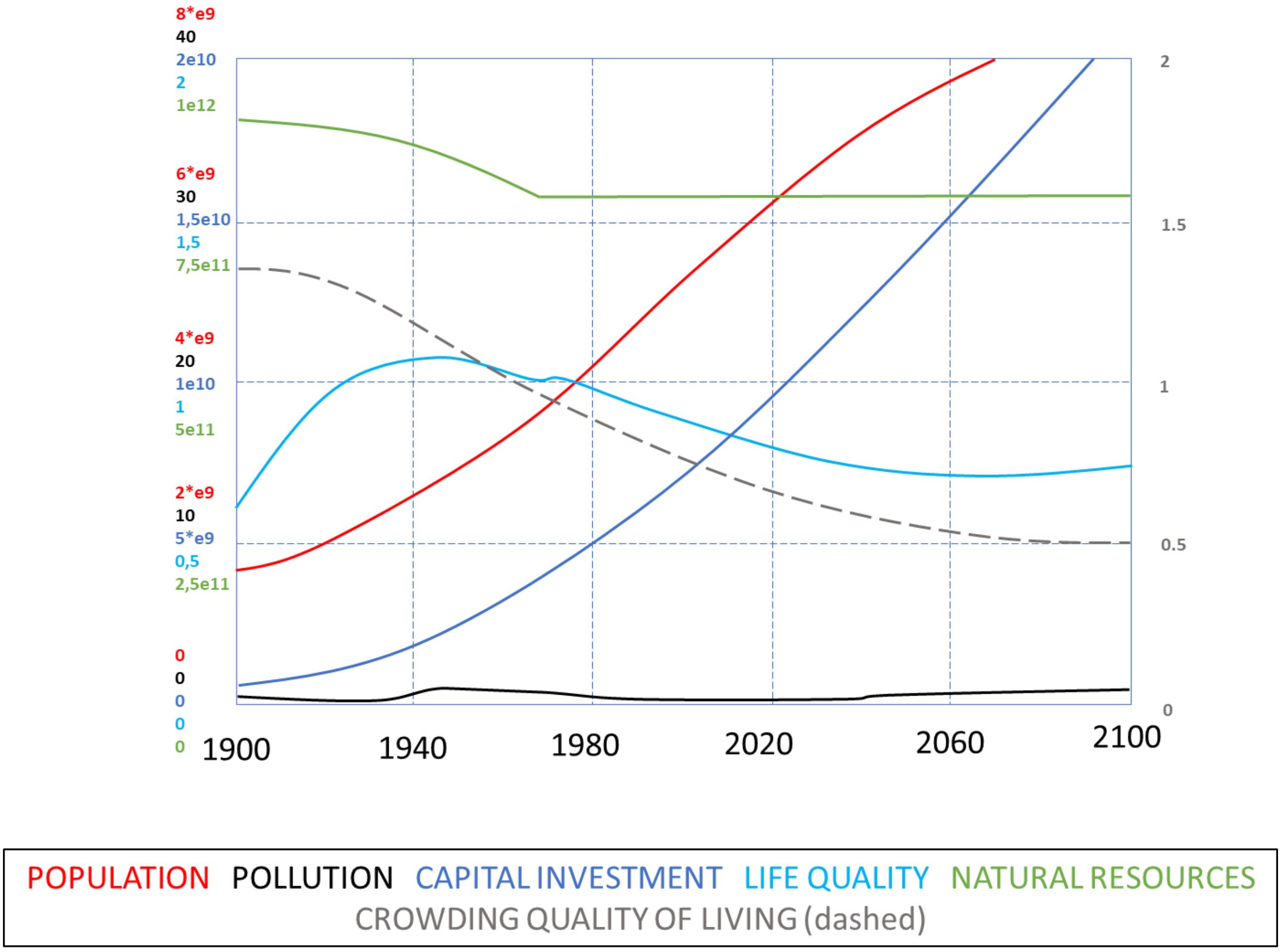
Considering that almost any parameter of the model is artificially built and, as already presented, they are not able to fully describe the phenomenon involved, even an imposed change in one of these indices produces not particularly reliable outcomes. Is the case in the reduction of 25% of NRUR, which is arbitrarily constrained, supposing the qualitative argument where the amount of material needed to produce a service or a good, decreases thanks to a better manufacturing or extraction process, such as the example of devices for data storing, presented in chapter one, but a quantification of a change based on an already forced systems, forces it even more. From a purely intuitive point of view, it is hard to believe that a moderate change of an index (from 1 to 0.75), in a model where there are dozens of interconnected parameters and important resistance to changes in the structure itself, can modify in such a heavy way and in short time the outcomes.

There are two other aspects unconsidered when is made a change in the model, and they are generally valid for any scenario. The first one is that an imposition of am indicator value is not very realistic because the system is extremely interconnected and, thanks to the high number of feedback loops, a change indirectly tends to its further variation: imposing a constant value in a dynamic model could damage its own logic of dynamism, as we have previously done, constraining a fixed normal birth rate: once we necessarily impose the initial values, they will likely change in time produces by the evolution of simulation. This effect can be negligible, that is, producing a variation a characteristic around some values, the simulation produces almost the same results (as happens with a change in normal birth rate), but as we have seen in this scenario, a slight change in NRUR produces a completely different outcome if compared with the first one.

The second aspect not considered is extremely important, and it is the absence of correction actions inside the model in the case a situation moves towards a decline; whenever there is a particularly degrading condition, as in this case for pollution, the simulation keeps producing results based on information already produced or previously imposed, without care about the path: it does not implement new strategy to reduce the decline. In practice the model is not able to identify a degrading situation, activating a countermeasure, and all the imposed conditions are maintained, while in reality humanity has the opportunity to take decision during evolution, such the disposition to limit the ozone's hole, imposed some decades ago, or the current energy transition to reduce CO2 emissions. This is a barrier common to several models, and it is one of the main reasons among which any scenario should be considered in the proper way: not as a future prediction, but a possible future condition under several constrains.

3.3.3 SCENARIO WITH REDUCTION OF POLLUTION

In this scenario it is kept the previous assumption made for natural resources extraction, with all the already presented consequences, and are introduced other two hypothesis, starting from 1970: the natural resources utilization NRUR changes to 0, and it is imposed the normal indicator related to pollution POLN equal to 0.1, previously fixed as 1.



41 Scenario with reduction of pollution (World dynamics, J.Forrester)

As other scenarios, this is prolonged up to the year 2300, but it will be here shown only until 2100; there are anyway going to be presented the main consideration for the subsequent period.

The assumptions at the base of this simulation have two meanings: the first one implicates that the natural resources extraction from reservoirs is nullified in 1970, while the second, as a consequence, displays the great reduction in pollution, which is almost eliminated. The first hypothesis could happen only if humanity would stop to extract resources or finding a way to recycle them integrally, but both these possibilities are extremely unreasonable. Stop using finite resources means it is only possible to use what is available in nature without pauperize the planet, which is the exact condition of humanity until about 3500 B.C., period when started the extraction of minerals used as tools instead of stone: this path cannot be followed. The road of recycle is accompanied by 3 main problems: it cannot be implemented in a short time and, considering that in 1970 there were little worry about this issue, a quick implementation would be everything but easy. The second barrier is linked with the impossibility to fully recover what is treated as a waste, even paying close attention to collection and processing: among the endless thesis in favour of this statement we can quote the irreversible loss of some kind of material, such as ink in paper recycle, or the product can disperse itself during utilization (spray and chemicals in general), or again, usury and aging can degrade the material, making impossible a recovery; in practice a fraction of physical objects is lost. The third problem about recycling is that, supposing solved the previous problems, it is necessary to maintain the same material standard of living of the year where the assumptions take place, but as shown in the scenario, there is a sensible increase in population and capital investment, both accompanied by a rise in natural extraction utilization, with a consequent denial of the total recycle possibility.

There are probably other considerations to be made regarding the inconsistency of already mentioned assumptions, and in general a strong and quick decrease in resource extraction together with an increase in population is inevitably followed by a reduction in life quality.

The weakness of these assumptions is also underlined by the comparison of already presented graphs, indeed we can observe an increase in the two elements mostly affecting model outcomes: population and capital investment. In the current scenario, number of people increases up to a stabilization in 2200, a little few than 10 billion, while the capital investment overcomes 35 billion units; the peak reached by these characteristics in the preceding scenario are respectively about 6 billion and 12 billion. The other characteristics are stabilized too, around the same values of 2100. We cannot see a decline in human condition, but a stability, despite the main parameters responsible for a general degradation present values sensibly higher, which is, rationally, a contradiction.

3.4 WEAKNESSES OF THE MODEL

There has been proposed only three out of a dozen of the scenarios generated in 1970, but their hypothesis are imposed in the same way: the critical issue of a scenario is fixed changing the related indicators causing it in the next one (the first scenario collapses due to natural resources, so in the second one the indicator about resources extraction is modified), therefore any following scenario is accompanied by an increasing number of assumptions.

Analyzing more in depth some characteristics and produced outcomes, we can underline some failures of the system; is important to note that the author does not propose the simulation as a certainty but possible trends, indeed the interest is in the qualitative aspect not in the actual value of an index: we have to look at the whole and compare it to the reality.

