Chapter 3

Thinking in Systems:
The long-term impacts of short-term business growth

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ABSTRACT

Short-term business growth is the main paradigm governing business activities today. This is important for employing workers, servicing debt, and being competitive in a complex world among others. In 1972, the Limits to Growth (LtG) demonstrated how short-term business as usual behavior could cause long term global risks, including the possibility of overshoot of the global economy to environmental limits and economic collapse within the 21st century. This chapter first gives a definition of complex systems, system thinking and sustainability. Then it explains the nature of financial risk assessment practices and exponential growth. Thus, it reviews the LtG model and compares it to historical data. The major drivers for growth, and the state of planetary boundaries are then assessed showing the relationships between risk, economic growth and environmental pressures. Potential leverage solutions to reduce long term risks, and directions for businesses to support a sustainability transition are highlighted.

Keywords: sustainability, Limits to Growth, planetary boundaries, financial risk, energy transition, Climate change, Sustainable Development Goals

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Introduction

Short-term business growth is the main paradigm governing business activities in the indefinite long term. This is important for paying salaries, employing new entrants in the job market, paying debt, coping with inflation, as well as being competitive in a complex world among others. In 1972, the Limits to Growth explored scenarios of long term business growth in a finite planet, demonstrating how short-term business as usual growth, could generate long term risks, including the possibility of overshoot of the global economy to global limits and possibility for economic collapse within the first half of the 21st century (Meadows et al 1972, Meadows et al 2003). These trends are partially confirmed today in the Intergovernmental Panel of Climate Change, exploring how climate change effects are creating difficulties and chaos all over the world (IPCC 2014).

Growth is generally planned within businesses as a goal towards the future, often adopting forecasting technology and risk assessment as a means to explore future possibilities. For example, a company might project sales towards the next quarter, and assess possibilities to meet projections. First, they would build expectations for the future (average sales), assess a possible variability from ideal expectations (variance), and consider those factors that have the potential to bring their plans away from expectations (risks). As a result, growth implies risk assessment and management as part of planning for the future.

Risk assessment is the core of the business model of financial institutions such as banking and insurance industries. For example, banks' lending activities need to assess the risk of creditors to repay their debt back over a certain time. The basic metric that summarizes the risk of a debtor is the interest premium calculated as a fraction of the debt that is necessary to service the cost of loans based on the likelihood capabilities to return it. The lower the likelihood to return the debt, the higher the risk, thus the interest rate and the cost of debt. At the same time, the higher the risk the lower the propensity of the bank to provide loans. In so doing, wealthy individuals would be in a better position for receiving liquidity, and will be granted cash for cheaper costs, thus supporting them to grow even further. This implies important dynamics of inequality between those who own capital and those who do not. In addition, the higher the risk, the higher the expected growth of a company to be able to make enough money to pay for their debt, thus creating pressures to boost growth even further.

But what are the long-term dynamics of the short-term goals of business leaders and managers? And most important, what if growth is the inherent cause of systemic risk increase over time? Is the forecast provided in the Limits to Growth consistent with reality today? These questions are complex and must be addressed using system thinking. In this chapter, we first give a definition of complex systems, system thinking and sustainability, and we demonstrate the most basic business methods employed today to manage future risks, providing a practical example of the dynamic of long-term exponential growth at the level of aggregated global economy. Thus, we briefly review the Limits to Growth model, and recent literature that compared such a forecast to today's data. This is followed by the descriptions of the major drivers for growth, including constraints and opportunities for growth. Ecological limits are then assessed demonstrating how growth can generate risks including resources depletion, pressures on the agricultural system, climate change and planetary boundaries framework. As a basic leverage point for the transition towards sustainability we show the state of the energy transition towards clean tech. Thus, the Sustainable Development Goals and the correct use of those is introduced, concluding with directions for businesses to engage in decision making towards a sustainable world.

1. System thinking and complexity

A complex system can be defined as a 'set of mutually dependent elements which interact one to another towards a purpose'. 'System thinking' is the approach required to understand and analyse complex systems. Whereas mechanistic, reductionist or atomistic views give emphasis to the elements that compose systems, system thinking (or organic, or holistic) gives emphasis to the whole. When systems are complex, their essential properties emerge from the interaction and relationships between parts, that cannot be isolated. In the words of Capra and Luisi (2016) "the nature of the whole is always different from the mere sum of its parts".

We recognize complex systems when we can describe them with the following terms:

1. *Feedback loop – a closed path relationship between an element and itself through the other elements of the system*
2. *Non-linearity – the typical behaviour of changing response to a perturbation that was recorded in the past, but with unprecedented final outcome*
3. *Path dependency – the tendency to lock in systems into paths that are dependent on the initial conditions, presenting difficulty to invert the path once taken*
4. *Emergency – The formation of aggregate system dynamics dependent on the interaction between components and often not intuitive a priori*

5. *Self-organization – the potential change in system connections dependent on their evolution over time*
6. *Hierarchy – the tendency to structure systems with particular elements to* have more importance than others, and generating a dynamic of cascading effects of some elements to the others*

In such a context, the sustainability challenge requires a mutual synergy between markets and governments to lead the world towards long term prosperity. In order to approach sustainability with a chance of success, it must be seen as a multidisciplinary challenge involving different systems interconnected through mutual feedbacks. One of the earlier definitions of sustainable development was provided by the Bruntland report in 1987 as: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Such a definition remains hard to interpret by policy makers and businesses when they make decisions, and unfortunately, the long term in the year 1987 has become the short-term in the year 2020. Governments and managers who are interested in creating long-term sustainable economic systems must act now with a long-term perspective while gaining short-term benefits along the way.

