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A post-growth society for the 21st century

Does prosperity have to wait for the return of economic growth?

Damien Demailly, Lucas Chancel (IDDRI),
Henri Waisman, Céline Guivarch (CIRED)

GROWTH, A POLITICAL OBSESSION

In political discourse, from both the right and the left, economic growth is held up as the solution to economic and social problems, in other words as a *sine qua non* of individual and collective prosperity. For the proponents of this discourse, high growth is not only desirable, but is also achievable, provided we give ourselves the necessary means.

DECLINING GROWTH RATES OVER THE LAST 40 YEARS AND AN UNCERTAIN FUTURE

The academic literature shows that beyond the current crisis, there is a good deal of uncertainty regarding the capacity of the different countries to restore high growth. Many factors, such as the expansion of the service sector, the pace and nature of technological innovation, and demographic change, all indicate that average growth within the European Union could be lower in the coming decades than over the last 30 years.

ENVIRONMENTAL CONCERNS ARE ADDING TO THIS UNCERTAINTY

Sometimes, the gravity of environmental issues is seen as an opportunity to spur on a new industrial revolution to deliver growth; at other times, it is viewed as a constraint that would further slow down the economy. The modelling exercise carried out in this report studies the linkages between climate and macroeconomics. It confirms the diagnosis of uncertainty surrounding the future of economic growth: under pessimistic but plausible assumptions for the coming decades (concerning energy resources, the cost of renewable energy, or lifestyle changes), the environment significantly reduces growth.

PROSPERITY WITHOUT GROWTH, A POLITICAL AMBITION

This study shows that very low growth rates in the future do not imply forsaking prosperity as it is conceived in European democracies. The linkages between employment, social protection, equity and wellbeing, on the one hand, and economic growth on the other, are less robust than is commonly thought. In terms of employment, some authors maintain that beyond the economic crises, it is not growth that generates jobs, but the opposite. In terms of self-reported wellbeing, or health outcomes, once a certain standard of living has been achieved, equality policies are a powerful force for progress, not growth. However, reducing economic inequalities and financing social protection are made more difficult in a context of low growth, which thus calls for a higher level of deliberation and arbitration. Ensuring prosperity in a post-growth world means more political action.

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Does prosperity have to wait for the return of economic growth?

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EXECUTIVE SUMMARY

BACKGROUND: AN INAUDIBLE DISCOURSE ON GROWTH

Since the 1970s, growth rates in the wealthiest European countries have been sluggish, if not in decline, and Europe is not the only region affected. For the generations born after the 1970s – in the wake of the thirty-year post-war boom – the political discourse on the return to growth is becoming increasingly outdated.

Some leaders are hoping for a return to the thriving post-war decades or the onset of a new industrial revolution, whilst others would be quite content with an annual 2% growth rate once the crisis has passed.[1] Moreover, for the vast majority of politicians, growth is synonymous with prosperity: more growth is needed to create more jobs, reduce inequalities, maintain the quality of the welfare states and, ultimately, make people happy.

These political discourses on growth are thus doubly dissatisfying. Unfortunately, the authors developing alternative ways of conceiving growth are failing to address this dissatisfaction. First of all, because the demonstration that the end of economic growth is inevitable given our finite world seems far from robust, as do the hopes for a new wave of growth buoyed up by green technologies. Second, although the literature on the growth indicators that can replace GDP certainly addresses paramount social and environmental objectives, it often says too little about the role of GDP growth in reaching these objectives, be it with regard to employment, income equality or access to essential services such as health care and education.

1. Do policies have an optimistic "leaning" as far as growth is concerned? We consider that this is often the case for medium-term and long-term growth, as evidenced by the hopes for a new wave of growth, as well as for short-term growth (take, for example, the French Government's growth forecasts over the last ten years, which have overestimated the growth rate for each following year by nearly one percentage point – which is to say as much as the average growth rate over the same period). In the short term, we have the obvious example of public deficits, which have worsened in recent decades. But is a matter of grave concern to overestimate long-term growth? The answer is no – as long as today's policy actions do not make achieving high growth rates an an imperative.

PURPOSE OF THE REPORT

To respond to this dissatisfaction with the current political and media discourse on growth, this report attempts to answer – as far as possible – the two following questions:

1. Can we have any certainty about the future of growth?

2. Assuming that the coming decades will be a period of weak growth fluctuating between an annual 1% growth and a stagnant GDP, can we still prosper?

To answer these questions, we have studied the economic literature, organised seminars bringing together practitioners, policy makers and experts and carried out a modelling exercise to investigate the links between the energy-climate nexus and the economy.

1. IS THERE A FUTURE FOR ECONOMIC GROWTH IN THE DEVELOPED WORLD?

Growth rates exceeding 1% a year are a recent phenomenon in the history of humanity and those seen in Europe during several decades following World War II are something of an exception. Growth is the result of complex mechanisms that can be linked up with factors such as the composition of the economy (tertiarisation), the diffusion of new technologies with a strong transformative potential, energy and the social compromise. However, economists are clearly quite unable to establish robust forecasts covering several decades.

For the last forty years, economic growth has been on the decline in the rich countries, and a weak-growth environment could well persist or even worsen. In fact, it is not inconceivable that today's new technologies turn out to be less "radical" than those that propelled the industrial revolution, or that the tertiarisation of the economy underway in industrial countries is durably slowing down productivity gains, particularly in those countries that have opted for development models based on education, healthcare, caring for the elderly and, more generally, on "personal" services.

On top of this, there is the challenge of growing energy resource scarcity and reductions in global greenhouse gas emissions. Here too, we find a great deal of controversy. While some consider economic degrowth to be inevitable, others believe that these environmental challenges present a tremendous opportunity to return to growth, start a new industrial revolution. As we have seen, the current state of natural resources is sometimes worrisome. Yet, to understand the possible macroeconomic impact of energy resource scarcity or emissions reduction, it is necessary to call on an economy-energy-climate model such as the CIRED model that we use. Our findings show that, while the most pessimistic scenarios are confirmed (for energy resources, trends in the cost of low-carbon technologies and lifestyles), the macroeconomic impact may be several tenths of a percentage point of annual growth or even stronger during the transition period spanning the next twenty years. Moreover, if growth is already weak, this represents a substantial drop.

There is thus "radical" uncertainty about the future of economic growth. Our future policy choices and the technologies that we may invent in the coming years are uncertain. This opens up a large range of possible economic pathways with an equivalent number of growth outcomes. And the eventuality of low growth rates, floundering around 1%, stagnation or worse, is not to be excluded.

2. CAN WE PROSPER WITHOUT GROWTH?

In political discourses, growth and prosperity are often synonymous. Yet, it would appear from this report that adapting to very low growth rates does not mean abandoning the objectives pursued by public authorities to reduce inequalities in wealth, secure social protection and improve life satisfaction.

The links between growth and prosperity are much weaker than is generally supposed. There is, in fact, no correlation between happiness and long-term growth in the richest countries, any more than between employment and long-term growth. Employment and growth appear to be strongly correlated in the short term, but many economists contend that it is not so much growth that drives employment as employment that helps restore growth: no need for growth in order to create employment, but rather a tautological need for "employment policies" (labour market, industrial strategy, wage policy, public-sector employment, etc.). Likewise, although happiness and growth are strongly correlated in the short term, this is primarily due to employment: what people need to feel happy is not so much growth as jobs. In the political discourse, the detour *via* growth is very often unnecessary.[2]

On the other hand, the links between growth, long-term inequality and social protection are much more tenuous. Weaker growth deepens income inequality over the long term, and yet greater equality seems to be crucial for self-reported happiness and the effectiveness of health care systems. A low-growth society thus needs to redouble its efforts as far as redistribution is concerned.

Similarly, we observe that weak growth complicates decisions about the trade-offs required to secure the financing of the state pension systems: without growth, there is all the more reason to step up contributions and/or work longer and/or decrease pensions *relatively*. The same holds for the health sector: with a rising demand for health care in a low-growth context, the need arises to increase contributions and/or cut expenditures and/or radically reform the system. Ultimately, without a "bubble of oxygen" from growth, we need more reforms, more political action.

Unfortunately, a weak-growth context puts a powerful brake on policy, whether the policy goal is to reduce inequalities or reform the social protection system. Since the pie is not growing as fast as it used to, it is intuitively more difficult to modify the distribution of wealth between workers and rentiers, active and inactive workers, or arbitrate collectively between public and private health services. A weaker growth regime thus imposes more arbitration and renders them even more politically sensitive.

2. This detour is made in the discourses, but is it made in reality?

By way of conclusion, we give a brief reminder of what has been outlined above. The analysis shows that it is not so much society's economic growth that matters, but rather the individual and collective choices that we make: whether or not to adopt a development model based on "personal" services, whether or not to reach our climate objectives. These choices will lead to different levels of prosperity and economic growth. The level and growth rate of GDP are above all the outcome of our choice of development paths – they are not what determines the prosperity of the industrialised countries. This conclusion may appear trivial to some, but it is nonetheless fundamental. Many political discourses make a "detour" *via* GDP growth to reach the destination of prosperity but in many respects this seems pointless and – after decades of sluggish growth – outdated.

It is now time for policy makers to take a fresh look at growth, accept the radical uncertainty surrounding its future and construct, first of all, a positive narrative for the future that bears no reference to growth and, then, a society that is able to concretely free itself of the shackles of growth: a post-growth society. We hope that this report has given policy makers some food for thought so that they can make themselves heard once again by the generations born after the post-war boom. We also hope that we have been able to encourage researchers to deepen the questions that have been left open: post-growth macroeconomics still remains to be built.