The first big issue in building the model is the graphical definition of elements composing it, each of which influences or is influenced by others. Some groups are relatively easy to build such ones related to population, while other are not, like capital investment, requiring at least a basilar knowledge in macroeconomics. In this building phase there is the risk to omit or not giving enough importance to a subject: energy is a topic of outmost importance, with interactions in many elements, even geopolitics, but it is not directly shown in the representation; it is indirectly present in some indicators, such capital investment and life quality.

Another note, similar to what already exposed for energy, is when a single scope is incorporated inside one or more elements, losing itself, therefore we cannot have the possibility to carry out targeted actions on them. A direct consequence is that anytime exists a relation among two elements, it is determined on the basis of a rational thought often combining information coming from different situation, and once we make a change, we are not affecting only what we are interested in, but also any component coupled. This is undesired, because if it is true that we want an outcome passing through a complex and interconnected set of relation, we would like to set input data as we wish, but we cannot have a strict control.

The last and already mentioned, quite important weakness, is the absence of corrections when a situation is degrading. Even with some retards, particularly when there is an economical interest in maintaining a “wrong path”, humans make actions to correct them. Joining the previous warnings with this one, we obtain scenarios comprehending unreliable values (population and life quality are the easiest to be related with actual numbers), and returning to base scenario, associated with the absence of different actions than the usual in 1970, the simulation proposes a worst result with respect to the reality; the second scenario has a reasonable assumption at is base, but again, it seems far worse than what really happens.

Despite these difficulties, thanks to the Author’s work, and his collaborators, the worries about global consequences of human actions on environment and social issues has become more and more relevant.

3.5 REVISED MODEL

The model previously proposed was later utilized and updated by a group of researchers of Massachusetts Institute of Technology (MIT), that wrote several books and had discussed scenarios for the future, basing their productions on J.Forrester work.

The programming language were changed from DYNAMO to STELLA, so the graphical representation undergone some modifications, but in overall the model remained almost the same. They made an upgrade on some values (think about natural resources quantity or birth and death rate), and more refined concept related to pollution and environmental impact were introduced, first among them the concept of ecological footprint, currently used to quantify the anthropogenic effects on the planet. It was also incremented the importance of delays between an action and the consequent effects in the system, already present in original model: this is a determining element in real world, as well as one of the most concern for the MIT group.

3.5.1 DELAYS

There are endless delays inside the model because fluxes modifying the levels do not act instantly; when an action produces a change, this is not immediately implemented. Time after which we can see the effect is imposed trying to mimic the real conduct but as previously seen, lots of simultaneous and inhomogeneous effects are described with a single value, generally months or years. An example of delay is given by the time necessary to a pollutant to become dangerous, to modify the parameters related to births and deaths, after its emission: inside the model, individual substances are not considered separately and as a consequence, delays are imposed as an average too, unable to keep track of how fast each pollutant actually diffuses, contact time, and life cycle.

The last factor is responsible for some hidden effects: in combustion products, we distinguish between primary pollutants, that are directly emitted (Sox, NOx, CO, metals, unburnt hydrocarbons), and secondary ones, created starting from the first, in particular chemical-physical conditions (ozone, volatile organic compounds); it is also possible that a pollutant can be produced in both ways, such as particulates. Another unconsidered subject is the different pathway a pollutant can follow, changing not only the time needed to become harmful, but the entity of damage itself: aquifers can be contaminated by several substances and the consequences vary depending on the usage of water, which can be used in agriculture, farming, for drinking use or as a process fluid. Given the countless sources of a pollutant, determining a delay concerning them is a hard work, and including them inside a model is even harder; the necessity of simplification, using a single or few values, is inevitably affected by errors. We must, of course, extend the problem of delays for any element of the model, not only at pollution.

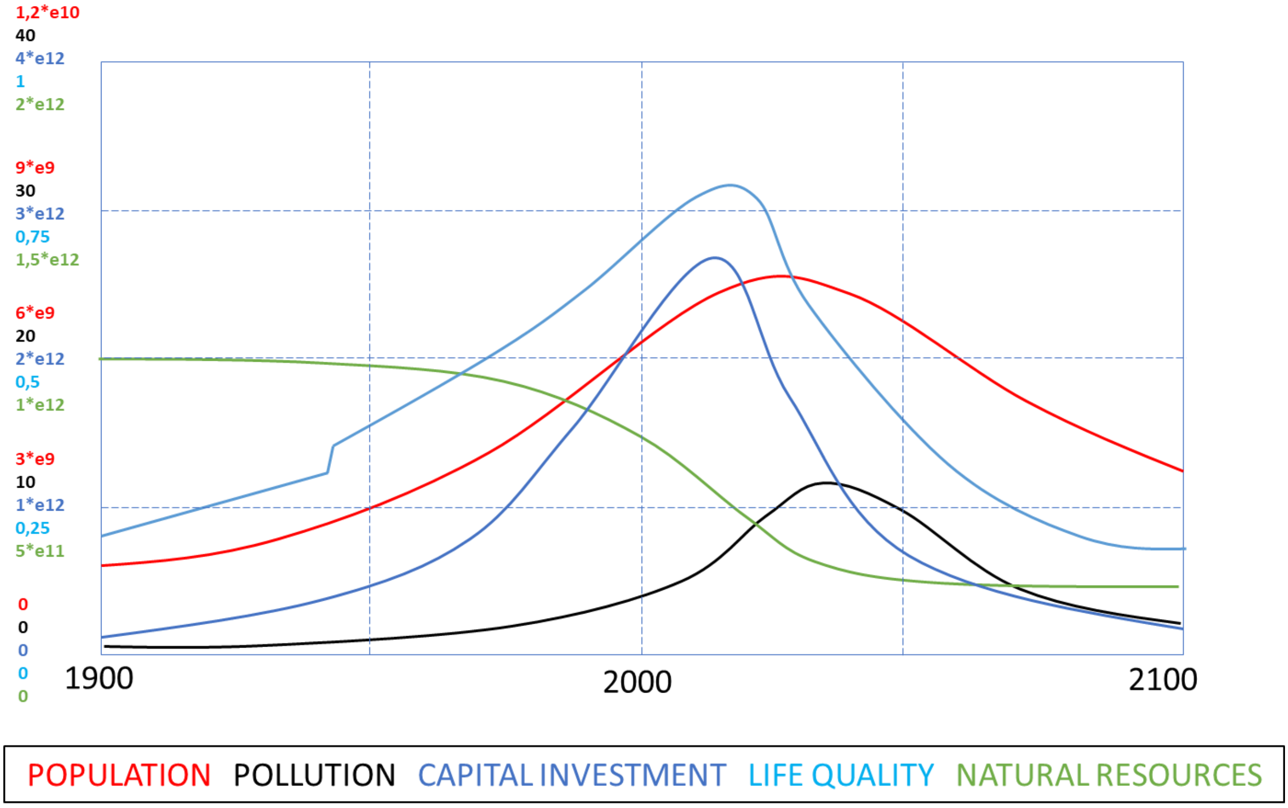
3.6 SCENARIOS GENERATED BY THE REVISED MODEL

Scenarios that are going to be presented based on the revision exhibit a different scale rather the one early proposed in 1970, furthermore, life quality has now a slightly different meaning, quite similar to the Human Development Index adopted by UNDP (United Nation Development Program). Is anyway still valid the concept that values of characteristics have a relative importance: what really matters is the comparison between them.

In the books there are 11 scenarios numbered from 0 to 10: again, we are not interested in a deep analysis of each one, and there will be presented two of them, the first to make a comparison with one scenario of 1970, the second to offer a different point of view: imposing a sustainable future instead of predicting it.

3.6.1 SCENARIO 1

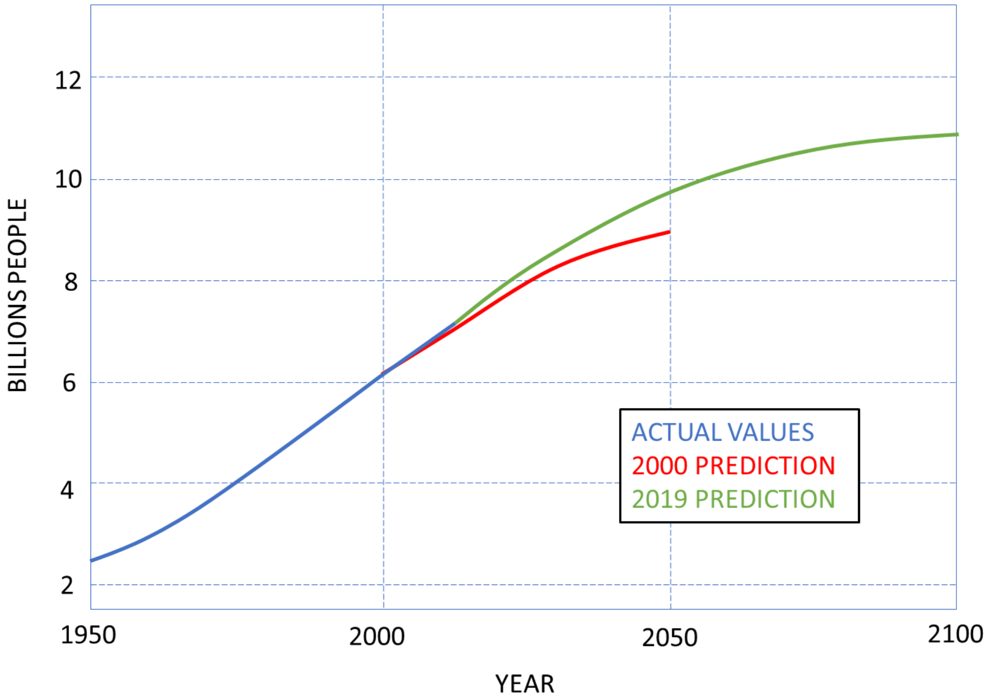
This simulation represents the evolution of system characteristic, maintaining the growth parameters stable starting from 2002, the year of production, and so it is equivalent to the standard scenario of original model, only transposed 30 years forward.