2. Short-termism and the long-term exponential dynamics of growth

When we seek information about the state of a national economy, it is hard to come across the absolute values of metrics that can assess its performance. These include the Gross Domestic Product (GDP) (i.e. total output), the total employed, or total assets within an economy. Most often, we find relative measures of these absolute values, such as GDP growth in the past period (i.e. the relative increase in GDP in a certain period), the yearly increase in sales (i.e. fractional increase in sales in the year), or the value share of a company (i.e. the prices of shares a company). In fact, when the GDP grows it shows that an economy is capable of producing more in comparison to that measured by past data. This has benefits such as increased potential for employment, value increase and wealth creation. In fact, if we assume no change in the state of technology, population size, or variation in the pensionable age, the rationale can be made simple. For example, if we assume stagnation (growth equal zero) we could imagine that the retirement of those in old age, will leave space for new entrants in the job market after completing their studies and degrees, whereas negative growth would make us expect that less people than those who retire could find jobs in the economy, generating unemployment. On the other hand, with growth, it could be easier to create new jobs and employ those new graduates to the economy.

Increasing the complexity, it is possible to assume that while population grows, the only way to generate employment for those people is to create more economic growth than the growth rate in population. The more health services improve and life expectancy increases, the more workers must accumulate their pensions to pay for their entire lifetime at the end of their employment. As a result, those who are already part of the job market will tend to remain employed for longer creating additional friction to those new entrants to the job market. Seen in these terms it appears that persistent, short-term business growth is the answer to all economic problems we will face in the indefinite long term.

But what are the long-term dynamics of short-term growth? The observation that made Limits to Growth (Meadows et al 2003) such an influential piece of work is that, when projected towards the longer term, short-term growth will have a dynamic of exponential growth. If business and population growth are coupled with the non-sustainable exploitation of ecosystems services, exponential growth can represent a dangerous threat to humanity. The best way to feel the power of exponential growth is to do the calculation. For example, assuming economic growth maintains a constant real growth rate at 3.6% per annum (this is the case of the average growth rate of the global economy from the 1960s), it takes about 20 years to double the size of the economy, as shown in Table 1.

Table 1 – Exponential growth at 3.6% per year over 20 years. The calculation is 1.036^{Years}.

Year	0	1	2	3	…	16	17	18	19	20
Value	1	1.04	1.07	1.11	…	1.76	1.82	1.89	1.96	2.03

In turn, a continuous doubling up of the size of the economy every twenty years for two centuries would correspond to an economy that is 1024 times bigger than its initial value as shown in Table 2. Another example, to appreciate the power of exponential growth, can be found in Box 1.

Table 2 – Exponential growth of a doubling economy every 20 years becomes 1024 bigger in two centuries. The calculation is $2^{\text{Year}/20}$.

Year	0	20	40	60	80	100	120	140	160	180	200
Value	1	2	4	8	16	32	64	128	256	512	1024

While population and the economy become bigger, the rate of resource depletion and emissions would rise proportionally. Even relatively small initial values of an economy and population living non-sustainably in the finite planet would become impossible to contain without a fast transition towards a non-material extractive and non-polluting economy. Considering that the global economy has already passed the point of no-return, it appears how thinking about a double in economic size from today's state in the next two decades, is no more than an aberration in the name of the environmental limits. In the following section a comparison between the Limits to Growth and today's reality is shown, followed by a description of the major elements in our economic and financial system that constrain the system's growth , a review of the state of environmental resources and global limits, and provides an indication on how business development could evolve to avoid the scenarios of Limits to Growth becoming reality.

Box 1 – Fold a sheet of paper

A typical example that is helpful to appreciate the power of exponential growth is to ask the learner to estimate how thick they think an ordinary sheet of paper can be. It is easy to realize it can be about 0.1 mm thick. As a second step they are asked to fold it on itself twice and estimate the thickness again. Of course, the result is 0.4 mm. The third and final step is to provide an intuitive answer when asked to fold the piece of paper for another 40 times (42 times in total). No use of calculators is allowed in this exercise.

When you feel confident with your answer you might want to check the correct response at the end of this chapter.

3. The exponential dynamics of material growth is non-sustainable in a finite world

The Limits to Growth's thesis was proposed as a scenario analysis using the ad-hoc developed World3 System Dynamics model. The main message of the Limits to Growth is that indefinite exponential growth of the global economy is not possible in a finite planet. If we employ technology and innovation as tools for reducing the impact of growth on ecosystems' depletion, then the major outcome will be to post-pone (not remove) the time of overshoot to global limits, and the thesis of economic downturn (with potential collapse of global society) will persist in a world governed by the growth paradigm. Most important, since it takes decades from the time problems are perceived to actual implementation of policies and technologies that can potentially solve the problem, we, as human society, will always lag behind the risks caused by growth, demanding a system change at the level of social policy to assure the economy can operate in a safe space in the indefinite long term. While monitoring the state of global systems over the past fifty years, the team re-proposed the same thesis in the years 1991 (Meadows et al 1992) and 2003 (Meadows et al 2003), performing small adjustments on the World3 model parameters to calibrate correctly with the historical data from 1970s onwards.

Concerned with the evidence of the Limits to Growth, Pasqualino et al (2015) implemented a calibration analysis of the World3 using the historical data from 1995 to 2012. The study both confirmed some aspects of truth in the Limits to Growth as well as revealing some elements of today's economic system that could not have been predicted in 1972. These include:

- Our world population and economy are growing in a finite planet, and the World3 model can be used to assess such a dynamic of growth;
- The pattern for economic growth has shifted to a services driven economy rather than mere industrial growth. This compares favourably to what was expected by the Limits to Growth indicating lower pollution emissions and less harm to people and the environment;
- Growth still remains the main paradigm the world society relies on, and such a growth remains based on the finite available resources of the planet. Resource scarcity as well as negative effects of the system, such as pollution, cannot be excluded in shaping the future possibilities of our world.
- Additional elements that characterize today's world were not included in the World3, such as possibilities for energy transitions, and climate change. These would need to be addressed separately.

As a result, the thesis of the Limits to Growth could not be rejected, despite the positive differences between today's world and what was expected by the team of scientists in the 1970s. The next section provides insights on the structure of the economic system, and a review of today's world limits and impacts. Additional details on the Limits to Growth study can be found in Pasqualino and Jones (2020).