Can we continue our economic growth in a finite world?

Does the increasing scarcity of energy resources or climate policy put a brake on growth? The analysis of the oil, gas and coal resources available to society sets the physical framework within which the economy has to operate. But to understand the complex changes inside this framework, it is useful to run an economic modelling exercise.

For this, we use the CIRED's economy-energy-climate model, IMACLIM, which is also used by the Intergovernmental Panel on Climate Change (IPCC), to discuss the macroeconomic impact of two environmental issues, energy and climate. This analysis shows that whilst the most pessimistic assumptions (on energy resources, trends in low-carbon technologies and lifestyles) are confirmed, the macroeconomic impact of climate change policies and/or energy scarcity would be several tenths of a percentage point of growth. Moreover, if growth is already weak (Chapter 1), this represents a substantial drop.

Quantitative modelling results obviously need to be handled with care. First, because if the most optimistic assumptions are taken rather than the most pessimistic, the macroeconomic cost becomes almost negligible. Secondly, because the results are orders of magnitude and not accurate predictions, and also because the trust one has in these orders of magnitude depends on the trust one has in the way IMACLIM represents the interactions between the economy, energy and climate. Note that we limit this study to the economic impact of climate policy, leave aside other policies, such as biodiversity conservation, for example; neither do we include the impact of major climate disturbances on the economy.

More generally, IMACLIM, like all models of this type, is not constructed in order to tell us whether we can grow in spite of energy or climate constraints, but rather to explore different possible development trajectories. So, while the political and media debate on the environment seems to focus overly on new technologies, we show here that changes in lifestyle are even more determining. We can pursue today's unsustainable lifestyles and place our bets on technological innovation alone: but this "strategy" could have a particularly high macroeconomic cost, if only because it is more vulnerable to the rebound effect.

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INTRODUCTION

BACKGROUND: AN INAUDIBLE DISCOURSE ON GROWTH

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Some leaders are hoping for a return to the thriving post-war decades or the onset of a new industrial revolution, whilst others would be quite content with an annual 2% growth rate once the crisis has passed.[3] Moreover, for the vast majority of politicians, growth is synonymous with prosperity: more growth is needed to create more jobs, reduce inequalities, maintain the quality of the welfare states and, ultimately, make people happy.

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PURPOSE OF THE REPORT

To respond to this dissatisfaction with the current political and media discourse on growth, this report attempts to answer – as far as possible – the two following questions:

1. Can we have any certainty about the future of growth?

2. Assuming that the coming decades will be a period of weak growth fluctuating between an annual 1% growth and a stagnant GDP, can we still prosper?

We begin by addressing the first question about the future of medium- and long-term growth in Chapter 1. We review the literature that investigates the phenomenon of growth and also present the current academic controversies on the possibility of growing in a finite world, the tertiarisation of the economy and technological innovation. To our mind, the question of the future of economic growth must be addressed within a framework that goes further than environmental issues.

The problem of growth in a world where energy is becoming increasingly scarce and where greenhouse gas emissions need to be drastically reduced is treated in Chapter 2. This involves a simulation exercise using the economy-energy-climate model developed by the Centre International de Recherche sur l'Environnement et le

3. Do policies have an optimistic "leaning" as far as growth is concerned? We consider that this is often the case for medium-term and long-term growth, as evidenced by the hopes for a new wave of growth, as well as for short-term growth (take, for example, the French Government's growth forecasts over the last ten years, which have overestimated the growth rate for each following year by nearly one percentage point – which is to say as much as the average growth rate over the same period). In the short term, we have the obvious example of public deficits, which have worsened in recent decades. But is a matter of grave concern to overestimate long-term growth? The answer is no – as long as today's policy actions do not make achieving high growth rates an an imperative.

Développement (CIRED). This chapter will also take stock of the "environmental constraint" and the increasing scarcity of natural resources.

The question of prosperity without growth, to paraphrase Tim Jackson (2009), is explored in Chapter 3 through a review of the literature, in order to gain a deeper insight into the economic linkages between growth, employment, equality and financing the welfare states. Do we need growth to attain the objectives that make up a country's prosperity? Chapter 3 aims to "put growth in its proper place" and understand in what ways it is – or is not – a necessity. The ultimate purpose of this report is to invite policy makers to develop a credible and long-awaited political discourse that is not based on economic growth, and encourage the research community to respond to the questions that we leave open-ended.

CHAPTER I ECONOMIC GROWTH: "BACK TO THE FUTURE"

1.1. WHAT IS ECONOMIC GROWTH?

Before looking into the history of growth, we need to run through some key definitions. *Economic growth* (or more simply, *growth*) is the year-after-year variation of what an economy produces or, in other words, all of the final goods and services traded through a price system within a given territory.[4] This definition is limited to monetary-based exchange and does not include non-monetary goods and services. Here, therefore, we focus only on national or individual economic wealth and on its variations – two components, among many others, of well-being.[5]

Long-term economic growth is the result of a rise in output per hour worked – intensive growth – and/or the increase in the total volume of hours worked – extensive growth. The total volume of hours worked depends on demographics (population growth normally induces an increase in output), standards for weekly working hours and the labour force participation rate.

Productivity per hour worked (or *hourly productivity)* depends on how work is organised and on the social contract,[6] on the technology made available to workers (quality and type of machines), etc. The concept is difficult to measure or compare over the long run (see Boxes 1.1 and 1.2) but it is nonetheless key, as productivity is what determines how monetary income per capita evolves over the long run. A rise in productivity also reflects our capacity to produce market goods and services in increasing quantities or of better quality. This is what prompted Paul Krugman (1992), the winner of the Nobel Prize in Economics, to say: "productivity isn't everything, but in the long run, it is almost everything". A country's ability to improve its average standard of living over time depends almost entirely on its ability to raise its output per worker". Historically, we see that productivity gains have accounted for 60% of growth in the United States since 1960 and 100% of growth in the eurozone between 1980 and 2005 (Jorgenson *et al.*, 2010; Gomez-Salvador *et al.*, 2006).[7]

Although economic growth is a prominent topic in the media and politics, economists and social science researchers still have only a partial understanding of its workings – be it short-term growth or the even more problematic long-term growth. The conceptual framework used by economists to describe long-term growth still refers to the one proposed by Robert Solow in the late 1950s: long-term productivity is sustained by technological progress. But this theoretical framework is something of an ill-defined "black box", and since the 1950s it has undergone some fine-tuning. Researchers have been trying to open the "black box" of technical progress (see for instance Aghion *et al.*, 1998) or integrate new explanatory factors by investigating the role of political institutions, culture, norms (North, 1990; Acemoglu, 2004).

4. Here, a distinction should be drawn between final goods and services and intermediate goods and services. To avoid double-counting, national accounts exclude intermediate goods and services (i.e. those that enterprises use as inputs to produce final goods and services) from their measurement of GDP.

5. It should nonetheless be noted that economic growth gives us only limited information on changes in economic wealth. In fact, growth only represents changes in income or output, which are flows, whereas wealth is a stock.

6. The ensemble of legal and non-legal standards regulating the relations between workers and employers.

7. Of the 3.58 percentage points of average growth in the USA (between 1959 and 2005), 2.2 are linked to an increase in labour productivity and 1.38 to an increase in the number of hours worked. In the eurozone over the 1980–2005 period, labour productivity growth accounted for 1.97 percentage points whereas hours worked made a negative contribution (-0.18 points).

Yet the fact remains that the causes of economic growth, its operative dynamics and their consequences are still controversial issues in economic theory.

We should also point out that integrating the complexity of economic growth is a nascent and extremely promising line of research [8] involving cross-disciplinary approaches that call on biology, archaeology, physics, history, sociology and political science – but it will take a few more years before these interactions are more fully understood. At the present time, "standard" forecasts do not take into account the complexity of the mechanisms in play. They do no more than prolong the productivity gains of recent years to project medium- and long-term gains. Thus, for the OECD, productivity gains in Europe for the 2030–2060 period will be 1.3%, which corresponds to the average rate reported over recent years, (OECD, 2012*b*).

1.2. A HISTORICAL PERSPECTIVE OF GROWTH

The work of Angus Maddison (2001) offers us a historical perspective of how growth has evolved over the very long term. Measuring this kind of trend requires the use of historical data sets that depend on multiple methodological assumptions and patchy information (see Box 1.1).

With these estimates, we are able to show that, for millennia, per capita output stagnated or increased almost imperceptibly across the world. Most likely, per capita income[9] even declined in Europe from 0 to 1000 CE.[10] During the second millennium, the increase of trade in some European States, the "re-opening" of the Mediterranean as a trading route *via* the Republic of Venice, and the conquests and pillaging of resources in the New World by the future colonial powers fuelled an average 0.14% annual growth in Western Europe, whereas the rest of the world experienced no more than an annual 0.05%[11] (Figure 1.1) Growth rates

Box 1.1.

Measuring income and economic growth over the long run

Constructing time-series

To trace back how the output and income of populations have changed over the very long term, it is necessary to use different types of data. The tax revenue accounts kept by public authorities have provided the economic historian Angus Maddison with a tool for measuring the evolution of economic wealth in different world regions. When these accounts are unavailable, for distant pasts or for countries with no central administration, other methods can be used, such as measuring changes in grain stocks in towns.

When no data is available, researchers have to estimate a country's wealth and income by formulating assumptions based on data from neighbouring countries. This is the approach used by Maddison, who produces very long-term data sets even in the presence of high uncertainty in order to spark controversy and encourage further research.