42 Scenario 1 (Limits to Growth: The 30-Year Update, Meadows)

Comparing this graph with the one proposed in 1970 we can see a stronger decline in human condition: population decreases slightly quickly, but life quality and industrial production undergoes a pronounced fall. Natural resources are going to rapidly run out, reaching in 2030 a value equal to about one third whit respect to 1900, maintaining this size onwards, to 2100, while pollution conspicuously reaches a peak few years before. In this case the decline happens because of a rapid decrease in industrial capacity, caused by an increasing difficulty of natural resources extraction and processing, so the reason of degradation has some element in common with what caused it in 1970 simulation, but now is stronger.

Population is, as usual, the only element we can directly compare with real values, and in this scenario is slightly underestimated rather than the actual one: we can assert the revision produced a closer estimation (at least in population and in the closer future) to reality, compared to the original model, but it disagrees with other predictions. From the graph the maximum population should be reached in 2025, numerically equal to 7.5 billion, however the current ONU prediction estimates that in 2050 there will be more than 9.5 billion people, and almost 11 billion in 2100. Considering ONU's prediction quite accurate looking at the past, we expect at least in the short period its correspondence with reality, but even this trend is changed in time; the following picture shows the World Population Prospect drown by ONU in 2000 and 2019.



43 How ONU's predictions on population had changed from 2000 to 2019 (World population prospect 2000&2019)

In 2000 ONU predicted the population until 2050, while in last years has been prolonged to 2100. What should be underlined is how this prediction changed in the relatively short period of 19 years: from the beginning of the millennium the hypothesis for 2050 has moved from a little less than 9 billion to almost 10 billion, a not negligible difference.

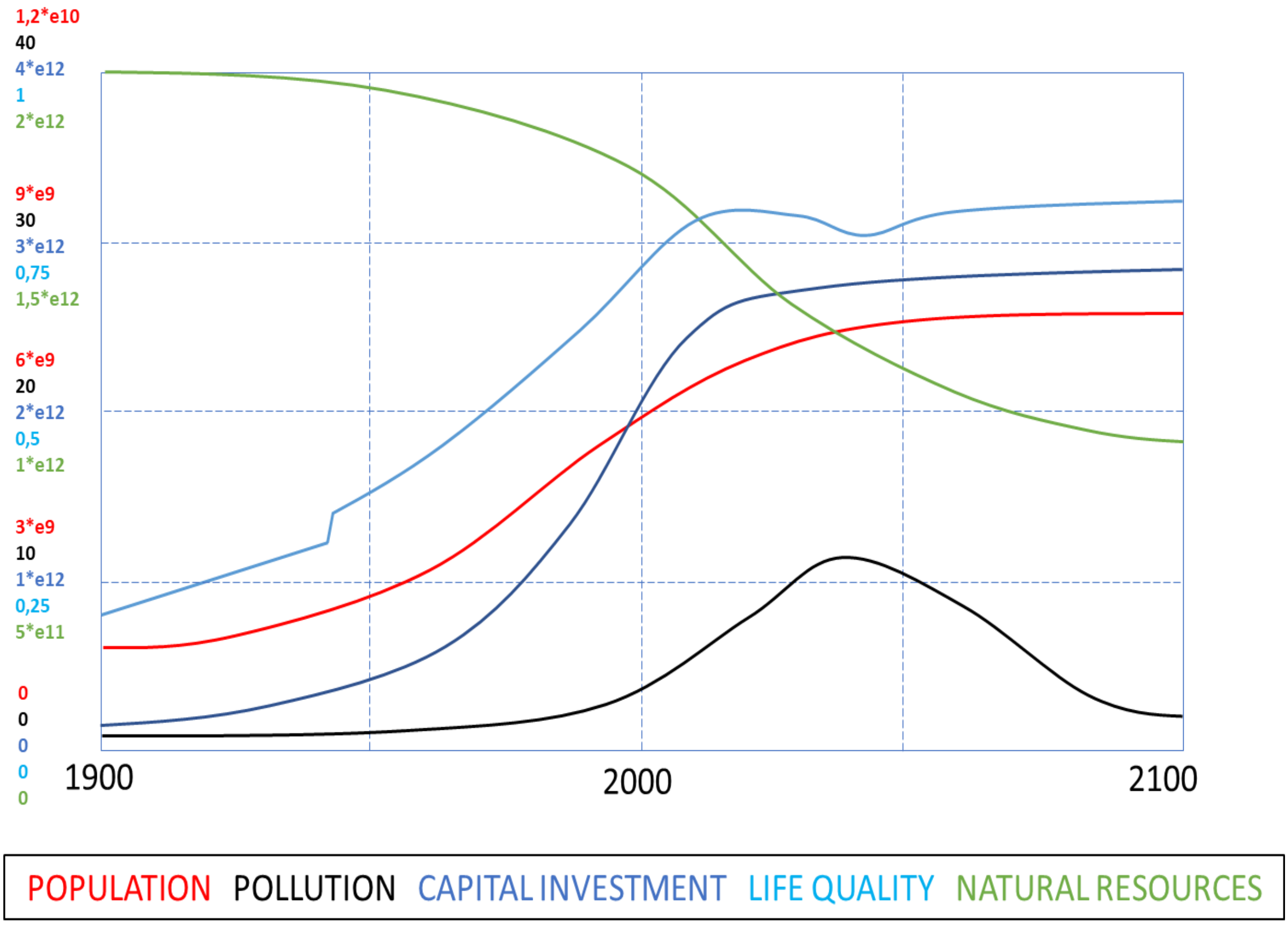
The population opposes a strong resistance to change unless the development of a severe and global catastrophe and if we also consider that the birth and death rate together are decreasing the new births, but not enough to produce a reduction in population, we can be sure to not being very close to the peak, as shown in this scenario. But what do we mean with catastrophic event? Probably something like a wide nuclear conflict, or a pandemic with great mortality (such black plague of 14-th century), or the impact of a space object of relevant dimension. Just to have an idea of the amplitude needed to make a sensible change in population growing trend, we can look at the historical demographic data of the first half of 1900: there are not observable changes in population curve, but in less than 50 years taken place the first and second World Wars, Spanish Flu and other large conflicts such Russian Revolution. These events belong to the most horrifying tragedies experienced by humanity, but they are not responsible for a demographic degradation.

Making consideration about the other component of the system is harder, not only because values proposed are mainly fictitious, but even cause today, according to the scenario, we should be at the beginning of decline in life quality, while capital investment has already started to fall since some years. Bothe these elements could be initially invisible, that is we cannot affirm with certainty a decline is not taking place, but at the same time there are no signal about its presence, even considering this decline as a consequence of a shortage of natural resources, surely an important issue, but not massively decisive at the moment. Global population has been slightly underestimated that the real so, according to the model logic, degradation should start before, indicatively some years, with respect to what shown in the graph, and the current decline should be more visible.

The conclusion about this scenario is: we cannot say with assurance that the evolution of human condition will be different from the simulation trend, but quite likely we are not going to stick to it.

3.6.2 SCENARIO 9

This scenario was developed imposing several assumptions, to obtain a sustainable equilibrium of human conditions, and has to be looked at in a different way with respect to previous ones: in technical terms, it is not a verification problem but a project one: we know the arriving point and we want to know the inputs to reach it.



44 Scenario 9 (Limits to Growth: The 30-Year Update, Meadows)

The first hypothesis is present in any scenario starting from the second and concerns the natural resources availability: it has been imposed a value two times greater than Scenario 1, supposing the discovery of new reserves. This assumption was already adopted and discussed; a summary is: the finding of new deposits is likely to occur, but it is quite hard to quantify them. In chapter 1 we seen a table showing the amount of some resources in 1970, a massive underestimation than current quantities.

Other hypothesis regard issues linked to the way of living of people and they try to fix many indexes of the model, imagining a series of personal social and far-sighted conducts, which can be turned in 3 statements: increase in technological level, stabilization of per capital industrial production and stabilization of population. The technological development had been discussed in chapter 1 and, as for natural resources reserves, is a reasonable and likely assumption to be made but not easy to be determined.

3.6.2.1 STABILIZATION OF INDUSTRIAL PRODUCT

Industrial product stabilization is obtained imposing a per capita value equal to 10% more respect the average one of 2000, so it is fixed the quantity of investments in goods and services available to population. Direct effect of this procedure is that in current industrialized countries, the material standard of living (indeed related to goods and services), tends to acceptably decrease while in developing and undeveloped countries it increases.

It is a quite unrealistic goal to be reached in real world because population of developed countries should voluntarily lower its lifestyle, and even worse, companies and industries should limit the production and supply of their products: in common view the world moves into the straight opposite direction, towards a continuous growth. We can be almost sure that this condition will not be spontaneously followed.