4. The drivers of economic growth and constraints to a non-growing economy

4.1. Debt money system

One of the engines growth relies on is the so-called Debt Money system, that governs the dynamics of money creation and lending in a capitalistic economy. Lending activity comes into play when a business (or whatever economic entity) needs to raise their cash to allow for purchase of assets while de-risking uncertain investments. The process consists of a lender who owns liquidity and provides finance to borrowers in the form of a loan at a certain fractional cost (i.e. interest rate) normally calculated at a monthly or annual rate. The resulting contract obliges the borrower to pay back the debt on a periodic fractional basis, while being charged with the interest premium for the service received. The interest rate represents a measure of the risk of the borrower to return their debt and must account for the uncertainty inherent in the market as well as the historical capabilities of the debtors to redeem their liabilities. The higher the probability of failing to repay the debt, the higher is the interest rate, the cost of financing and the pressure for growth to pay the loan back.

In general, a business uses loans as a financial leverage to invest in expansion of productive assets that are expected to generate revenue over time. In so doing, a loan increases the resiliency of a firm mitigating their risk of failure in the markets they operate in, and has become normal management practice to keep a fraction of financial assets via borrowing to approach new markets without risking the default of their entire business. From the perspective of a lender, the risk of default of the borrower has to be assessed a priori to reduce losses. The default of some producers can increase the interest rate for all participants in the same sector, thus increasing the barrier for new entrants. Larger firms, that have access to financial resources tend to record lower default rates, supporting the dynamic reduction of interest rates over time. This is an important balancing feedback loop used by banks to stabilize the economic system today.

Since all business requires debt to operate, then the long-term dynamic at the aggregated system level is the one of exponential growth, where the interest rate imposed to each loan corresponds to the minimum exponential growth rate of the economy. This is the fundamental requirement for the stability of an economy today. When businesses fail in attaining exponential growth rates sufficiently to repay their debt, creditors can renegotiate their contracts for debt return, or apply compound on the financial assets of the borrower. While losses increase interest rates, the job of the financial sector is to avoid such a situation by means of a careful interpretation of risks and supporting exponential growth in financial terms and value created.

4.2. Financial markets and pension funds require growth

If debt can be considered as an unbalancing force towards growth, financial markets can be seen as the attraction point of such a disequilibrium to sustain growth even further. Financial markets rely on a reinforcing feedback loop which lies at the foundation of most of the economic activities today. In fact, more money provides the liquidity for more investments, which in turn lead to more profit, supporting the accumulation of more money and so on. Their role is to distribute funding from the investor to corporations and to the public sector, which must grow to honour their investments. Financial markets operate based on different products, including the trading of government and household debt (bond or credit market), corporate equity (stock market), primary commodities such as coffee, wheat or oil (commodity market), and, since the abandonment of gold standard in 1970s, currency (foreign exchange market). The use of information technology to operate financial transactions supported its detachment from the real economy, operating at a much higher speed without the inertia of real systems. In so doing, speculative behaviour in trading platforms and short-termism to gain high return as fast as possible took dominance in the system, often with no concern about the possible effects on the real economy (Capra and Luisi, 2016).

An interesting case for use of financial instruments for long term sustainable transitions is represented by the pension funds (or household long term savings) managed within risk assessment firms. A pension fund represents the withdrawal of a small portion of a household's income to be returned to their owners after they retire. As a result, a pension fund represents the perfect pot of money that can be invested in the time frame of a sustainable transition due to the long-term investment return. As explained in Silver (2017), pension funds tend to be invested in low risk stable growth opportunities, often represented by large private firms and government bonds. Interestingly, the main principle that underpins a successful pension fund is also the ability to grow exponentially. An economy with zero growth would be able to return to workers as much money as that which was withdrawn, and most likely be insufficient to provide subsistence spending capabilities as enjoyed during working life. Thus, slow growth would imply lower returns to pension funds. In fact, a major concern for the sustainability transition is in relation to what are called stranded assets, that is valuable assets that might not be usable due to the sustainable transition. In the past forty years, a vast majority of pension funds were invested in large energy companies, based on coal, oil and gas, which could promise sustainable growth. As explained in the following section, a transition away from fossil fuels is a necessary requirement for a sustainable world, implying disinvesting from those resources, and risking a low return of pension funds for the future generations.

4.3. Productivity and technology growth

One of the main arguments against the thesis of the Limits to Growth was in the underestimation of the potential of technology and productivity growth when assessing the power of growth in the global economy (Nordhaus 1973). Economists long established the importance of productivity growth as the most important determinant of long-term economic growth and rising living standards for all (Schwab 2017, Maxton and Randers 2016, Jackson 2016). Productivity growth can be defined as incremental changes in the ability of one person to produce a certain unit of economic output over time. The relation between productivity growth and economic growth was first proposed by Adam Smith in the Wealth of Nations (1776). Smith observed that international trade could support the specialization of firms and cost reduction of output, with the potential to make goods and services affordable for the vast majority of people. At that time, widespread poverty could be found in every corner of the world, mainly because it was not possible to produce enough output for all. Such a thinking could take off thanks to the invention of the steam engine by James Watt in 1781. Its main benefit gradually allowed the substitution of human and animal muscles with machine systems powered by coal, increasing productivity of workers over time, and giving birth to today's capitalistic economy led by growth (Pasqualino and Jones 2020).

The first and second industrial revolution are characterized with widespread diffusion of technologies in every field, including metallurgy, mechanics, and cement. The second industrial revolution was heavily impacted by the discovery of crude oil in 1859, which found applicability due to its cheap price and versatility in comparison to coal. The discovery of crude oil is probably the most important factor explaining the wellbeing and wealth generated in our global economy to date. This was followed by the electrification of machines and the development of telecommunication technologies, with expansion of transportation systems including train, airplanes and the automobile. An important innovation in agriculture is represented by the Haber-Bosch process in the early 1900s that allows fertilizers to be obtained with the use of natural gas, supporting land productivity growth.