What the data mean

The goods produced by economies change with time. Over the long term, comparing income levels boils down to comparing very different baskets of goods and services. In order to take into account the discontinuities resulting from inventions or improvements to goods and services, statisticians mainly rely on the hedonic price method, which involves attributing a price to an innovation (Gordon, 1990). Yet, it is impossible for a price to reflect all the forms of progress contained in a manufactured good or a service (e.g. how can we measure the gains linked to radical innovations, such as a drug that cures a new disease?). In sum, the more the gains obtained represent non-monetary benefits, the greater the limits of this method. However, an analysis of growth rates does allow a comparison of marginal changes at different points in time. There is a difference between comparing two levels of income fifty years apart and comparing the 1950–1951 variation in incomes with the 2000–2001 variation. When marginal changes (growth rates) are compared, there is lesser risk of cluttering the results with major technological or social upheavals.

But there is yet another problem: the available data are in the form of averages. Averages, however, give no indication of how income is distributed during a given period of time. A rise in average income may mask a virtual standstill for most of the population, as has been the case in the United States since 1976 (Atkinson *et al.*, 2007). These long-term data should therefore be interpreted taking of all these limitations into account.

8. See in particular the work of the Institute for New Economic Thinking (INET).
9. In macroeconomists, a country's average income is equal to its average output, or production.
10. In fact, after the *Pax Romana*, which ensured political and economic stability in a Roman Empire criss-crossed by 60,000 km of paved roads, there came a fragmented political system that was fragile and unstable. The breakup of the Empire was accompanied by the decline of urban centres, a return to local feudal systems and a slowdown in trade. These broad trends help to explain the decrease in European production during the second half of the first millennium.
11. Productivity growth rates are thus identical to growth.

nonetheless remained modest relative to those in the later industrial societies.

It is not until the first industrial revolution that we see a sharp upturn in growth rates. According to Maddison, between 1820 and 2006, per capita income rose on average by an annual 1.5% in Western Europe and 1.8% in Western offshoots. In Japan, the growth rate even reached 2% even though the country had not stood out from the world average during the previous centuries.

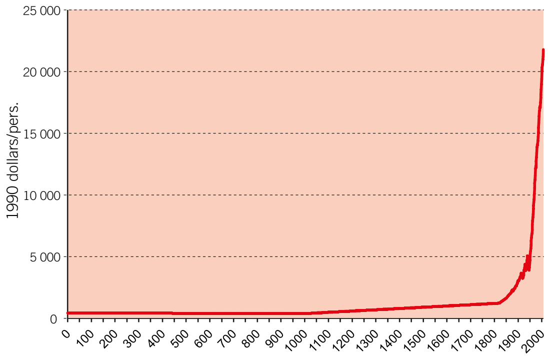
It was the increase in productivity gains that accounted for most of this growth (Galor, 2011). Thanks to technological innovations (weaving machines, steam engines, chemistry, electricity, etc.), more could be produced within a working day.[12] These technologies facilitated a profound reorganisation of production and distribution processes. Steam power, which replaced hydraulic power, not only provided a cheaper source of energy, but also meant that factories could be concentrated geographically and production sites located closer to primary resources and consumers. Later, the introduction of electricity led to an even looser link between the energy resource deposits and the siting of industrial facilities. And thanks to the electric motor, it then became possible to reorganise the space inside factories and increase the efficiency of production processes.

But productivity gains were not only spurred by technology. Technological innovations go hand in hand and interact with other transformations of a "social" nature.[13] Large-scale factories and assembly-line work are typical of the new types of work organisation that appeared. Moreover, the "take-off" of growth, to use the term coined by Rostow (1960), occurred in settings that had more mature economic and social institutions. For example, the importance of educational systems is emphasised by Oded Galor (2011), who argues that training workers to transfer their skills to new machines played a key role in developing the potential for technological progress during the first industrial revolution.[14] Banks, foreign exchange markets and insurance schemes also played a central role (Wagener, 2009), as did the trade-oriented diplomacy practiced by the fifteenth-century Venetian Republic. These social innovations gradually spread to the rest of Europe (Maddison, 2001). The roots of the European industrial revolution thus date back to several centuries before the invention of the steam engine.

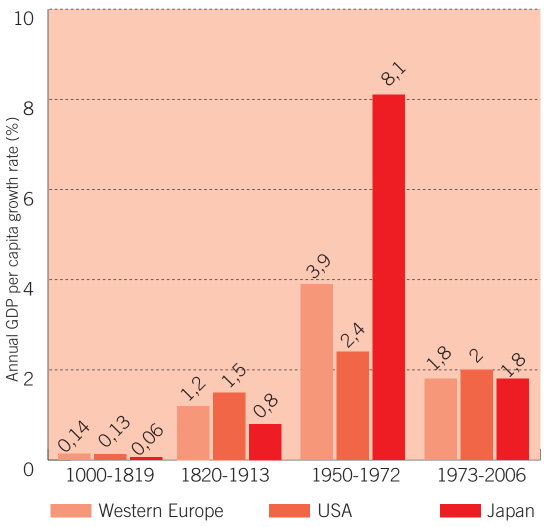
Finally, another point not to be overlooked is the political and military aspect of economic development, notably the effects of colonisation, which enabled the European powers to increase their capital and speed up the process of specialisation,

Figure 1.1. Two thousand years of economic growth

A - Evolution of average income in industrialised countries



B - Growth rate of per capita output from the year 1000 to the present day



Source: Maddison, 2001.* Formatted by the authors.

Note: we do not show growth rates for the 1914–1950 period, marked by the two World Wars. These were 0.9% in Europe and Japan and 1.8% in the USA. Before 1820, the American growth rate is aggregated with that of the other European colonies.

12. Broadly speaking, the increase in hourly productivity also means that time is freed up for non-agricultural activities. This is what Sauvy (1980) terms "*déversement*" (overflow): the number of farmers needed to feed society decreases and some of them (or their children) then reconvert to jobs in manufacturing.

13. We refer to social transformation as being changes in legal norms, political frameworks and social relations.

14. The impact of schooling on growth is widely recognised in the literature. Using cross-sectional data, Mankiw (2011) shows that the school enrolment rate of 12-17 year-olds has a positive effect on aggregate income, after controlling for other factors in cross-sectional data.

whilst at the same time benefiting from cheap slave labour (Pomeranz, 2000).[15]

1.3. FROM THE TAKE-OFF OF GROWTH TO THE "GOLDEN AGE"

With the advent of the industrial revolution, market output reached levels of growth that were not only high but also sustained for the first time in human history. Growth levels in Western Europe and the United States average an annual 1.5% and 1.2% respectively from 1820 to 1913. At the outbreak of World War II, the monetary income per capita in France had almost tripled compared to the same date a century earlier. Prior to this, it had taken more than seven hundred years to attain an equivalent rise.

However, economic growth in the industrialised countries had not yet reached its record levels. The highest growth rates in the economic history of the industrialised world were reached after World War II. The "Golden Age", or what is known in France as the "*Trente Glorieuses*" (the Glorious Thirties), refers to a period with GDP growth rates of over 2%. The United States, which spearheaded the Golden Age, saw its GDP rise by an annual 2.4%, while average income per capita in Western Europe experienced increases bordering on 4% and, in Japan, these even attained 8%.

What goes to explain that growth rates were so high during the European and Japanese Golden Ages? The two World Wars paradoxically helped to fuel the growth rates of those countries that had suffered the most war damage. The factor that drove post-war growth in European countries was the "accumulation of physical capital" through the recontruction of housing (almost half of Germany's dwellings were destroyed or uninhabitable) and factories or machinery knocked out of operation during the war[16]. A second explanation involves technological and organisational innovations. These were thriving in the United States, and post-war Europe and Japan were thus able to benefit from an economic "catch-up" phase *vis-à-vis* the USA. In fact, by 1945 the United States had invented technologies and developed industrial production methods, such as aeronautics, intensive agriculture and mass production, which were taken up by the Europeans in the post-war years (Cohen, 2006).[17]

A third explanation for the Golden Age in Europe, Japan and the United States stems from the way in which productivity gains from the agricultural and industrial sectors were shared. This sharing led to wage increases, high and sustained profit margins and a relative decrease in the prices of output from both sectors (Giraud, 1996). This paved the way not only for mass consumption fuelled by higher pay, but also for new investments to increase production capacities and productivity (entrepreneurs gave priority to mechanisation rather than to a workforce whose wages were on the rise).[18]

Mention should be made here of the dual role of welfare states in supporting the "Fordist social compromise". States intervened in the share-out of productivity gains, both indirectly through the standards framing the labour code and directly by setting the level of social contributions. Thanks to these compulsory contributions, they were also able develop the public services sector, which absorbed–together with the private-sector services industry–surplus labour from other sectors and created new forms of wealth (education, health, post office services, etc.).

This sustained growth drives, and is driven, by the rapid rise in the living standards of most of the population in the industrialised world. The graphs below (Figure 1.2) depict the huge increase in the earned income (before redistribution) of the 90% poorest people in France, Germany, the United Kingdom and the United States. The trends show a similar dynamic across the four countries: a slow rise in income until World War II, followed by a very sharp increase from the end of the war until the second oil shock and then a much slower increase (stagnant even in the USA) until the present day – except for the UK.