3.6.2.2 STABILIZATION OF POPULATION

Together with capital investment, population is the major responsible element to induce a collapse in the global system, consequently, is legitimate trying to keep this parameter under control to avoid a decline: inside the model the associated assumption provide that any couple gives life to 2 children. Such approach is quite easy to understand because the first thing people think when talking about these issues is the global overpopulation, followed by an increase need of food, product and services other than negative problematics such unemployment and increasing pollution.

Birth control method have already been introduced into some countries, first of all China, where in first years of 1970 this issued expanded until 1979, when were introduced the one child policy (in force up to 2015, then substituted by the two children policy); as suggested by the name, in China couple were allowed to have only one child. Many social and economic side effects arose with this law: lots of Chinese eluded the rule without registering their child at birth, creating a precarious situation for the whole family. The absence of registration means that the child does not exist for the society, and so it would not be able to take advantage of services for people, health care and instruction at first; these children cannot in general hope in a future inside the country and are obliged to live in unstable conditions from birth. On the other hand, parents are exposed to heavy repercussion if they are spotted: there are many testimonies of fines far beyond the economical possibility of a citizen and working barriers such dismissal. The one child policy damaged the whole economy of China too, because it is producing a population aging, with a probable revision of pension system: workers are not able to sustain the increasing number of people retiring, unless provoking a social and economical collapse (this issue will be deeply explained in the next chapter).

The latter fact is really controversial because we observe that higher is the crisis to fight, stronger should be corrective actions, but at the same time stronger are the corrective actions, more are the undesired effect produced (social or economic friction); enlarging this problem at a global level rather than a single country, even as influential as China, these undesired effects could be such strong to obscure the starting goal, producing a collapse while they were introduced to avoid it. At this point, is necessary to reach a compromise does not allowing a decline, choosing lighter policies, and we must ask ourselves if less invasive methodologies can assure the goal or if they are too soft. From the graph we can see that a two children policy can stabilize the population and together with the other imposition, can prevent a degradation; these are assumptions, so the model ensures that in the simulation they are respected, but as we have seen from Chinese case, we have huge non-compliance among population.

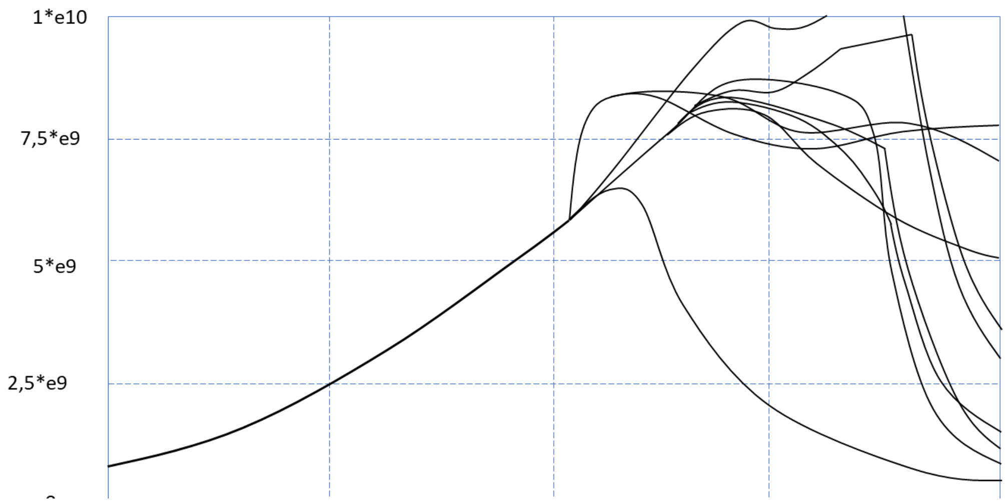
There are other examples of population control, but they are not entirely focused on its reduction; some countries incentivized or have incentivized births, such Japan, which is undergoing a population aging, such as Russian Federation. If the politics and economics conditions of a country tend to increase the natality, others have to decrease it in order to maintain the global goal of two children per couple, risking to move towards the already mentioned negative effects on Chinese case.

3.7 NEW CONSIDERATION ABOUT THE MODEL

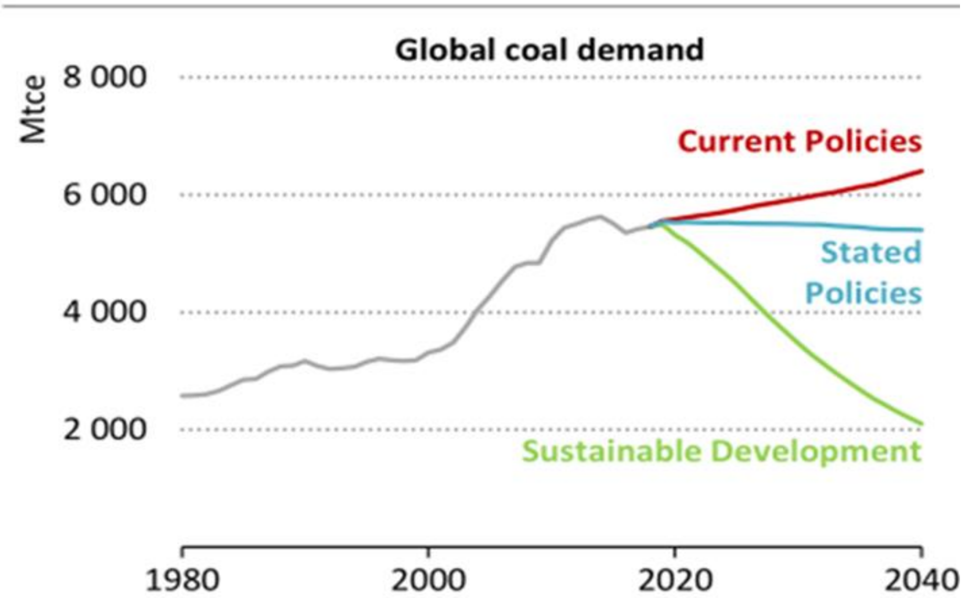
One thing we can notice about the original and revised model is that, reasonably, extending the period where we have real data (up to 1972 and 2002 respectively), the outcomes are closer to reality when we are closer, so in the revised model (look at population prediction). This happens because further is the period of prediction, less accurate is the result: there is a bigger error propagation; this means that even if in the short term, revised model produces better results, it does not mean that will continue to do for medium or, even worse, long period.

Assumptions made in scenario 9 ensure prosperity, but considering the high level of population, life quality and industrial product, the theoretical effort to be made are huge. As said, this is not a prediction but an imposition, and we can be absolutely sure we have not followed a path similar to this, policies in force should be adopted at least 15 years ago. A more relevant reason is given by the impossibility for humanity to fully comply to a directive: when an individual plan some actions, is likely that he will behaves in a slightly different way, or in larger time, or changing some of them, reaching a similar result. Increasing the dimension of system, and time necessary to complete the actions, the deviation from initial plan tends to elongate: it is well known how construction companies, especially in industrial field, time and expenditures increase, and at the same time some decisions change during construction. There are quite a lot possible causes of deviation: some companies taking part in the project could not be able to provide their services in time, or they can bankrupt; working can be slowed down or prevented by public opinion; bureaucracy can stop some project phases, or the operation cannot be guaranteed once the construction is complete. Imagining an extension of these problems to a national, or as in the case of the model, at global level, problems can grow enough to become impossible to be solved, or the result could be sensibly different from expectations. Human factor has a determining effect on the result, or better in the failure to succeed an objective, and there is no way to eliminate it.

Assessed the complexity of the model, another noteworthy aspect is the definition of most probable scenario (producing hundreds of scenarios is useless if they have nothing to spare with reality); to have an idea about this problem, the next picture



45 Population trend for all the scenarios (Limits to Growth: The 30-Year Update, Meadows) compares the outcomes of revised model with a graph presented in the first chapter, showing coal demand.



46 Graphical representation of coal consumption prediction (IEA, WEO 2019)

Both graphs present a time interval filled with known values preceding a series of possible future trends, but in the case of coal consumption, despite there is a sensible difference between higher and lower limits, the action to reach one of them are clear: we can suppose to stay in an intermediate point depending on efforts made to reduce the coal utilization. In the case of global model instead, a characteristic such population (which is the easiest to predict), shown in the first graph, depends on numerous other elements, and vice versa, so we cannot act on a single parameter to predict an intermediate, or in general fixed, arriving point; unless we stick to each assumption imposed in the corresponding scenario, the result can be surprisingly different: remember how a small variation in natural resources utilization rate generates a result looking nothing like the previous one. In practice there is not a linearity between cause and effect, and if we want to move from a scenario to another, we have to process all the new assumptions unless we are sure that part of them are negligible. This statement is obviously for all the other elements.

4 UPDATE IN 2012

Jorgen Randers, a member of the MIT group working on the previously proposed global model, had recently written a book where updates those thematic, called “2052: A global forecast for the next Forty years”. The method used to analyse the global system is not the same as already used: there are still employed instruments od system dynamic, but in this case there were collected many professionals opinions: economists, politicians, ecologists, biologists, journalists, besides data coming from authoritative sources.