Starting in the 1950s, the advent of internet, transistors and computers allowed for the gradual digitalization of human society leading to the cusp of the fourth industrial revolution which is characterized by the use of disruptive technologies. These include artificial intelligence, robotics, 3D printing, cloud services, internet of things and many more. These allowed an industrial era to move into a services era, transforming both human lives as well as the financial sector. The overall effect of these innovations was a general reduction in cost of production while employing the same amount of people, or, in other words, the ability of producing more output employing the same people. For example, the resources extraction industry has seen a gradual cost reduction in extraction of resources despite depleting in the past fifty years. As we will see in the following section, this trend might not last forever.

Alongside productivity growth, innovation has always brought concerns in relation to the transformation of labour, systemic inequality and the possibility of reducing employment in the long term. In fact, a capitalistic economic system must rely on consumption to support growth. But without the assurance of high employment demand may fall, generating a downturn on the global supply side (Jackson 2016). According to Capra and Luisi (2016), financial networks conserve the power on the real economy today, with unskilled labour remaining locally constrained. On the other hand, in an economy that is driven by information processing, knowledge creation and innovation, the skilled personnel is often involved in share option schemes as an incentive to retain their loyalty and assure that their tacit knowledge is passed along the organization. Despite the innovation of the last 70 years, historical data shows that labour productivity growth has been falling globally (Jackson, 2016). The term secular stagnation emerged again requiring to deal with slow economic growth towards the future.

4.4. Projections for population growth by region

Figure 1 shows the historical data and projections of global population from 1950 to 2100 divided in six world macro regions (Asia, Africa, Europe, North America, Latin America and the Caribbean, Oceania). Today's global population is approximately 7.7 billion people, expected to reach between 9.4 and 10.3 billion people by 2050 and between 9.6 and 13.2 billion by 2100 (UN, 2018). Approximately 800 million people are undernourished mostly concentrating in Sub-Saharan Africa and Southern and Eastern Asia (FAO, 2015). Population growth increases global demand for food and commodities, even though the distribution of growth and income is uneven between world regions. In fact, approximately 1.8 billion people live in the most developed regions where population is expected to remain stable or decrease. This is due to the expectations that highly educated women, involved in professional careers and living in urban areas would find it more difficult to have large families.

A large portion of population growth is expected to be recorded in Asia, that today accounts for approximately 4.5 billion people. It is expected that the Asian population will surpass 5.2 billion people by 2050, and then slowly decrease until 2100. The most populous countries in Asia are China and India at approximately 1.4 and 1.3 billion people respectively today. While China per capita consumption is way lower than most developed economies it is expected it will find benefit from the economic transition, economic growth and wealth creation, bringing approximately 300 million people to the threshold of high income experienced in the most developed parts of the world. This will most likely generate pressures to demand growth (for example via the substitution of rice consumption with meat) and determine a slow-down in population growth leading to a similar dynamic experienced in the western world (IIASTD 2009). On the other hand, India, that will not benefit from the same positive trend as China, is expected to remain mostly poor with continuous expansion in population growth, becoming the most populous country in the world with about 1.6 billion people by 2050. African countries will register the largest increase in human population, moving from today's 1.2 billion people to 2.8 billion in 2050 and above 4 billion by the end of the century. Among those, Nigeria is expected to record exponential growth over several decades, becoming the third most populous country with above 400 million people by 2050.

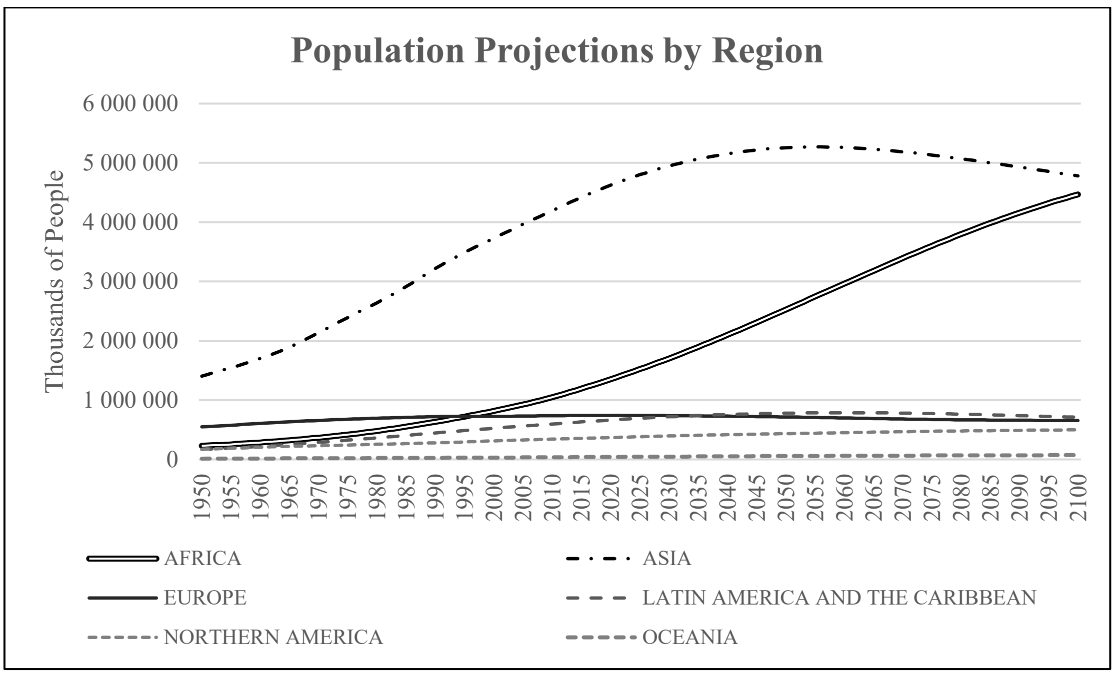

Figure 1 – Population projections by region over time (source: United Nations Population Division, 2018)

5. Ecosystem negative feedback on economic growth

5.1. Energy

While the economy grows, energy and food systems will face additional pressures to supply enough output to feed people and the economy. The energy system is today dominated by the fossil fuels, represented by coal, oil and gas. IEA (2017) shows that total primary energy supply increased two-fold between the 1970s and 2015, whereas the dependency on fossil fuels just changed from 86% to 82%.