As can be seen from these trends, the virtuous circle of growth came to an end in the 1970s. There is a drop in hourly productivity gains in most European economies, as well as a much slower rise in income. The decrease in productivity gains is particularly pronounced in France, but also visible in Germany, Finland and the United Kingdom – all of

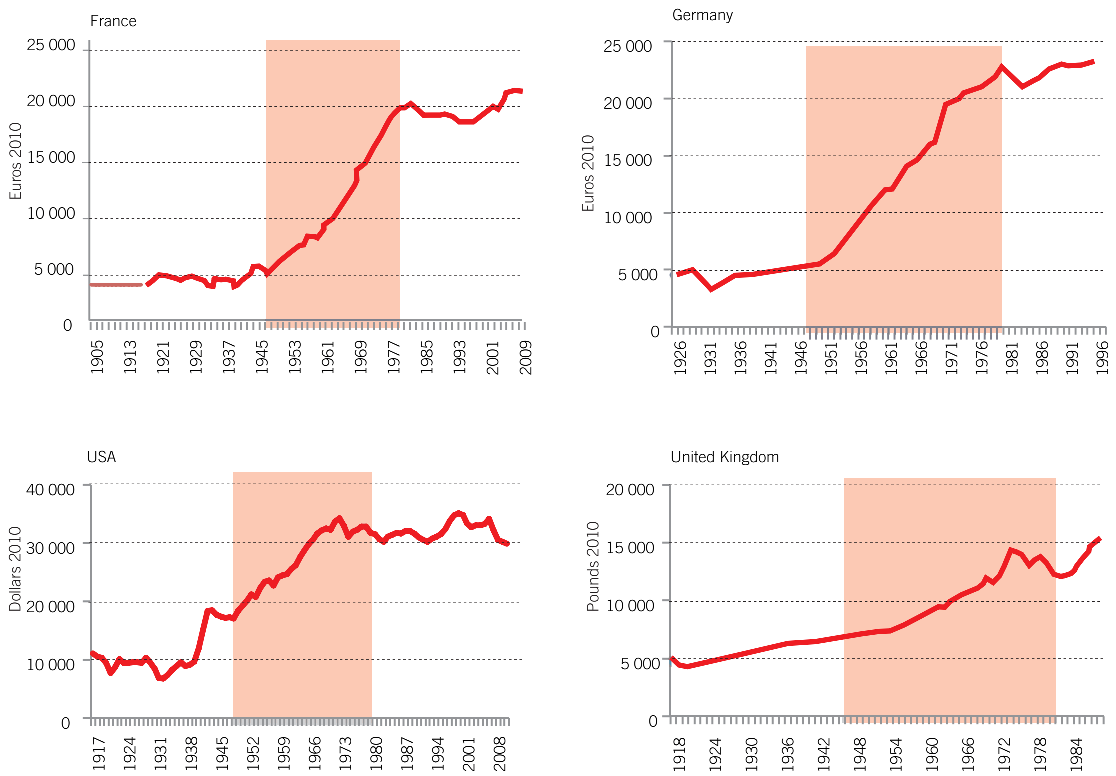
15. Whereas colonised countries and territories often experienced a fall in income.

16. In France, material damages cost the equivalent of one year of GDP. In Germany, material losses were estimated at one and a half years of GDP (Piketty, 2013)

17. This technological catch-up was made easier thanks to post-war reconstruction, which had provided the opportunity to modernise production systems. As a result, productivity gains were made in the industrial and agricultural sectors: between 1895 and 1974, the price of a bicycle was divided by a factor of 20, and the number of work hours required to produce a bicycle was divided by at least as much.

18. Moreover, the decrease in prices for agricultural and industrial goods meant more disposable income for spending on the consumption of services. The tertiary sector thus absorbed the surplus labour from the agricultural and industrial sectors, which created a situation of full employment.

Figure 1.2. Income trends in France, Germany, the United Kingdom and the United States



Note: Trends in gross earned income, excluding social transfers. The Golden Age of growth is shaded in pink. Source: www.topincomesdatabase.org

which have capitalistic welfare state regimes (Esping Andersen, 1990)[19] that are nonetheless very different.[20]

1.4. WHAT EXPLAINS THE DECLINE IN PRODUCTIVITY GROWTH RATES SINCE THE LATE 1960S?

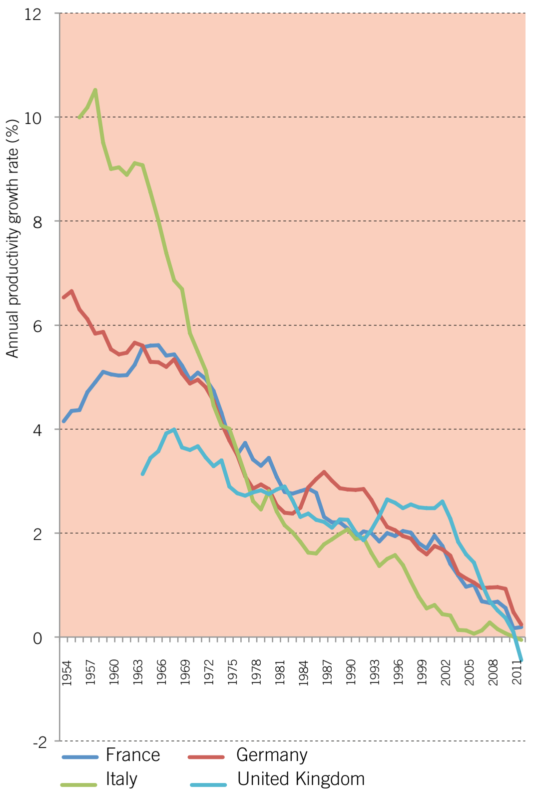
The end of the catch-up with the American economy explains a large part of the decline observed in most other industrialised countries. By 1980, agricultural systems had been mechanised, factories had been modernised and reorganised, and the European and American economies were more similar than they had been at the end of the war. From then on, European countries developed in step with their own innovations (see Aghion *et al.*, 1998). But does the end of the catch-up with the United States explain everything? According to Gordon (2012), the United States also experienced a drop in annual productivity gains – a trend that we will return to later. So, what other reasons are proffered to explain this decline in growth rates? The tertiarisation of the economy is proposed as one explanation for the slackening-off of productivity growth. An economy's industrial sector generates higher productivity gains than the service sector (see Section 1.6), but industry's share in total output has shrunk significantly since the 1970s. In France, industry accounted for 40% of total output in 1970 compared to 28% forty years earlier, while the share of services rose from 44% to 63% of total output over the same period.

For Gordon (2012), one factor that can explain the decline in all of the economies relates to the nature of innovations (cf. Section 1.7). In his view,

19. Esping-Andersen distinguishes three types of regime in capitalistic Welfare States: liberal (United Kingdom), social-democratic (Scandinavian countries) and corporatist or conservative (France, Germany, Italy).

20. For the sake of clarity, we do not show all European countries but, with very few exceptions, this trend is common to all of them. We should also point out that the economic crisis has greatly influenced the trend curves since 2007.

Figure 1.3. Trends in hourly productivity in the European Union



Note: 10-year moving average. Source: TED (2013). Formatted by the authors.

innovations now have less transformative content than at the beginning of the past century, and the inventions of the second half of the twentieth century are not as revolutionary as those before them: sanitary facilities and electricity have a higher "life-bettering" potential than Facebook or mobile telephony.

The increasing fluctuation and levels of energy prices since the 1980s is also put forward to explain the slowdown in productivity gains. Since the early twentieth century, industrialised countries had benefited from cheap energy resources – raw material prices and energy prices had decreased significantly between the late nineteenth and mid-twentieth centuries with the discovery of abundant resources and the invention of new extraction techniques (McKinsey, 2011). However, the rise in oil prices since the early 1980s may have hampered productivity gains insofar as it has pushed up the cost of manufactured products and services that use petroleum products (transport, heating, etc. - cf. Section 1.8).

The globalisation of the economy is sometimes advanced as an explanation for the slowdown in productivity gains in industrialised countries. Two arguments can be foregrounded: the inability of nation-states to adapt their instruments for regulating the economy (wage policies, industrial strategies, etc.) to a new framework (see particularly Boyer, 2004). A further argument holds that growth rates have slowed down due to the exhaustion of the scale economies that were facilitated by the globalisation of trade from the 1980s and 1990s onwards, and to the fact that customs duties did not drop significantly thereafter.

A plateauing of educational achievement can also play a determining role. We have already seen that a linkage exists between educational levels and a rise in income. Yet, enrolment rates in primary and secondary education have been stagnating since the 1980s in the United States and many European countries. This trend could translate into a slowdown in productivity gains. This is what Jorgensen *et al.* (2006) contend when they point out that a levelling-off in enrolment rates would lead to an annual decrease in growth of 0.2 percentage points.[21]

In addition, income inequality has been on the rise since the 1970s in most European countries.[22] Although there is an abundant literature on the relationship between growth and inequality, it is nonetheless difficult to draw any general conclusions as the relationship operates in both directions and depends on specific socio-economic contexts. Nevertheless, we should note that wage inequalities can affect worker productivity (Cohn *et al.*, 2011) due to effects of dissatisfaction and demotivation. They can also have impacts on health and security (Wilkinson *et al.*, 2009) – which in turn can adversely impact productivity at work. Educational inequalities may also present an obstacle to developing the capabilities of the less well-off sections of the population, to the detriment of society and the economy as a whole (Stiglitz, 2013).

Finally, population growth can limit increases in per capita income growth.[23] Average income in an economy depends on the number of economically active people relative to the number of economically non-active people. It is the incomes of the employed that support the incomes of non-active people. When the number of the latter increases more rapidly than the former, average income decreases – all other things being equal. European societies are currently facing a rise in the number of non-active people relative to the number of economically active people, since life expectancy has increased and the baby-boomers are retiring. In

21. These computations were done for the United States.
22. Except in France, Greece and Belgium (OECD, 2012).
23. This factor does not have a direct impact on productivity growth but on the per capita growth rate.