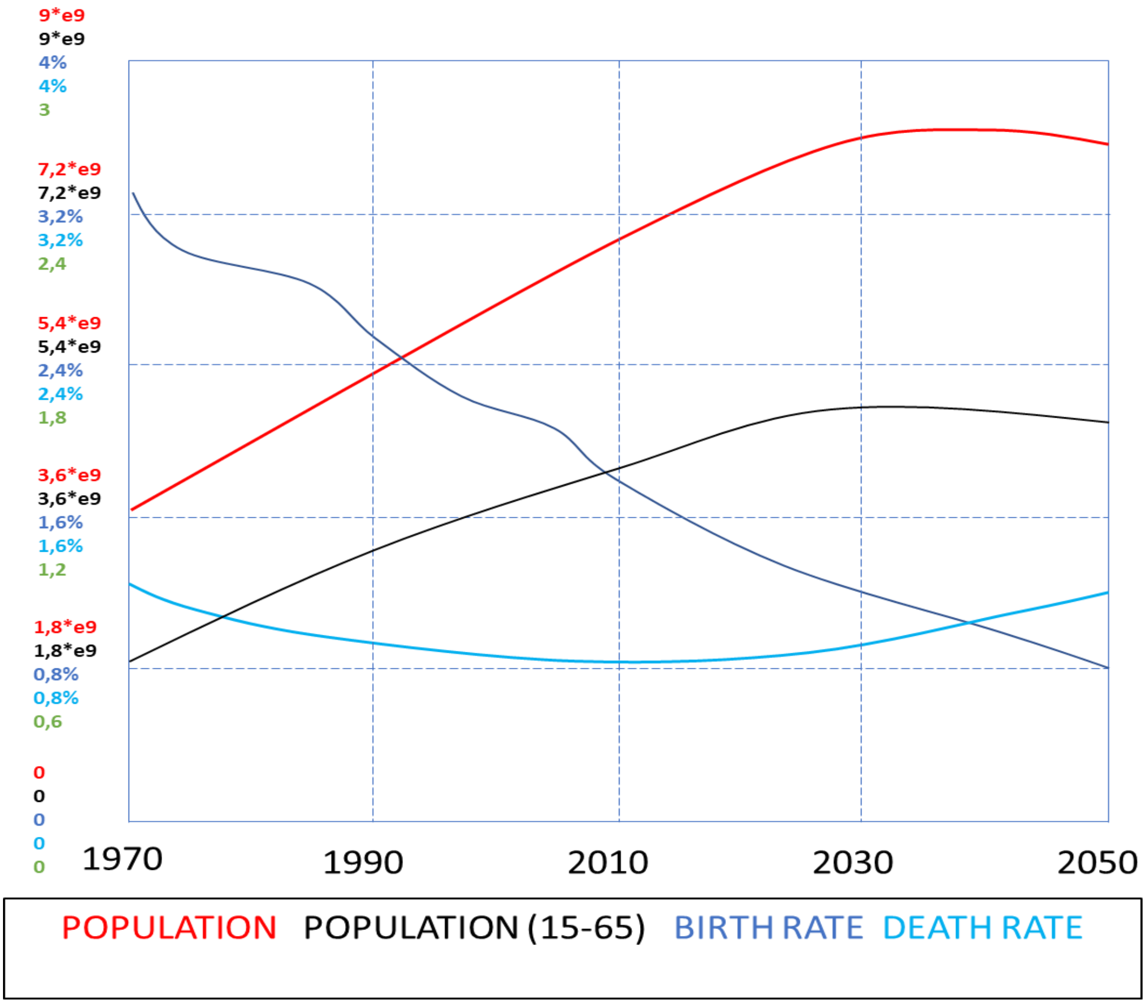
This way to proceed presents advantages and disadvantages; among the first we can underline the possibility to describe more concretely the events happening globally, referring to current phenomenon, having the possibility to use a bigger experience to compare models and reality, furthermore there is a greater ease in data collection. A disadvantage is to match opinions trying to be objective, but necessarily in agreement with discussed themes, and so the risk of losing the model impartiality; another negative aspect could be the forcing of the system under current global evolution, imposing to the future possible choices that can be only valid at the moment or for some years, but this is a common issue anytime we make assumptions.

Is not sure that predictions will take place, but contextualize real causes and effects, than suppose the quantitative results they induce on the system could be a more refined way to make evaluation rather than using only fictitious values based on past trend produced inside the simulation itself, keeping a sort of rigidity, as the relation between birth rate and material standard of living presented in paragraph 2.2.3, unless predictions remain as objective as possible, without being too much contaminated by personal opinions.

4.1 DECREASE IN POPULATION

Increase in population will surely reach a peak, then it will probably start to fall or, at best, it stabilises; in the previous discussed global model, the majority of scenarios follow the path of decline, often produced by a quick decrease due to a worsening in life quality, while only in few cases the population stabilizes, but only when we impose this condition and we search an equilibrium condition. The moment when this peak appears is contained in a large interval, but excluding the most improbable and extreme scenarios, this interval is predicted to stay in the years around 2050 (look at the last paragraph of chapter 2).

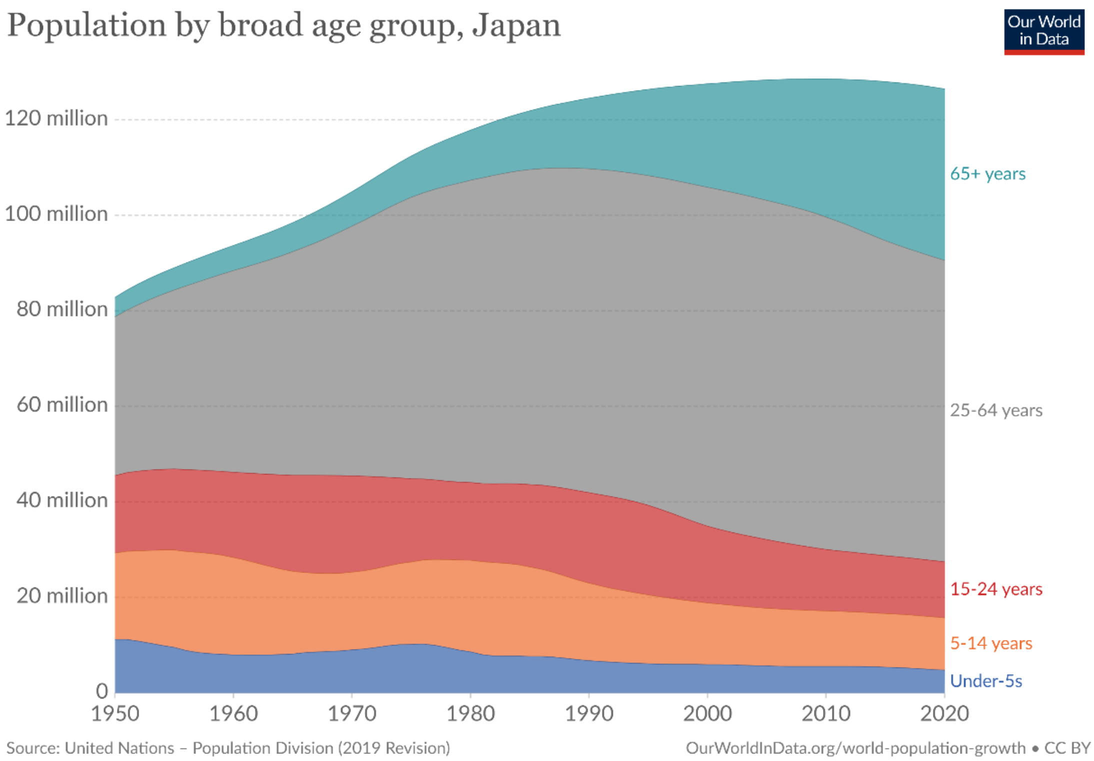
According to 2012 forecast, population trend is somehow similar, reaching a peak sightly after 2030, not with a drastic decrease, at least in short term.



47 Population prediction to 2052 (2052: A Global Forecast for the Next Forty Years, J.Randers)

In this graph we can see how a reduction in population takes mainly place due to a reduction in birth rate, ad in a lower extent as an increase in death rate. This happen because, in author's opinion, the country will experiment a depopulation in favour of cities (as have happened since industrial revolution), consequently there will be a tendency to have less children, no more seen as a "resource", as already said. The increase in death rate is not produced by a worsening in life quality, but by population aging: number of older people tends to increase as a fraction of the total population just because of lower birth rate and average life quality. It is possible to look at the differences total population and that one included between 15 and 65 years old: the deviation among them is increasing and adding the decrease in birth rate, the result is nothing but aging.

This phenomenon starts to be seen at a global level despite not particularly strongly, but clearly visible in some countries, among which the most striking is Japan.