A peculiarity of the fossil fuel industry is that resources that can be extracted more cheaply have priority over those that are harder to extract. When the cheaper options get depleted, prices will start to increase, justifying investments to develop the technology necessary to extract the more expensive ones. The era of cheap oil and coal have found great benefit from these dynamics over history. While an oil well could shoot out from the ground in the 1860s, these reserves are long depleted. A major technology in use today for oil extraction is fracking. It consists of injecting liquid into subterranean rocks and extracting oil with the help of a long pipeline and systems of pressures. Of course, the capital intensity of the second method is more expensive to that that people enjoyed a century ago. Today, geologists have found most of the reserves, and no major oil wells have been found since the 1970s (Wijkman and Rockstrom 2013), thus assuming that the only dynamic going forward will be the one of resource depletion and increasing cost of energy.

Two common indicators used to measure the availability of resources in the ground are the RP ratio (resources to production ratio) and the EROEI (energy return on energy invested). The RP ratio is well established but not very good when interested in the dynamics of depletion. It consists of calculating the ratio between total economic known reserves in the ground and present yearly production. The ratio is an intuitive measure that expresses the number of years that it is possible to assume we would not run out of a resource while keeping the same extraction rate. Figure 2 shows the actual historical data of coal production in the UK between 1880 and 2000, and aligns it with the relative RP ratio calculated at each year by the author. For simplicity in the calculation, it is assumed that geologists would have known the total amount of reserves since the 1880. As figure 2 shows, the shape of coal production followed a bell shape curve, growing during the nineteenth century, slowing growth and peaking around the 1930s, and then declining reaching all the way towards the end of the twentieth century. The reserves to production ratio indicated 160 years of available reserves in the year 1880. However, while production grows, and reserves deplete, the RP ratio decreased to about 40 years worth of production left by 1930 (50 years later). On the other hand, after peak is reached, the production declines because cheaper ores are depleted, and it requires more effort and cost to dig in the ground to extract other coal. As a result, the RP ratio would provide a distorted metric to assess the time an industry can keep operating both during growth and during decline of the industry.

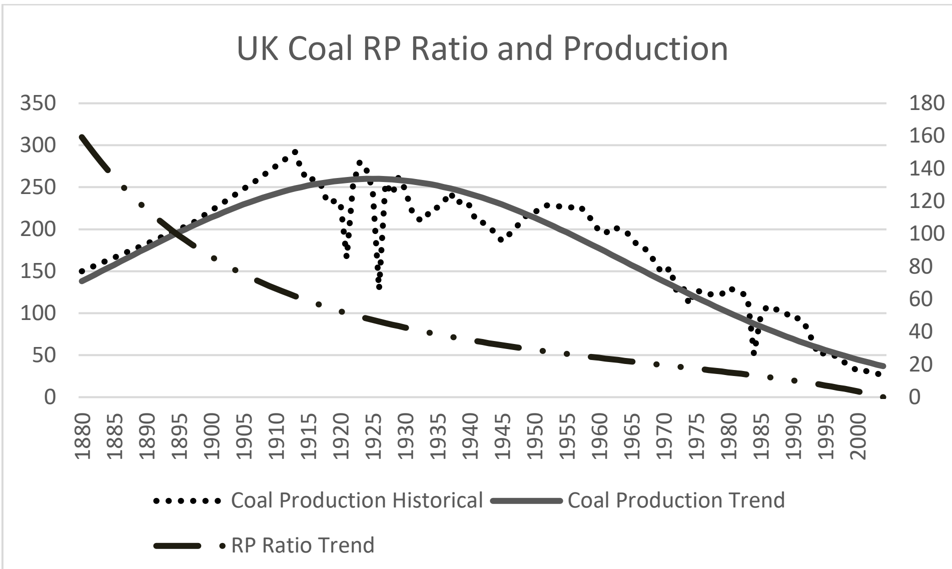

Figure 2 – RP ratio and Coal Production in the UK (adapted from: UK Government Department of Business, Energy and Industrial Strategy, 2018)

A better indicator than the RP is the EROEI, which allows to assess how many units of energy can be obtained by employing every single one of them. Following the same perspective of depleting resources, higher EROEI sources would be extracted before the low EROEI resources. In general, a source is considered to be economical for production as long as EROEI is higher than 5, while preferring the sources at higher EROEI. When EROEI is between 5 and 1, sources are considered to be marginally economic, and below 1 not economic. In this latter case, resources should never be spent for extraction since it is more energy intensive to extract than the energy obtained. For example, in the case of crude oil, EROEI had been between 50 and 100 for the most of twentieth century, decreasing to 15 to 20 during the last decades (Bardi 2014, Wijkman and Rockstrom 2013).

5.2. Agriculture

Similarly, to fossil fuels, population and economic growth require more food to be produced. Most importantly, the relationships between fossil fuels and food output describe a physical dependency mostly due to the technology adopted today to increase land productivity while injecting fertilizers in land. In fact, it is estimated that 30% of the cost of production of crops is linked to oil and gas, which are fundamental to extract nitrogen from ammonia and subsequently produce fertilizers (IIASD 2009). In other words, it is possible to say that every calorie of energy contained in our daily food requires seven to eight calories of energy from fossil fuels to be produced (Wijkman and Rockstrom 2013). As a result of all the above, a decrease in EROEI of oil will increase the cost of energy extraction, and this will impact the price of food directly.