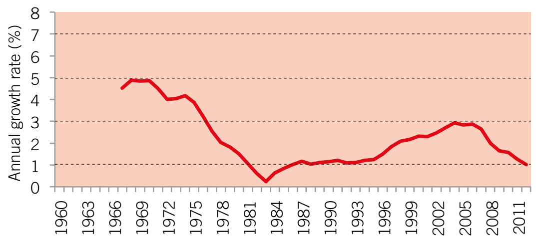
OECD member countries, the active/inactive ratio fell from 7.2 in 1950 to 4.1 in 2010 (OECD, 2011). Bloom *et al*. (2011) find that, if the active/inactive ratio had been as low in 1950 as it was in 2010, the OECD member countries would have grown at a considerably slower rate than the rate reported for this sixty-year period (i.e. an annual average of 2.1% compared to an actual 2.8%).

1.5. RELATIVIZING THE DECLINE?

First of all, the fall-off in productivity gains needs to be qualified given the problems surrounding productivity metrics. Currently, the production of goods and services seems to be increasing more in quality than in quantity.[24] Yet, it is no easy task to measure productivity gains involving improvements in product quality, and the statistical methodologies used are a subject of debate (cf. Gadrey, 2012; see also Box 1.2 on the limits of the concept of productivity).

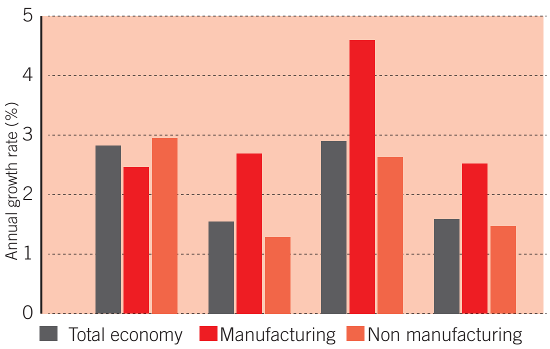
Moreover, in some countries the decline is imperceptible. Sweden has not followed the same trend as its continental neighbours (Figure 1.4).[25] In fact, the decline seen from the 1960s to the 1980s was followed by an increase in productivity growth rates right up to the global financial crisis of 2007–2008, mainly in the manufacturing industry. In the United States, the decline is also more difficult to characterise. What is mainly observed is a rebound in the 1980s. Are these countries exceptions that can be explained away by specific national factors? Several reasons have been advanced to elucidate the Swedish case. One of the most compelling explanations argues that the rebound at the start of the 1980s stems from the conjunction between an egalitarian social compromise and an industrial sector based on leading-edge technologies. The social compromise seems to have guaranteed relatively high wages for the working classes and helped to channel their consumption towards innovative goods with high research and development content, thus stimulating productivity in industrial sector and the economy as a whole. But it is too early to say whether this renewed increase is sustainable (see Equest, 2004).[26]

Figure 1.4. Productivity growth rate in Sweden



Note: Hourly productivity. 10-year moving average. Source: TED (2013). Formatted by the authors.

Figure 1.5. Productivity growth rate in the United States



Source: Gordon, 2013.

In the United States (Figure 1.5), the explanation for the rebound observed in the late 1990s – after a levelling-off – is also associated with an NICT boom (but without the egalitarian aspect). Gordon, however, shows that this buoyant period was very short-lived and suggests that it was simply a "flash in the pan".

In France, Germany, Italy and Japan, the decrease in productivity rates over the two last decades may also be linked to a relative fall-back compared to the American frontier. Although these countries' productivity rate relative to the USA increased until the 1990s, after this point it began to decrease (OECD, 2013). The explanation for this may lie in national factors, such as wage and profit levels, the labour market system or the composition of the different economic sectors.

Will the recent economic trends be followed by a new Golden Age in the industrialised countries, or will they experience low levels of productivity growth? Answering these questions would require a perfect understanding of the dynamics of economic growth, which is still sorely lacking – as

24. The probability of dying from drinking a glass of milk in 1960 was not insignificant, whereas today it is almost zero. This change in quality is not however taken into account in growth or productivity metrics.

25. Some countries, such as Finland, Switzerland or the UK, have seen their hourly productivity stagnate since the mid-1970s; the sharp rise in Sweden has not been observed in other European countries with a similar per capita income.

26. There is a debate on how productivity in the Swedish manufacturing sector is measured. Some authors argue that this productivity has been overestimated due to the calculation method used.

evidenced by the controversies on the reasons for the 1970s slowdown.

We will now explore in detail three factors that fuel uncertainties on the future of growth: the transition to a service economy, technological innovation and the environmental constraint. There is a need for more in-depth research on the factors presented earlier and notably on the reasons for the relative fall-back of many European states compared to the United States, but this is beyond the scope of the present report.[27]

1.6. RADICAL UNCERTAINTIES ABOUT THE FUTURE OF GROWTH: THE IMPACT OF TERTIARISATION

Many industrialised countries are undergoing a relative deindustrialisation that is more or less pronounced. Between 1990 and 2010 the share of the manufacturing industries in GDP dropped from 20 to 13% in France, 31 to 24% in Germany and 23 to 17% in the United States.[28] Part of this deindustrialisation is in appearance only as industries have tended to offshore some services or "servicise" their offering, but the decline of industry's share in GDP is very real (Demmou, 2010).[29] It should also be mentioned that, in absolute terms, industrial GDP is increasing in these countries.[30]

Relative deindustrialisation is thus a fact in most of the more advanced economies. But what is driving this trend? Globalisation is a prime suspect, but the extent of its impact is a subject of lively debate.[31] For Demmou (2010), in the case of France, deindustrialisation stems primarily from changing market demand: accounting for 30% of industrial job losses since 1980, but more significantly 65% since 2000. A rise in living standards is effectively accompanied by a structural shift in demand towards a greater use of services. Productivity gains are higher in industry than in services[32] (Figure 1.6) and the relative decrease in the prices of industrial goods does not create enough demand to offset the strong trend towards services.

This means that the service-based content of advanced economies is growing. As far as hopes for GDP growth are concerned, this is a major factor in the slowdown of productivity gains. A simple example serves to illustrate this. We will use a very simplified notion of an economy with two sectors: a manufacturing sector accounting for 70% of added value and with a 4% growth in productivity; and a service sector accounting for 30% of the value added and with a 1% growth in productivity. The productivity growth for the economy overall would thus be 3%. If we reverse the relative shares of the two sectors without changing the productivity gains of either, productivity growth falls to 1.5%. These figures are not very far removed from reality, as is shown by the figure below taken from the OECD (2003) report on productivity in the tertiary sector.[33] The transition to a service economy seems to be a likely explanation of the slowdown in productivity gains: the manufacturing industries accounted for two-thirds of productivity gains in the recent period even though it represented only 30% of GDP.

However, if we want to focus on future trends in productivity gains, it is necessary to disaggregate the various industries making up the service sector, as this category is a catch-all for everything not under the umbrella of the extraction and manufacturing industries. We will thus separate out two types of services on the basis of their productivity gains.

Drawing on the OECD (2003) report, we can group together those services that generate high productivity gains, bearing in mind that cross-country disparities are high: telecommunications, transportation and trade, as well as services directly linked to ICT, such as software.[34] Productivity gains in these services can match those of the best manufacturing industries. The OECD ties this level of performance to the fact that these services

27. What specifically needs investigating is the impact of shorter working hours and lower unemployment rates, and the types employment and job qualifications.

28. *Source*: UNECE Statistical Database, compiled from national and international official sources.

29. According to Demmou, international sourcing is responsible for 25% of deindustrialisation in France – measured in terms of job losses – over the past thirty years, but this effect is waning as more recently it accounts for only 5%.

30. Industrial GDP increased in real terms by 25% in France between 1990 and the mid-2000s, 12% in Germany and 45% in the United States (figures are from the UNECE Statistical Database, compiled from national and international official sources).

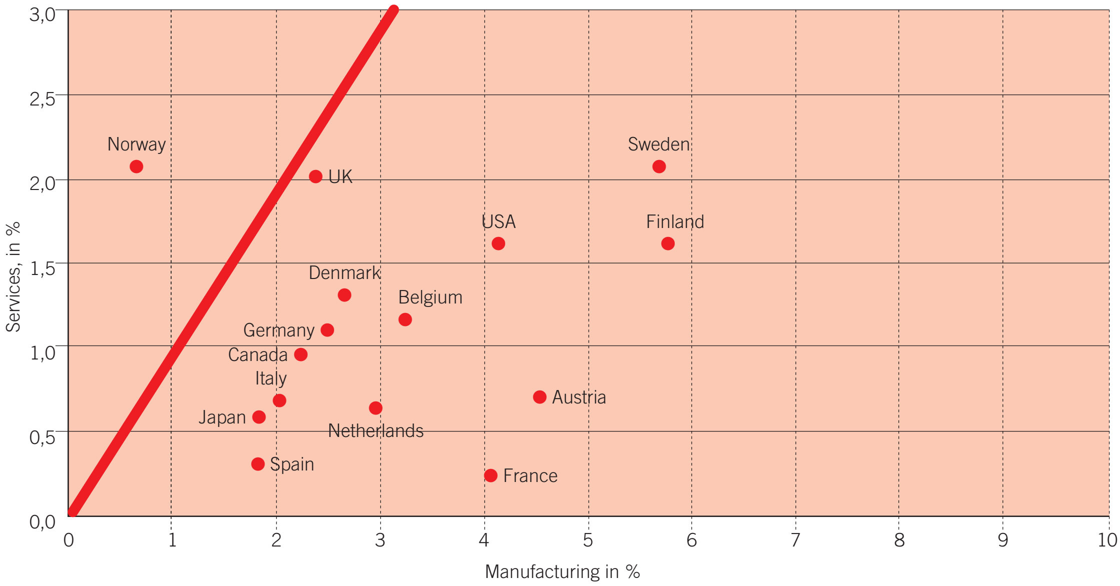
31. Its impact is difficult to measure. According to Demmou (2010), in France, it may be responsible for 30% of the job losses in industry over ten years, which is a much higher figure compared to previous decades. Even though this estimate is no longer computed using the input-output method (measuring the employment content of imports or exports), but by econometric method that still includes trade factors, with a 95% confidence interval of 9 to 70%. The impact of globalisation is thus found to be uncertain.