48 Population divided by age in Japan (Our World In Data,2020)

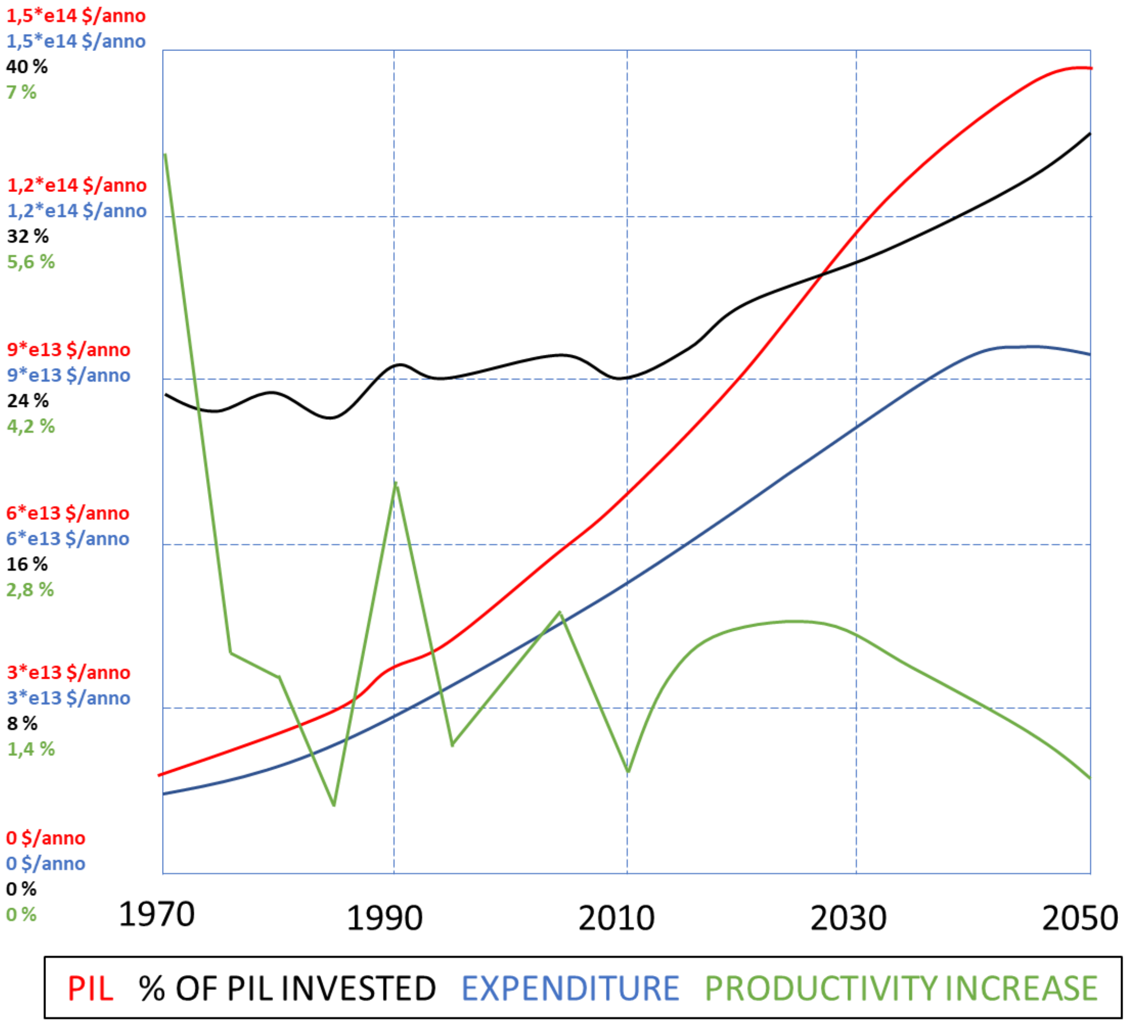
Aging is a natural and unavoidable consequence linked to population reduction, but hides an important economic problem already mentioned: productivity of a country is strictly related to the working fraction of citizens, shown in the graph with the curve named “population (15-65)”, an approximative but reasonable interval, changing country by country. As we can guess and observe in the picture, the decreasing fraction of working citizens, together with the increasing fraction of older people, little contributors to the economy, generates an overall impoverishment.

The author supposes that the way to globally fight this trouble will be the increase in retirement age, reducing welfare expenditures; in this way the demographic transition is accompanied by a relatively moderate sacrifice for the entire community. Answers, however, could be as different as inhomogeneous is the economic and social structure of each country: population of a far-sighted nation, based on a shrewd society and economically stable (such Northern European countries), can accept this sacrifice for the greater good at medium term, but the same cannot be said for many other places. An example is Italy, where it has perceived an increasing population discontent for at least 10 years, caused by various reasons, among which a rise in retirement age. In this case the elongation of working life could be partially due to demographic issues, considering this country has one of the lowest birth rate in the world, but another important reason is associated with economic and social problems, and an increase in retiring age could give rise to disorders. Events like this one could verify in several Mediterranean countries, central Europe and even USA, theatre of many demonstration: territory and population are extremely variegated and different ethnic groups or social class are in conflict each other; if it will not be found a meeting point among the whole community, with a common objective, often outside of the mainland as the past suggests, situation could escalate. Other places of the planet such North Africa, Middle East or some countries of Latin America, are currently subjected to riots or conflict: imposing more severe condition can only make the situation worse. Turning back to Japan, aware of its problem, among the measures to control it is the births promotion: if in one hand it would be able to fight the aging, on the other would not keep population increase under control.

The last consideration regarding demographic trend is that the one proposed by author predictions sensibly differs from what proposed by ONU in 2019, where the peak appears after 2100. We have already seen how, unlike the global model of chapter 2, estimation of United Nations has been quite similar to the actual population from the second post-war up to now, but this period has experimented an economic and social development such as to allow the increase. In case in next decades humanity will attend a decline, population trend could be closer to Randers's prediction than the one proposed by ONU.

4.2 DECREASE IN PRODUCTION

In this brief paragraph will be presented an element of outmost importance in the delineation of a possible future, that is PIL, strictly linked with economic development. The aim is not to approve or disapprove thoughts of prediction's author, but to illustrate it and offers some reflexion having an impact in the next decades.



49 Economic prediction to 2052 (2052: A Global Forecast for the Next Forty Years, J.Randers)

PIL is an index reflecting the economic value of goods and services, it tends to increase on global scale up to reach the peak about in 2050. In industrialized countries the positive rate of PIL growth tends to decrease in last decades, while developing countries shows a rise. This increase in PIL is globally slowing down, as shown in the picture with the curve "productivity increase", obtained as the ratio of PIL by number of people in working age (15-65 years). Expenditures is the amount of money effectively used for production and maintaining of goods and services, goes up slower than the PIL, thus a higher fraction of the latter is invested.

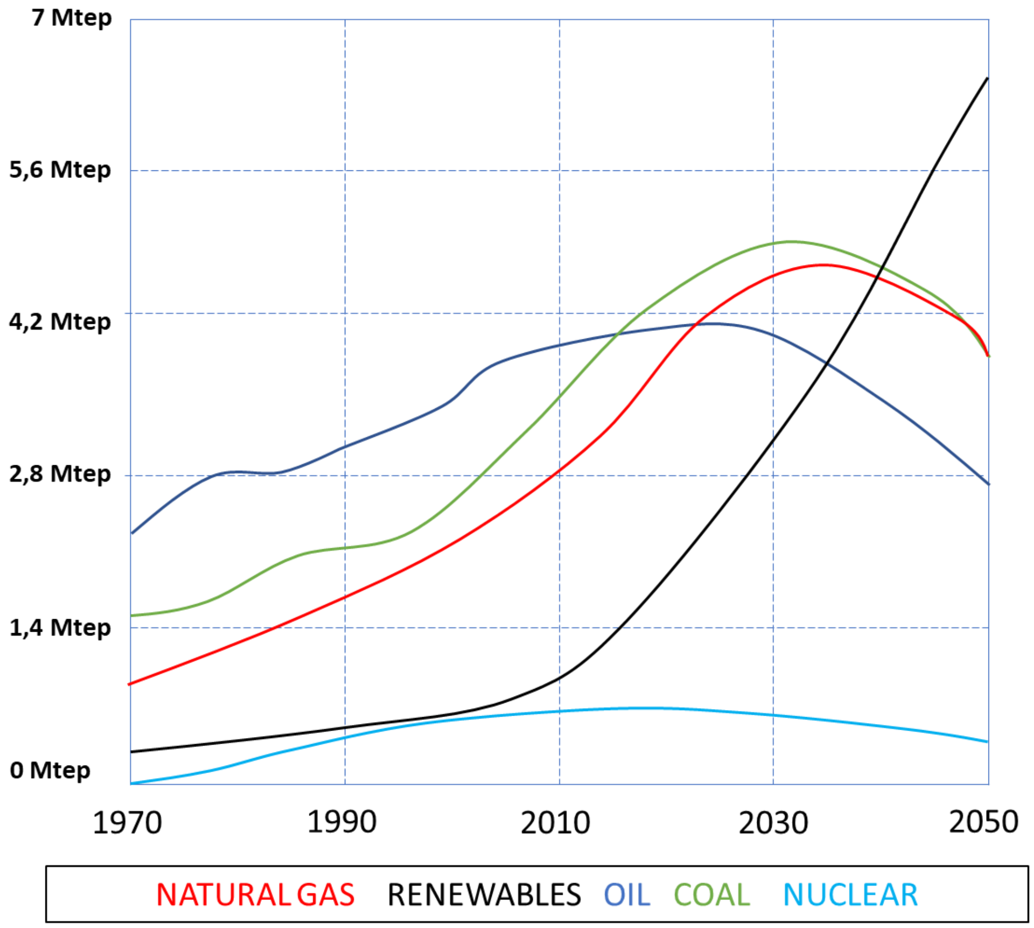
Invested PIL is a determining effect in a future prediction because one of the main reasons of its increase is the overall impact of human activity on Earth. New investments are mainly used to solution of problems, some of which social, like emigration of people as a consequence of conflicts, but in substantial part linked to overload of pollutants production and natural resources extraction. One strong statement of MIT group which worked in the global model involves the relationship between economic growth and expenditure associated to it: increase in richness (and so PIL), does not take into account hidden expense caused by the growth itself, such environmental damages and their cost for society. We can point out direct expenditures, regarding damages incurred at infrastructures, or construction of works needed as a defence against always bigger threats, and indirect, hidden expenditures, linked to global events: an impoverishment of soil or water has economic impact on productors, and so, on consumer of product or services deriving from this branch. If the “expenditures” are higher than the “gains”, we cannot talk about development; this concept is called uneconomic growth.