Agriculture consumes approximately 70% of all fresh water we use for food production as well. When analysed from the sustainability perspective, agriculture remains the most complex sector of our economy. When accounting for deforestation linked to agricultural land expansion, agriculture is the first sector of anthropogenic emissions and thus, first cause of climate change. Together with fossil fuel production they account for 50% of total emissions globally (IPCC 2014). On the other hand, agriculture is the major source of employment and wealth creation in developing countries, employing 40% of the worlds labour force and bringing hope for poverty reduction. The next section reveals the relationship between agricultural production, demographics and climate change.

5.3. Climate

Climate change (or global warming) consists in the overall increase in global average temperature, that is correlated with the accumulation of anthropogenic greenhouse gas emissions in the atmosphere (IPCC, 2014) (Figure 3), and thus is a direct consequence of growth. Global concern with climate change today relates to the variety of systemic risks linked with the imbalance in the climate system stability as well as distribution of its effects all over the planet.

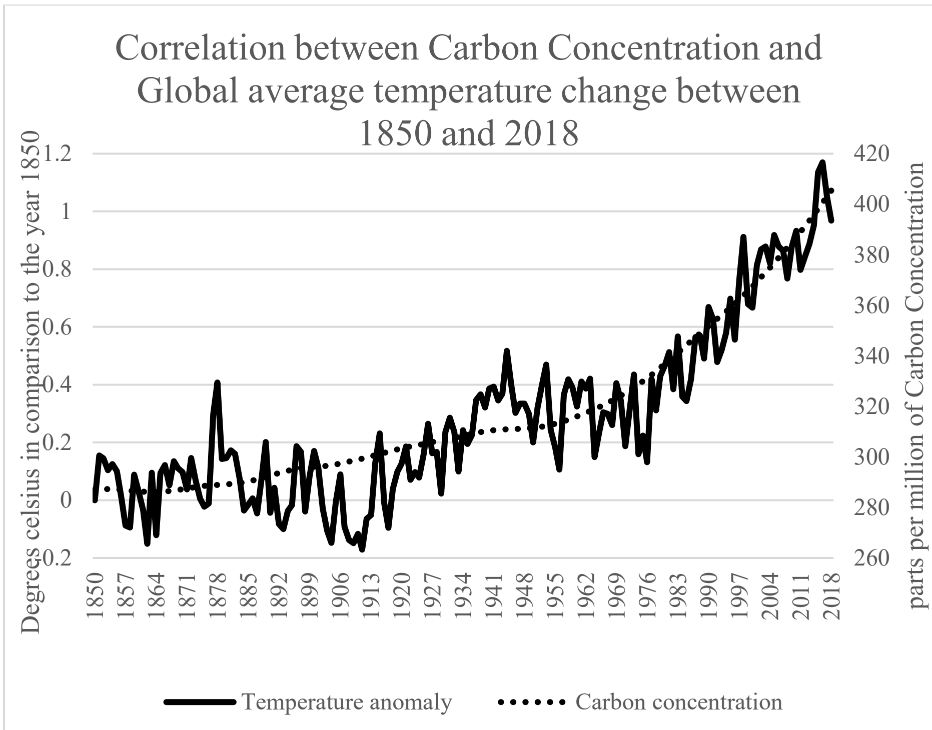

Figure 3 - Correlation between CO_2 concentration and global average temperature (sources NASA 2019)

One of the most unjust consequences of climate change is that its impact will be uneven across the world, impacting more those countries that influenced it least. In particular, agriculture represents both the first cause as well the most vulnerable sector to climate change. Temperate regions are expected to be less impacted, with short term increase in crop yield due to the increase in carbon in the topsoil and a more humid climate. However, medium to long term projections expect a productivity fall due to increased diseases and infestation (Wijkman and Rockstrom, 2013, IPCC, 2014). In addition, short-term shocks such as shifts in weather patterns, extreme weather events and rising sea levels will have negative consequences for food output over the medium to long period.

IPCC (2014) predicts a reduction in available fresh water in several regions including southern Europe, northern Africa, parts of western Africa, southern Africa, southern

Australia, the north-eastern parts of Latin America and parts of western North America. Extreme weather events, such as hurricanes, floods, or heat waves (Wijkman and Rockstrom, 2013), are becoming more frequent and violent in the Tropics than in the past decades, increasing food loss and land erosion which ultimately will impact on food availability and international prices (Stern, 2006, IPCC, 2014, Lloyd, 2015).

Aware of these issues, 196 country representatives met in Paris in 2015 at the 21st Conference of Parties (COP21), as part of the United Nations Framework Convention on Climate Change (UNFCCC) to set a climate target at +2 degrees Celsius of global temperature increase, and commit to implementing policies to achieve this goal. Such a target could be met by keeping the average carbon concentration in the atmosphere below 450 ppm (parts per million) of carbon. It is worth noting that such an objective would imply an 80% reduction in greenhouse gas emissions from their current level by 2050. Recent studies from Steffen et al (2018) demonstrated that +2 degrees might not suffice to keep global warming in a stable condition. Rather ecological feedback loops could be activated leading the world systems towards the path of +5 degrees (the so-called Hothouse effect) without the requirement of any human additional emission, causing irreversible damages to ecosystems and economy. Global scenarios addressing the impact of Hot House effect on agriculture can be found in Pasqualino and Jones (2020).

As Figure 1 has shown the increase in population is expected to be registered in the areas of the world that will be most impacted by climate change, and characterized with food poverty and undernourishment. This will create pressures from migration from poor to rich countries, and potential cause for conflicts and populist sentiment across the borders. On the other hand, it is worth noting that the problem of food security today is not a matter of producing enough food for all the people, but rather a matter of economic systems and supply chain inefficiency in distributing food output. Today's supply chains waste approximately 30% of the entire food product from land, one third of which could suffice to satisfy the food demand of the poorest in the world (FAO, 2015, Kummu et al, 2012).