32. We will see below the broad heterogeneity of the service sector. It should also be pointed out that there is also a large diversity in the manufacturing sector.

33. The figures cited in the rest of this section are all extracted from this report.

34. Finance and insurance are often cited as leaders of this category, and while their gains are real, they must nonetheless be adjusted to take into account losses from periods of declining productivity.

Figure 1.6. A comparison of labour productivity growth in the services and manufacturing industries



Note: Growth in labour hourly productivity, 1990-2000. Red line: points where productivity growth in services = productivity growth in manufacturing. Source: OECD, 2003.

are the most exposed to the effects of international competition. Whatever the explanation, the report sees no reason for a reversal of this positive momentum.[35]

In the category of services with low or "stagnant" productivity gains, we find hotels and restaurants, real-estate services, social and personal services, education and retail trade. Productivity gains for these services are low, and even negative for some countries. At this point, it must be underlined that measuring productivity in such sectors is a highly difficult exercise.

Do "stagnant" sectors have a potential for significant productivity growth in the future? Productivity "optimists" place emphasis on the development of platforms for personal services provision (Debonneuil, 2009), the transformation of education through NICTs and health through nanotechnology, as well as the entry of large companies onto these markets in place of small and medium-sized firms or associations (OECD, 2003). Another argument advanced is that, even if it is difficult to increase productivity in the performing arts such as theatre, an increase can be obtained through personal audio-visual services, particularly the Internet-TV boxes (Parienty, 2005). Clearly, behind all these developments, we find implicit societal choices and strong uncertainties with respect to measuring productivity.

Conversely, authors who have little faith in a strong potential for productivity growth in these "stagnant" services highlight the fact that gains are often synonymous with a decline in service quality. This may mean that teachers spend less effective time with children, healthcare staff with patients or dependent people. Baumol (1966) gives a well known example: today, it takes as many singers and orchestra musicians to produce Purcell's opera *Dido and Aeneas* as it did for its first performance in 1640. Similarly, it cannot be performed faster or it would no longer be the opera that Purcell composed. More generally, in services with a high "interpersonal" content, the time spent with users is not easily compressible unless we accept changes that are not neutral for our societies and thus need to be made explicit: video surveillance or robotised services for the elderly.[36]

35. It is interesting to note that the productivity gains generated by "business services" – as computed by the OECD – are not as high as expected. The OECD authors generally anticipate a strong impact from the diffusion of ICTs, and insist that, if potential productivity is to materialise, work methods need to be reorganised to keep apace of computerisation. We will come back to this in a later section.

36. To ensure continuing increases in productivity, firms or the State can also put pressure on working conditions and/or wages of workers with more or less secure jobs. This bolsters the criticism of "neo-domesticity" formulated by Gorz (1988) with respect to jobs involving personal services. This term heralds the drift towards a system where the wealthiest members of society pay low wages to those employed in domestic services, which are considered as low-productivity jobs.

The counter-intuitive example of Sweden adds grist to the pessimists' mill. The ongoing reform of the Swedish State is often described as highly positive and we could suppose that this brings large productivity gains in education or healthcare with no drop in service quality. However, findings show that, whatever the impact on quality, the gains in these "public" services were around 0.7% per year between 1980 and 2000, a period when reform was still underway. This is a relatively disappointing figure compared to the manufacturing sector or the more "dynamic" service industry, and quite similar to the French case.

What does this disaggregation of services teach us about productivity gains in the service sector? The OECD (2003) concludes that it is difficult to draw a conclusion. On one hand, there are the high-potential services and, on the other, services with flat growth and uncertain prospects. It is not easy to estimate the respective weights of these two types of services but neither seems to clearly dominate the other. The future is uncertain but, to sum up, it should be remembered that we are starting out from a situation where the top "performing" countries show current gains across the entire service sector of no more than 2%, while most countries stand at between 0.5 and 1% (cf. Figure 1.6). The future is all the more uncertain for countries that have chosen the growth model qualified by Robert Boyer (2002) as anthropogenetic – the "production of man by man" – in which a growing fraction of production and consumption comes from "interpersonal" services in the areas of health, care for the elderly, education, training, leisure.

1.7. RADICAL UNCERTAINTIES ABOUT THE FUTURE OF GROWTH: THE TECHNOLOGY FRONTIER

Many classical economists foresaw the advent of a stationary economy. For many of them, the slowdown in growth is linked to the law of diminishing returns. Out of all the key factors that has helped us to outstrip this law for several centuries, this section has chosen to focus on technological progress in the strict sense of the term: new products, new manufacturing processes and, more sketchily, human capital (e.g. education).[37]

Box 1.2.

The shortcomings of service productivity metrics

Measuring productivity in general and the productivity of services in particular is a delicate matter and a source of debate among statisticians. In fact, apart from the issues of product and service quality, it is conceptually difficult to measure output per unit of input for a sector such as insurance, gaming or banking. In services like education, health, culture or even personal services, measuring productivity is even more complex. The solution developed by statisticians is to measure the output of these sectors on the basis of their cost to the State and the number of hours worked. This comes down to quantifying output by input, which is somewhat paradoxical. It should be noted that services, and particularly "public" services, are still very poorly suited to cross-sector comparisons using a single productivity indicator.

The question of measuring productivity also links up with the metrics issue addressed by the Stiglitz-Sen-Fitoussi Commission (2009) and the broader issue of the very notion of value. Market value is a concept that is alien to many externalities that impact the functioning of our societies. Is a health service that protects everyone in the same way less productive than a service that is inaccessible to the poorest? What is the productivity of a service that restores the autonomy of those in need of care? The economy is not isolated from rest of society, but rather embedded in all societal activities (Polanyi, 1944). It affects social ties, the quality of life in a broad sense and, of course, the environment.

As technological progress is above all a matter of knowledge – particularly scientific – it helps to avoid a decline in yields. Certainly, if one posits that ideas produce ideas and can be accumulated with no loss of yield, then nothing stands in the way of exponential growth. This raises hopes that growth can "easily" be revived. Aghion *et al*. (2007) thus argue that, in France, potential growth could increase by 0.5 percentage point each year by investing wisely in reformed higher education and research.

While no one challenges the goal of stepping up investment in R&D and training, some authors tell us that it is increasingly difficult to raise the level of educational attainment (Cowen, 2011), and that the returns to R&D decline with rises in living standards (Maloney & Lederman, 2004). This is typically the case of the pharmaceutical industry, which has to invest ever-increasing amounts in R&D, while at the same time the number of new molecules is decreasing (Parienty, 2005). Robert J. Gordon (2000) defends an original theory: the industrial revolution's big productivity wave is currently ebbing. Today, there is no groundbreaking invention comparable to the steam engine, electricity or the automobile and, for this reason, we are witnessing a slowdown in productivity gains.

37. Unfortunately, we cannot deal here with the progress linked to the organisation of work (Taylorism, Toyotism, etc.), even though it is a key factor for productivity gains during the industrial revolution. We will simply mention here that there is a very fruitful debate – between the proponents of the new economy and those who underline the stress and greater suffering at work – on the productivity potential to be gained through organisational change.

This theory may come as a surprise given that the age of the "digital revolution" is upon us. Interestingly, the debate between the innovation "optimists" and "pessimists" has come to focus on the real effect of NICTs on economic productivity. A detour *via* this controversy is both illustrative and instructive with respect to the different "technological revolutions envisioned" and the challenge of long-term growth.

In 1987, Robert J. Solow pointed out a paradox: although NICTs benefited from very high levels of investment in the 1980s in the United States, their impact on productivity figures is nowhere to be seen. However, from 1995 to 2000, productivity gains began to revive, averaging 2.2% a year. This is much less than during the Golden Age (2.6%) but twice as high as those reported post-1972 (Gordon, 2000).

In the optimists' view, this rise – even though it has since been disrupted by cyclical crises – is mainly attributed to the NICTs. These technologies are seen as the driver of a new wave of growth in the Schumpeterian tradition (Perez, 2002). Yet, if the NICT productivity potential is to be fully exploited, this would require restructuring the economy and adapting institutions (technical and legal standards, public infrastructures, regulation, education, etc.) – as was the case for the previous technological revolutions. The diffusion of the technological wave takes time but the NICT-driven gains are seen as lasting, and could even accelerate.

For other authors, NICT-related productivity gains in the 1990s are more akin to a "flash in the pan". Firstly, it would be going too far to attribute all of the revival to NICTs. As Robert Boyer (2002) reminds us, the explanatory factors are many: structural effects, lower commodity prices, dollar rate fluctuations, R&D efforts and labour market reforms.

Moreover, the exact nature of ICT-related productivity gains needs to be investigated. According to Gordon, the "recovery" of productivity between 1995 and 2000 is primarily due to gains in the manufacture of computer equipment, which shows an annual productivity increase of over 40%. But computer equipment represents only a fraction of what society consumes. The challenge of the "new economy" to bring about a new wave of growth is whether it is effectively able to trigger a virtuous productivity cycle in the traditional industries and service industries that extends beyond the IT sector. But between 1995 and 2000, these traditional industries stagnated or suffered from a decline in productivity. Although a slight recovery can be observed in the service industries, thanks to finance and trade, growth rates remain much lower than those achieved during the Golden Age. Could this mean that NICT is not a "generic" technology, even though it is a key element for "real" technological revolutions?