The effects of an increase in PIL investment are multiple, but one in particular way could sensibly modify human condition in medium terms, and it concerns how these funds are used in environmental impact reduction. Efforts can be directed in two directions: fight the already present damages, such creating embankments near watercourses that risk overflowing, removing pollution from contaminated areas or promoting carbon capture and storage; second possibility ensure the prevention, investing in behaviours not accompanied by particularly harmful consequences, like energy transition, recycle or reduction in natural resources utilization.

The first choice is generally cheaper, but it does not eliminate the problems, it hides them, which represent themselves always and always strongly: undertake such actions can be useful or even necessary sometimes, but we have to follow the prevention path in parallel. Investing predominantly in cure without prevention, means that the medium term future will probably be worse because besides the growth of actual (unsolved) problems, hitting the ecosystem, the expenditures which are going to be used to restore or fix them will enormously increase, and PIL fraction available for consumption (expenditure curve in the graph), will reduce, followed by a decrease in life quality and social discontent.

4.3 ENERGY TRANSITION

Many concerns about human impact on the planet are linked with exploitation of energy resources, mainly used in the energy field, turned into heat or power, with a significant greenhouse gas emission and pollutants. These problems, despite the retard from emission to damage, have been diffusing at global level and there is an always greater awareness in the necessity of an energy transition: not only to avoid emissions, but also because conventional resources are finite.



50 Energy prediction to 2052 (2052: A Global Forecast for the Next Forty Years, J.Randers)

From 1970 the author, together with MIT group, has tried to sensitize the world about this issue, but economic and politic resistances remarkably slowed down the awareness about negative effects; in this simulation, renewable energy touches 40% of global primary energy demand in 2050, with a reduction in fossil fuels starting in 2025-2030; nuclear will be gradually abandoned in the same period.

4.3.1 NUCLEAR FROM FISSION

Nuclear is a quite controversial issue and currently, at global level, the intention is to decrease its presence, but not drastically considering there are several new plants in construction (mainly of third generation, in China and India). There are three big worries about nuclear:

- Safety: a sever nuclear accident is followed by negative effect on large scale, as it is known from Chernobyl and Fukushima. New plants (generation 3 or more) are built in such a way to have an incredibly low accident probability, furthermore, maybe more important is the fact that safety systems besides being diversified and redundant as old plants, are partially projected to activate without the necessity of human or external actions. These systems are called passive, and their operation is based on natural physical phenomenon such gravity force and natural convection. As risk analysis teaches, null risk does not exist, but for these new plants the worrying about safety is mitigated.
- Nuclear waste: the amount of waste produced from fission are relatively low: a reactor of 1000 MW (electrical, so considering the average efficiency, 3000 MW of heat at the core) produces about 100 tonnes per year other than cladding, but these materials have to be handled with care; their disposal requires the storing in underground structures built for this scope (such Onkalo in Finland). Waste recycle is possible with a recovery higher than 90%, but global dispersion and number of plants, together with a probable reduction in nuclear exploitation makes this practice not interesting.
- Cost: investments in construction (and decommissioning) of a new plant are extremely higher compared to a conventional plant, requiring a longer working period to expenditure return. A private company does not generally accept the risk to build without the guarantee of operation up to end life, or at least until a discrete economical income, while in case of public company must charge on taxpayers the missing incomes as a consequence of an early closure.

The last point imposes a question: if the intention is to reduce green house gases (and seems it is), imagining investing in new plants, considering that lots of nuclear plants are close to decommissioning, what is the best way to procced between nuclear and renewables? The answer depends on several factors: legislative situation (some countries have banned nuclear); social and political stability (energy infrastructures are among the most important targets in conflicts); land availability and its energetic quality (renewables need big areas, and some kind of sun, wind or water availability); the membership in an organization voted to sustainability. In principle the best path to chose is renewable energy, indeed fission nuclear can be useful in transition towards a carbon free economy (supposing that can exist), but as fossil fuel it is a finite resource.

4.3.2 FEW WORDS ABOUT RENEWABLE PROBLEMS

Renewable resources represent the main goal to reduce global impact, but they are accompanied by problems too, and the most discussed is biomass, widely used in unindustrialized countries, with an increasing interest in developed ones. In order to use biomass in a sustainable way is necessary to respect some guidelines: first of all their exploitation should be as close as possible to collecting areas to avoid large emission due to transportation; pre-treatments (dehumidification, shredding, pre-heating) should be carried out with the lower amount of energy consumption; in case of direct combustion, many effort must be done in pollutant emissions, quite higher than conventional fuels. These problems have to be carefully analysed during project phase, particularly the latter, because public opinion is often unfavourable to realization of these plants nearby their homes. Another global concern is biomass origin: several areas of the planet are experiencing a change in land use for energy crops (think at South America and South East Asia); the author thinks this induce an increase in food price, increasing the already poor in food countries even more poor.

The other major renewables are also affected by problems other than the presence of the source itself (wind, sun, water): hydroelectric plants can be accompanied by important impact on surrounding flora and fauna, while solar and wind power are sometimes opposed by population for ground protection, landscape interference (often linked with tourism activities), or again the competition with agriculture.

4.4 A COMPARISON BETWEEN SHORT TERM PREDICTIONS

In the next table is presented the prediction of 2012 concerning global total primary energy demand and by source for 2020: there are values proposed by the author and the three scenarios of IEA, together with actual demand in 2019, again measured by IEA.

2012 PREDICTION FOR 2020 (Mtep)					
	COAL	OIL	NATURAL GAS	RENEWABLES	TOTAL PRIMARY DEMAND
Randers's prediction	4,60	4,20	4,00	1,80	15,00
IEA current scenario	4,42	5,12	3,63	2,05	15,33
IEA new policies	4,08	5,02	3,55	2,09	14,92
IEA 450 ppm	3,57	4,83	3,35	2,26	14,18

51 Energy predictions by IEA and J.Randers for 2020, made in 2012 (2052: A Global Forecast for the Next Forty Years, J.Randers; IEA, WEO 2012)

Despite the measured data are valid for 2019 and not 2020, it seems the total primary energy demand is slightly lower than the one proposed by author and, comparing it to the IEA outcomes, we are between the New Policies and 450 scenarios. This trend is similar in fossil fuels, while renewables produce little less than expected by IEA, but more than the author prediction. In overall the effort to reduce emission and energy demand are a litter better than expectation.

In the following table there are the same prediction for 2035, again made in 2012.

2012 PREDICTION FOR 2035 (Mtep)					
	COAL	OIL	NATURAL GAS	RENEWABLES	TOTAL PRIMARY DEMAND
Randers's prediction	5,00	3,90	4,80	4,00	18,20
IEA current scenario	5,52	5,79	4,76	2,70	18,68
IEA new policies	4,22	5,32	4,46	3,08	17,20
IEA 450 ppm	2,34	4,21	3,58	3,93	14,79

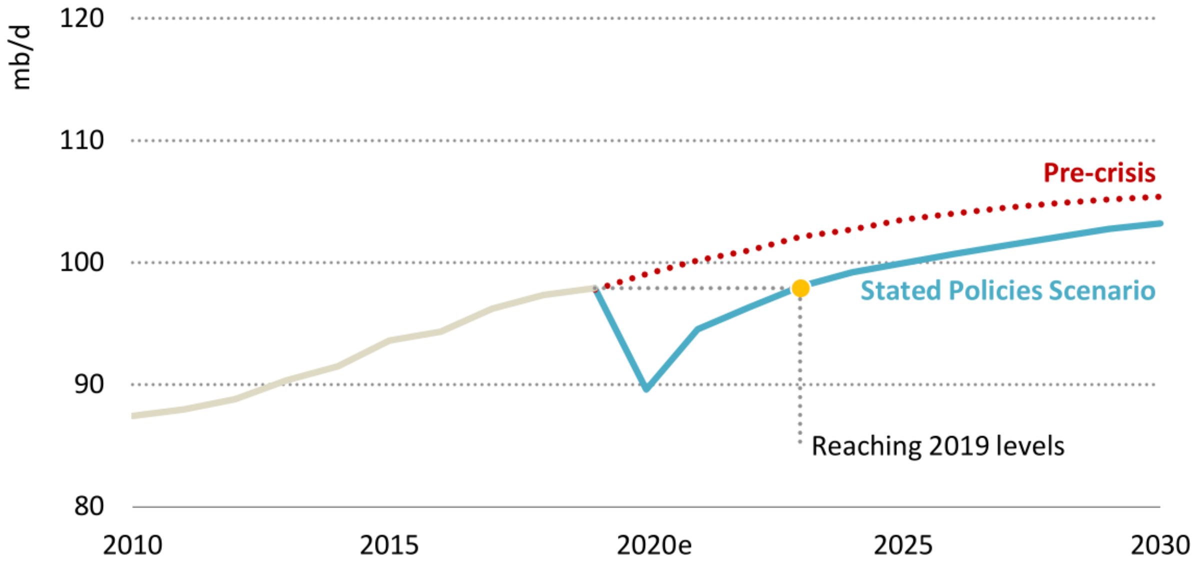
52 Energy predictions by IEA and J.Randers for 2035, made in 2012 (2052: A Global Forecast for the Next Forty Years, J.Randers; IEA, WEO 2012)

The author foresees a sensible reduction in oil exploitation and a strong increase in renewables with respect to IEA scenarios, while gas, coal and primary energy are between the worst scenario of IEA (current scenario), where we do not make huge effort in emission reduction, and the New Policies one, which represents our expectations.