5.4. Planetary boundaries

In line with the Limits to Growth study and the complex system sciences, the planetary boundaries framework (Figure 4) shows that climate change represents only one of the nine thresholds that, as humanity, we are supposed to not overpass to keep operating in a safe space (Steffen et al 2015). According to this framework, all thresholds are interconnected systems, and should be managed not in isolation but looking at the full picture. The global challenge of climate change is in an uncertain risk zone. However, thresholds that are far beyond safety relate to agriculture. These include the continuous increase of production via the use of fertilizers and genetic biodiversity. The first has already unbalanced the phosphorus and nitrogen cycles (both standard fertilizers), and started to negatively impact ocean ecosystems and fisheries through eutrophication of poisonous algae, whereas the second was mostly led by the use of pesticides to protect the food we eat and decrease food production loss.

Among the thresholds, climate change, ocean acidification and stratospheric ozone depletion are all global in nature. Biosphere integrity, land-system change, freshwater use, biochemical flows, and atmospheric aerosol loading remain regional in nature and solutions must be approached within countries or specific areas of the world.

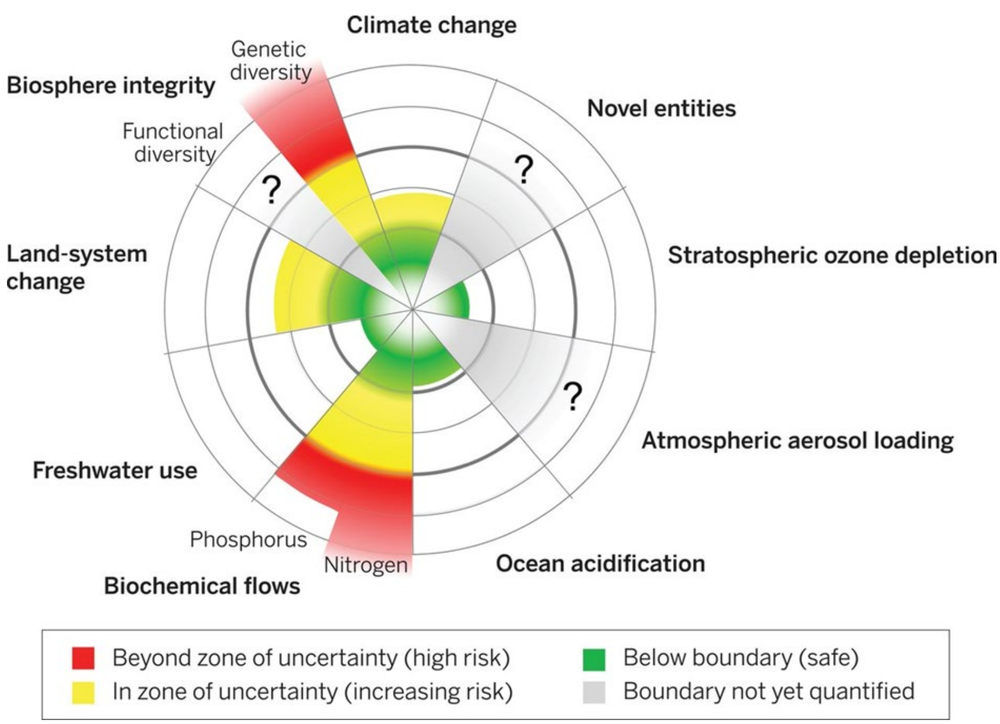

Figure 4 – Planetary boundaries framework (source: Steffen et al., 2015)

6. Current state of the energy transition

Given the above picture, it appears how the transition towards sustainability must account for constraints in the ecological sphere and rely on system thinking to be successful. Whereas each of the planetary boundaries might require specific skills and know-how, in this chapter we focus on just one of the elements that can be considered a fundamental leverage point for the sustainability transition. That is the energy transition towards clean-tech and green finance economy. In so doing, in this section we provide an overview on the state of global green energy.

Table 1 shows the current energy mix of fossil fuels, renewables, and nuclear energy divided between electricity generation, heating and transportation at the global level (REN21, 2018). As it is possible to see, the green energy sector is way behind the fossil fuel sector in relation to the issue at stake.

Resource\Sector	**Electricity**	**Heating**	**Transportation**	**Global fraction of energy mix by source**
Fossil fuels	66.30%	72.70%	97%	**78.60%**
Renewables	23.10%	26.20%	3%	**18.90%**
Nuclear	10.60%	1.10%	-	**2.50%**
Fraction of final consumption by sector	**18%**	**53%**	**29%**	**100%**

Table 1 – Global energy mix in 2016

The electricity sector accounts for approximately 18% of total energy supply, 23.1% of which is supplied with renewable energy. Today's renewable electricity is 70% supplied via hydroelectric, that is a mature technology. Wind energy represents the 15%, bio-energy 8.4%, solar photovoltaic 5% and geothermal 1.6% of total green energy (IRENA 2018). Most of the hope for green energy transition relies on the exponential growth of solar and wind energy technology to supply the electricity necessary to also sustain the global transportation and heating energy supply. As these data show, these two sectors represented 0.8% of the total energy supply in 2016.

In fact, the 26.2% of total heating energy consumption is represented by renewable energy. However, 90% of this latter comes from the combustion of traditional bio-mass and of timber in developing and underdeveloped countries (IEA 2017). The sustainable development goals (UN 2019) show that indoor air pollution in low income countries is the second largest cause of death after HIV due to the inadequate ventilation for cooking and heating. The rest of heating supply from renewables is represented with 2.1% coming from solar finding applications in household heating at low temperatures, 0.5% from geothermal, and 6.1% from modern biomass plants (REN21 2018).

The transportation sector is mostly run with oil, and a tiny 3% divided between 2.85% in modern biofuels and 0.15% in electric vehicles (IEA 2017). The transportation sector can be further divided in 76% represented by road vehicles, 12% marine, 11% avionic, and 2% rail sector. (REN21 2018). The transportation sector being responsible for approximately one third of total emissions from energy, it is possible to say that today's avionic correspond to approximately 3.2%, marine 3.5% and road transport is 22% of carbon emissions from energy.