It is clearly impossible to reach a clear-cut conclusion. The optimists rightly base their arguments on the fact that the effective diffusion of the technological revolutions that have marked history has taken decades. After Thomas Newcomen patented his steam engine, his invention took eighty years to emerge from the economic niche in which it had been confined. While this is no proof that the NICTs will trigger a new wave of growth, it is an aspect that needs to be kept in mind when commenting on their currently disappointing performances. Furthermore, following on from the NICTs, the "nanotechs", "biotechs", "cleantechs" and more generally the efficient use of resources are now cited as new sources of productivity.

1.8. RADICAL UNCERTAINTIES ABOUT THE FUTURE OF GROWTH: THE ENVIRONMENTAL QUESTION

While productivity in the United States began to slacken in the late 1960s, it was more pronounced after the 1973-1974 oil price shock. The beginning of the downturn in many other countries coincides with this crisis. Whatever effective impact this shock had on growth, it served as a pointer: an economy is not independent of its environment. The environmental question is of a different nature to the earlier described constraints as it can lead not only to stagnation, but also – according to some – to "degrowth"; and this question is very often at a global scale.

In this section, we present a review of the literature on the controversy about the growth-environment nexus. In Chapter 2, we investigate this question with the help of data and a macroeconomic modelling exercise.

The environmental question should be understood in the broader sense. Economic activity makes use of natural resources (energy and mineral resources, arable land, forests) and also discharges pollutants (water and air pollution, greenhouse gases). Consequently, it can be impacted by the depletion of these resources and by a degraded environment: loss of ecosystem services, climate-induced damage, the impact of air pollution on health, etc. In response to this deterioration, public policies are implemented that "constrain" the economy to a more sustainable pathway (climate targets, reduced use of pesticides, fight against urban sprawl, protection of endangered species).

Can the increasing scarcity of resources cause the productivity of our economies to decline? In theory, the answer is yes. But are these constraints "biting" or, in other terms, are they likely to significantly slow growth now or in the near future? Malthus and Ricardo were already concerned about resource constraints. Malthus argued that land produced a steady yield of food that would be unable to meet the demands of an exponentially increasing population, while Ricardo was concerned about the persistent depletion of fertile land. International trade could do no more than delay the onset of a steady state economy.[38] Stanley Jevons (1865) anticipated the exhaustion of coal resources, a decline in production and national ruin. More recently, the Club of Rome and those authors concerned about the "Population Bomb" have alerted us to our planet's limitations. The oil price shocks affected economies more than imagined (Hamilton, 2005), but it appears that the optimists have always triumphed over the pessimists. The recent record oil prices and the price rises for many mineral and agricultural commodities, driven by global growth, should nevertheless cause even die-hard optimists to stop and think. Although the scarcity of many physical resources seems to have been deferred, "economic scarcity" is still with us.

As for the burden of environment-related regulatory constraints, the optimists adopt the opposite line of reasoning, and defend the view that climate policies can foster growth, in line with a win-win rationale. They call on a whole raft of arguments reprised by Jacobs (2012). Here are some of them: (i) the Keynsian stimulus effect of a "green" investment plan; (ii) the competitive advantage of green products on world markets; (iv) the double dividend obtained by transferring taxation from labour to pollution; and (iv) putting a stop to the wasteful use of many resources (McKinsey, 2011).

38. For Malthus, a steady state results from the linear growth of resources along with an exponential increase in population; for Ricardo, the yield from land is diminishing, which explains that in the long term the wages of agricultural labourers cannot exceed subsistence level (the "iron law of wages", attributed to Ricardo).

Certainly, all this will not create the Schumpeterian-like green growth wave that some are hoping for (Rifkin, 2012; Stern, 2012). It does, however, give good hope that the climate change mitigation and the rising cost of resources are compatible with or could even enhance growth. At least, this is the hope of major international institutions, including the OECD, UNEP and the World Bank.

It is nonetheless useful to ask the question of whether environmental protection measures always have a "win-win" outcome. The "degrowthers" – the most pessimistic – insist that it is impossible to decouple growth and natural resource consumption (Gadrey, 2012; Latouche, 2006). While relative decoupling is feasible, examples of absolute decoupling are few and far between (according to Camara [2013], only 13 out of 125 countries for CO_2 over the 1980–2005 period). Certainly, advanced economies are more eco-efficient, but the volume of resources they consume seldom decreases,[39] as we shall see in Chapter 2 of this report. And when the direct CO_2 emissions of a country decrease, indirect emissions (i.e. emissions made in third countries in order to serve national consumption) increase (Pasquier, 2012). The "post-industrial society" is not immaterial, and services supplement rather than replace industrial goods – and in developed countries a part of this industrial production is outsourced.

39. Jackson (2009) shows that direct material consumption (DMC) has stabilised since 1975 in the United Kingdom and risen slightly in Germany, Austria and Japan – but these results do not include the consumption in third countries needed to meet domestic needs.

1.9. CONCLUSION TO THE FIRST CHAPTER

This first chapter has traced the evolution of economic growth from a historical standpoint and highlighted the factors that go to explain growth over the past century. Knowledge on growth is still limited and controversy abounds as to its long-run drivers. Below is a brief outline of the findings and controversies discussed in this chapter.

In the long term, productivity gains (the increase of market production per hour worked) determine the growth of per capita income. Increases in productivity stem from the reorganisation of production and consumption processes that increase the capacities of human labour. Organisational changes are triggered by both technological and social innovation.

It is important to bear in mind that productivity and GDP growth rates are driven by complex mechanisms related to factors such as the composition of the economy, social organisation, demographics and energy. But what interests us here are the growth regimes shaped by the interplay between these different factors, rather than the "GDP" or "productivity" indicators, which in fact do little more than translate – imperfectly – the trends followed by these regimes.

Sustained and substantial economic growth is a recent phenomenon in human history. The growth rates seen during the so-called Golden Age actually constitute an exception in modern economic history. In the developed countries, they have hovered around 2% since the 1970s, which corresponds to the average since the beginning of the first industrial revolution.

A slackening-off of growth has been observed in most developed countries since the 1970s. We point up three main "suspects" to explain this slowdown: lesser benefits from innovation, the tertiarisation of the economy and the environmental constraint. However, there is little consensus among economists on the relative importance of these three factors, or even on their relevance to the debate. New controversies are also debating how these factors will influence economic activity in the near future.

For the optimists, recent innovations in the new information technologies have not yet come to fruition. Moreover, the services economy offers the potential for new growth. Finally, the fight against environmental degradation should also help to reduce our consumption of material resources, while at the same time increasing our income.

For the pessimists, recent innovations have weaker transformative power than past innovations. The tertiarisation of the economy makes it more difficult to achieve productivity gains and thus sustained growth. And environmental protection or the increasing scarcity of natural resources represents an additional cost and therefore an impediment to growth.

There is a "radical" uncertainty about economic growth. The political choices that we make in the future and the technologies that we may invent tomorrow remain uncertain. This opens up a broad range of possible economic futures, along with an equivalent number of growth outcomes. We cannot reasonably associate a probability with each of these futures – in fact, we are not even aware of the whole range of these futures.

Different societal choices can be made, each of which will have different impacts in terms of future GDP growth: do we want to address the elderly's need for autonomy by providing more home help or by robotising solutions and dispensing remote medical care? It would be paradoxical to make these choices conditional on the economic growth that they would generate – unless, of course, economic growth is a society's ultimate ideal. In other words, a reasonable position would be to first make these choices and then examine what the consequences these had in terms of economic growth.

This implies, however, developing societies that can adapt to a broad range of growth rates in the future. This is what we qualify as a "post-growth" society. This does not mean being indifferent to growth (as we shall see in Chapter 3) but elaborating a collective proposal for a future in which the economy and society would no longer be dependent on the need for a sustained increase of GDP.

CHAPTER II – A FINITE ENVIRONMENT – A BRAKE ON GROWTH?

THE ENVIRONMENTAL QUESTION, ONE OF THE MANY CONTROVERSIES ON THE FUTURE OF ECONOMIC GROWTH

In the first chapter of this report, we have shown that the level of long-term economic growth[40] is a controversial subject. The pace of innovation, the tertiarisation of the economy and rising commodity prices are all factors that could hamper tomorrow's growth. In this chapter, we examine more closely one of these factors – environmental constraint – using physical data and an economic modelling exercise.

This involves first of all identifying the environmental resources used in economic processes: energy and non-energy mineral resources, agricultural resources, land and water resources. Our focus here will be specifically, but not exclusively, on the reserves available to the European Union.

In a second step, we examine in greater detail the impact of energy and then climate policy on the global and European economies, using a macroeconomic model that integrates the complex interplay between the economy, the stocks of energy resources and climate protection.

Environment and economic activity: what are the synergies?

The linkages between the environment and human activities are not limited to energy resources or the climate. Based on the literature on ecosystem services, different types of services that the environment provides to society can be identified:[41]

- Services that support the conditions for life on Earth (carbon cycle, nutrient cycling, biomass production). These services are necessary for the production of all other services needed to support life on Earth.
- Services that regulate ecosystem processes (mangroves, coral reefs, etc.). These services support other ecological services, but at a more limited level.
- Services that provision different resources (energy, food, water, biomass used for the production of goods) enabling humans to satisfy their material needs.
- Cultural services (beauty of a beach, the silence of a mountain, etc.) relating to the recreational, spiritual or aesthetic benefits to human societies.