There is a sensible variability of results, and they clearly depend on future political decision about energy; IEA tends to a global reduction in consumption and a moderate change in energy mix, while Randers believes in a small reduction in energy demand, but a greater effort towards renewables.

4.5 CHANGES IN 2020

COVID-19 pandemic has changed many of human habits (some countries more than others), among which energy demand, undergoing a sensible reduction. The disease diffusion is another subject that can be included into the paragraph of not foreseeable or reproducible events of chapter 1. IEA, using the most recent available data, has tried to recreate the impact of virus diffusion is producing at global level: primary energy demand is estimated as 5% less than 2019 and CO2 emissions drop for 7%. Fossil fuels are the most hit energy resources, with oil as a leader: the next graph is compared the Stated Policy Scenario before and after the pandemic.



53 How the COVID-19 pandemic affects an energy scenario (IEA, WEO 2020)

The “e” subscript for 2020 means “estimation”, indicating the incomplete knowledge of data about this year; in the graph we can notice how the oil demand drops about 10%, closing the pre-pandemic in next year, remaining anyway below it.

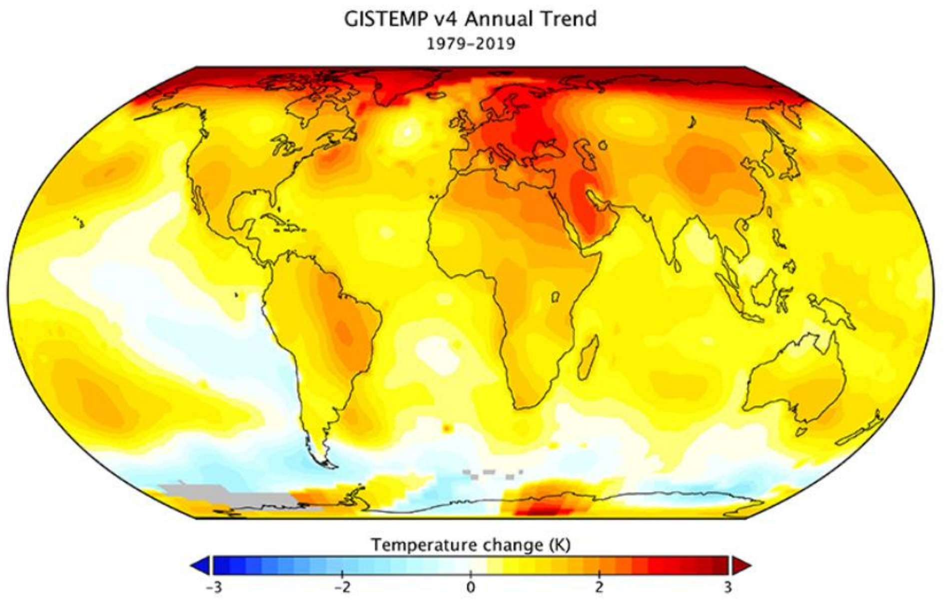
Such variation is absolutely not negligible, and it is likely to have a relapse on global energy field, as happened in 2014 from the Russian-Ukrainian gas crisis, after which it was posed more attention in safety of energy supplying: in that particular case risen am interesting in liquified natural gas (LNG). We cannot exclude a consolidation in renewable energy interest, considering their reliability, specially for fuel importers countries.

5 CONCLUSION

The fundamental concept that springs from this analysis concern the difficulty, if not impossibility, to have a reliable prediction on extremely non-linear systems where anthropic presence plays an important game, independently by the goodness of the model (the one presented in chapter 2 is quite good).

One of the main critical issue, strictly linked with variation in time for possible situations, is precisely given by the extension of period analysed: summing to error propagation the difficulty in definition of events even in short terms, produced outcomes can be different, as we have seen in two simulation with same assumptions, made in different years (paragraphs 2.3.1 and 2.6.1).

A questionable subject is the “global value” of a parameter or characteristic (excluding population, which can be easily globally determined): it is clear that an average is an sort of middle ground among lots of values, but when we can observe a great inhomogeneity as in many elements of our planet, the mean deviation can increase so much to make the average value meaningless (it is unable to really represent the system), if coupled with other consideration about the model. The next picture regarding global warming helps to understand this concept, but the same can be true for several other objects, such some of the elements presented in chapter (life quality, industrial production).



NASA GISS Surface Temperature Analysis (GISTEMP v4) trend map of observed global surface temperature change for the period from 1979 to 2019. Future global warming depends on Earth's climate sensitivity and our emissions. Credit: NASA's Goddard Institute for Space Studies

54 Distribution of temperature differential in the world from 1979 to 2019 (NASA, Global Climate Change, News and Features 2020)

Global warming is, as the name itself suggests, “global”, but its effects are extremely dependent on location: due to increase in water level, small islands (particularly those in Pacific Ocean) are going to disappear, and in general many sea places will face this huge problem (in reality it is not a future problem, it has already started). On the other hand, some areas of far north like Siberia and high latitude zones in Canada, currently little inhabited, are going to be more comfortable areas to live in. From the picture is evident how the biggest warming is taking place exactly around North Pole, and the chance to make navigable these cold zones is more and more discussed, with clear commercial advantages: we can think at a safe connection between Russia and Europe, and a possible new Silk Route bypassing the numerous and unsteady countries of middle and close East. If the global intention to slow down the warming is generally agreed, how much are really intentioned to stick at this purpose the countries that would benefit from the overheating? The IPCC (Intergovernmental Panel on Climate Change, being part of ONU), the biggest international organization working on climate is accused to be a lobby of renewable energy industrial groups, and at the same time other people or organizations accuse it to have too little power, implementing soft decisions against climate change, being strongly influenced by companies and governments interested in the maintaining of current exploitation of conventional sources. These inhomogeneities linked to different local and market effects, seriously damage the possibility to talk about a global direction, which going back to model means using incorrect assumptions or relations.

In reality we can look at simulation offered by models in a different way than a simple deviation from reality, as is happening with the increasing demonstrations about climate change. One of the most famous person engaged in this issue is Greta Thunberg, a young Swedish activist, which consent is only equal to her dissent: her knowledge about climate and environment is likely low, and there are several people working behind the girl, suggesting what to say, both elements that in scientific field tend to generate little credibility. However, we cannot deny the interest risen all over the world thanks to her speeches, quite higher whith respect to professionals and international organizations, such IPCC. The same thing happened for the book “Limits to growth” wrote by the already mentioned MIT group (look at bibliography), which proposed wrong simulations, gave international importance to decline in human conditions, and public opinion, industrials and governments seriously began to worry about social, economic and political consequences.

We can say that this is the objective of a model for the future: not to describe what will happen, but what could happen, giving at the same time possible (or even improbable) solutions if the prevision is undesirable, making everyone participate about the relative subject.

6 BIBLIOGRAPHY

My thesis work has been developed on the basis of the following books:

- Jay W. Forrester, *World Dynamics*, Cambridge MA: Wright-Allen Press, 1971
- Donella H. Meadows, Dennis L. Meadows; Jørgen Randers; William W. Behrens III, *The Limits to Growth*, 1972. (traduzione italiana: Donella H. Meadows, Dennis L. Meadows; Jørgen Randers; William W. Behrens III, *I limiti dello sviluppo*, Mondadori: EST, 1972)
- Donella H. Meadows, Dennis L. Meadows; Jørgen Randers, *The Limits to Growth: The 30-Year Update*, London: Earthscan, 2004.
- Jørgen Randers, *2052: A Global Forecast for the Next Forty Years*, White River Junction VT: Chelsea Green Publishing, 2012.

Additional data and graphs are taken from the following sources:

- International Energy Agency (IEA), yearly publications "World Energy Outlook" (WEO 2000, WEO 2019, WEO 2020, specifically the first section related to prediction in energy consumption)
- Our World in Data (with the following quotes: Solar PV module price; death rates from air pollution, World, 1990-2017; Children per woman; population by broad age group Japan, with data updated in December 2020)
- British petroleum website (Annual report 2020, specifically the section related to reserves and exhaustion time of oil)
- Macrotrends (Crude Oil Prices, Historical Chart)
- NASA, Global Climate Change, News and Features 2020