While exponential growth of the global economy appears to be a challenge to economic sustainability, the exponential growth of the green energy sector seems to be a major hope on the way to sustainability. Of course, exponential growth will always find limits, coming both from the social and the environmental sphere, making it an unprecedented challenge to be faced by businesses seeking profit while addressing environmental sustainability.

7. Sustainable Development Goals and growth

The definition of the +2 degrees climate target at COP21, and the update of the Millennium Development Goals to the seventeen Sustainable Development Goals (SDGs) (UN 2019), make the year 2015 an important one for sustainability. The SDGs are a complex set of indicators that, if used correctly, can support the transition towards a sustainable economy. The aim of the SDGs is to provide balance in the world society, demanding governments, businesses and citizens to act in synergy toward the best performance of all of them. Ideally, each organization should target the larger number of SDGs simultaneously, since that targeting single indicators might result in under-performance on the others.

For example, if an organization should decide to target the indicator 8 only (sustainable and inclusive growth and decent jobs), this might result in no impact to sustainability at all. In fact, targeting growth without considering the others would correspond to act in business as usual condition along the way. While, on the other hand, approaching simultaneously indicators 13, 14 and 15 (climate action, life below water and life of land respectively), this would require thinking carefully about the maximum synergy possible between the planetary boundaries framework and economic growth, leading toward a more meaningful use of the indicators.

8. What should a corporate do for running a sustainable business today?

Short-term focused business as usual growth of the past fifty years has gradually created wealth in the global economy, while causing concern for the future generations that must deal with sustainable challenge as a short-term issue today. The way of thinking of the past must be changed to perform well in this challenge, and must be approached in synergy between managers, policy makers and scientists along the way. System thinking and appreciation of complex systems science to approach these problems is a way to change the mindset required to deal with such a set of issues.

Pasqualino et al (2015) has shown that the concern of the Limits to Growth with exponential growth in a finite planet could still holds true today. However, Pasqualino et al. (2015) also showed that the overall economic system has developed better than expected creating more wealth with the services sector rather than just material industrial growth. This is a positive trend of growth, and businesses should aim to outperform on this activity in the future.

On the other hand, constraints to the limits to growth mission are also presented as elements that form the foundation of our economic and financial system. These include the debt money system, the use of interest rates as risk assessment metric, the functioning of financial markets and the importance of pension funds in shaping long term investment towards global sustainability. Productivity growth and technology development in the past fifty years have partially helped in dealing with world limits, and still remain an engine for wealth creation, despite not being sufficient to stop damaging ecosystems to date. While population grows in the areas of the world that will be most impacted by the negative consequences of approaching global environmental limits, concerns emerge around the areas of food security and mobility of people in the safe areas of the planet. These include the rise of social response with likely increase in populism and conflicts worldwide.

The limits of fossil fuels and agriculture have been proposed in light of recent literature, together with the climate problem, and the overall frame of the planetary boundaries report. These shows how the challenge ahead is a complex issue, that requires an important synergy between public and private sectors. The Sustainable Development Goals have been presented as a good complex system tool to approach this transition, and corporate biases to support the correct use of these indicators have been highlighted.

In sum, what should a corporate do for running sustainable businesses today? This is a complex question that only the practice of management and collaboration between businesses and government can provide. It is worth noting that 'if you cannot measure it, you will never be able to improve it'. A great challenge of the sustainable transition is that problems are hard to measure, and thus are most difficult to approach with clarity. The SDGs help in this context, even though each organization should develop and create indicators that fit to them, linking, for example, their balance scorecard or accounting metrics with complex system metrics such as planetary boundaries and SDGs. Implementation of practices that support this transition at the micro scale could provide benefits as well, while aligning business objectives with the larger sustainability frameworks as provided in this chapter.

Over the long run, continuous development of novel technologies that improve productivity will be an important factor, in particular when they can generate more jobs throughout the supply chain than the ones they directly substitute. This trend is important for reshaping the entire economic system, in particular where exponential growth of the green sector should be supported and incentivized as possible. Alternatives to the standard energy framework might include the decentralized approach of creating local solutions of green energy rather the employing large energy plants. Transportation sector could be improved giving more emphasis to rail when distance allows, and substituting air travel with video conferencing tools when possible. Food security can be supported with novel technology that aim at improving the match between supply and demand and targeted to the reduction of food waste in the global supply chains. A service economy should take a dominant role, creating value beyond the mere material consumption going forward.

Short-term business as usual growth, while creating wealth and eradicating poverty along the way, has also caused concerns for environmental limits. The size of the challenge appears not to be a simple solution to be tacked by free market alone, and the constant and persistent collaboration between governments and businesses will be an important element for the success of this transition going forward.

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Biography:

Roberto Pasqualino is Visiting Researcher of the Global Sustainability Institute at Anglia Ruskin University, UK and Chief Innovation Officer of Exoshock Ltd, a global risk analysis company based on Roberto's research. With background and culture in industrial engineering, Roberto's research interest is in system dynamics modelling of industrial policies for the analysis of financial risk and sustainability.

Roberto developed his own Economic Risk Resources and Environment system model to quantitatively capture the financial risks emerging from the interaction between the dynamics of growth and global ecological constraints during his Research Fellowship, under the Economic and Social Research Council CUSP project. This allowed him to create his own company Exoshock Ltd to help businesses to deal with those environmental and economic shocks that have the potential to disrupt their markets in a complex world thus reducing future risks. Roberto is one of the maximum experts on the Limits to Growth in the UK and author of the book "Resources, Financial Risk and Dynamics of Growth – Systems and Global Society, Routledge Oxford" co-authored with Professor Aled Jones.

Roberto's expertise encompasses sustainable supply chain management, business practices, risk assessment, circular economy, energy transitions, climate change, food security, behavioural and evolutionary economics, and strategy. The methods adopted include system dynamics, econometrics, game theory, complex networks, statistics, and simulation techniques in general. Roberto has been teaching university lectures at BSc, MSc and MBA levels since 2013.