The linkages between these ecosystem services and the economy, or in other words their "economic impact", depend largely on the particular service considered.

- Provisioning services such as energy or food have *a direct-use value* and are integrated into a price system. Other provisioning services such as air quality have an indirect-use value. Although these are not "priced", they have indirect effects on economic activity.
- The *indirect-use* value thus corresponds to ecosystem services that are not priced, but could be if the positive effects[42] that they contribute to

40. Beyond the current economic crisis.

41. It is immediately clear that the concept of "service" is anthropocentric. In fact, the frame of reference used here is the environment's *utility* to human societies. Moreover, we take the economy as our point of entry. This, of course, is a reductionist approach, which we will use with the necessary precautions.

42. In economic parlance, these are known as "externalities" – a term that may appear misleading as it

the economy were internalised. For example, a regulating ecosystem service providing protection against tropical storms has a value that can be measured by the economic impacts of such storms. This is the approach proposed by P. Sukdhev in his book on the economic valuation of biodiversity (Sukdhev, 2010[43]).

- Existence value, or intrinsic value, involves valuing nature for itself – in other words, giving it an *intrinsic* value. Some species with no direct or indirect market value for human societies nonetheless have a value *simply because they exist*. This does not mean pricing them, but rather organising economic activity so that their value is preserved.

Our reason for focussing the section below on natural resources (which represent only some of the provisioning services) rather than on other ecosystem services is not only because of the many concerns about the limitations that natural resources place on economic activity, but also because these resources receive most attention from the academic literature and economic modelling. An "integrated" model of all ecosystem services, particularly one that takes biodiversity into account, is yet to be constructed. However, to broaden out our perspective, later sections of this report will explore climate policy and its economic impact.

introduces a distinction between something "internal" and "external" to an economy.

43. The Sukdhev (2010) report puts a value on the overall economic benefits linked to biodiversity and the costs relating to a decline in the number of species. It considers biodiversity as a resource that intervenes in trade and economic production. The services provided by ecosystems are seen as dividends paid out of a natural capital. Thus, biodiversity losses are likely to induce global GDP losses of around 7% by 2050. This approach involves the notion that ecosystem services may be compensated by human labour or technology.

PART A. ASSESSING RESOURCE STOCKS

1. THE CONSUMPTION OF NATURAL RESOURCES IN THE 20TH CENTURY

As a first step, we look at how global consumption of natural resources has evolved over the past century. The Figures 2.1 and 2.2 show the growth of material consumption since 1900. The data inform us on the trends in consumption of biomass, fossil energy carriers, ores and industrial minerals, and construction minerals.[44] This representation is somewhat simplified as it compares volumes of materials that have very different energy, nutritional or "utilitarian" content. But the advantage of using a common unit of measure is that it provides a synthetic and consistent panorama over a long time span. Here, we use domestic material consumption (DMC), which measures the mass of materials (in tonnes per year) used to satisfy human needs.

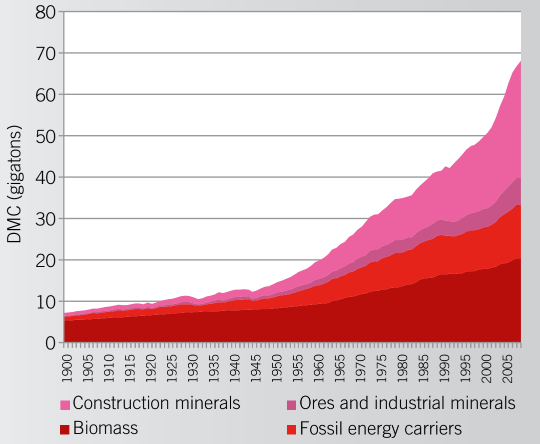
At global level, DMC rose fourfold between 1900 and 2008. The steepest increase was for construction minerals and ores and industrial minerals: their production multiplied by a factor of 42 and 31 respectively. The consumption of fossil energy carriers (oil, gas, coal) rose by a factor of 13 from the beginning of the twentieth century. The tonnage of agricultural products increased "only" threefold. What is striking is that the increase in DMC was mainly for the purposes of housing, industrial construction and transport but not to feed the planet's population.

From the end of World War II, DMC took off in what was to be a golden age of growth for the developed countries. Thereafter, the pace was sustained, although the tonnage of materials consumed per capita remained stable from 1980 to 2000 due to efficiency gains. Global DMC enters a new phase of growth in the early 2000s with the economic rise of the emerging countries, led by China.

In Europe, the main spate of growth in material consumption was from the 1950s to the 1980s, driven by the consumption of construction minerals, hydrocarbons and biomass. Thereafter, it grew less rapidly and the volume of materials used

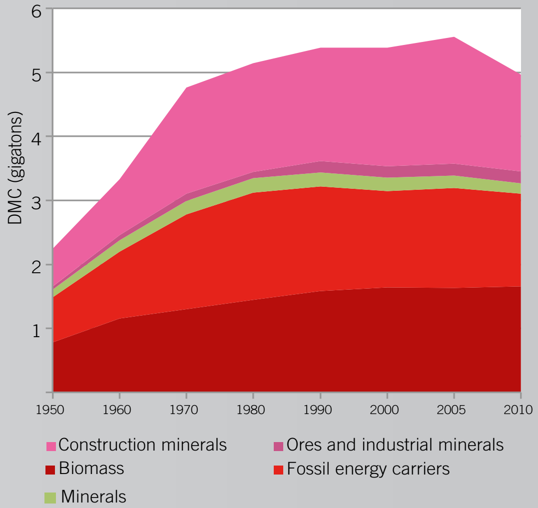
44. Biomass covers all agricultural commodities; fossil energy carriers include petroleum, gas, coal and the other non-renewable energy minerals; ores and industrial minerals include notably gold, graphite and rare earths; and construction minerals include sand and gravel, limestone, cement-related minerals, etc. (cf. Krausmann, 2010 for details on the methodology).

Figure 2.1. Global material consumption (1900-2005)



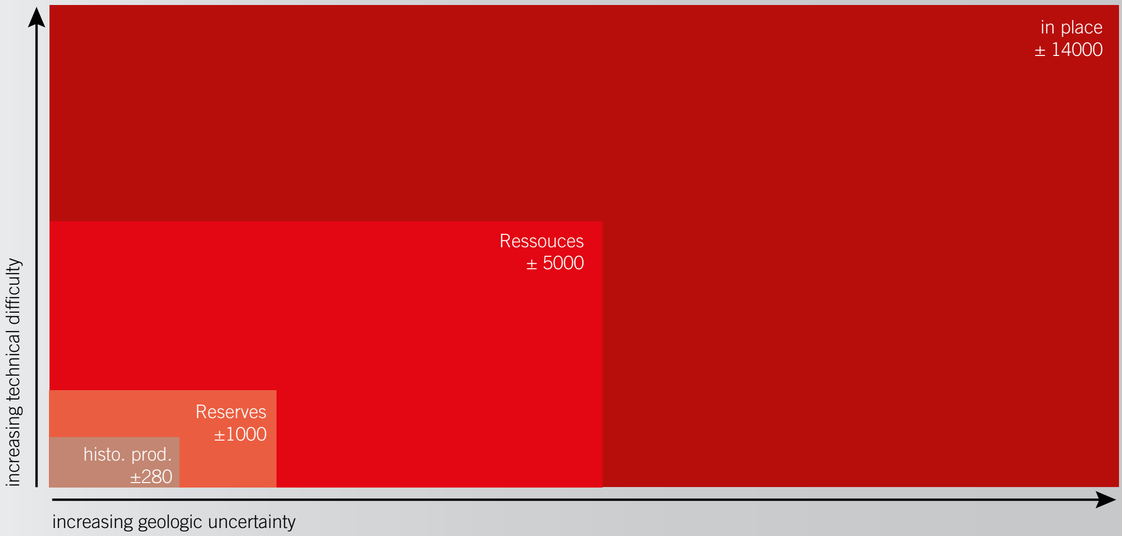
Source: Schaffartzik, 2013.

Figure 2.2. Natural resource consumption in Europe (1950–2010)



Source: Schaffartzik, 2013.* Publication of the data is forthcoming. For reasons of methodology, non-metallic ore consumption is underestimated. The values are 10% lower than those reported by Eurostat.

Figure 2.3. Global coal reserves, resources and in-place resourcesl



Note: billion short tons (not to scale). Sources: Grossling (1981) and EIA (2005).

virtually stagnated after the 1990s with the reduction in the imported tonnage of fossil energy carriers. Europe thus seems to be increasingly efficient in its use of material resources. The drop observed in 2010 is due to the economic crisis much more than the greening of the global economy.

2. FROM FLOWS TO STOCKS

The above section looked at the trends in material use or, in other words, the *flows* of materials removed from the environment to meet human needs. However, these flows do not inform us on the quantities of available resources.[45] Below, we first assess the available stocks and then compare these to the rate at which they are used.

We will first deal with the mineral resources used to produce energy (hydrocarbons and uranium), then other mineral resources found in the Earth's crust (metals, rare earths) and, finally, land and water resources.

For hydrocarbons, a distinction needs to be made between *in-place resources*, *resources* and *reserves*:[46]

- *in-place* resources correspond to all the materials present in the Earth's crust that are likely to be identified. This thus involves a theoretical estimate of resources that have not yet been found but which can reasonably expected to exist.
- *resources* correspond to the materials that have been geologically identified. However, these are not necessarily recoverable because of the technology required to extract them. Before the invention of horizontal drilling in the 1980s many oil fields were inaccessible. Over the past few years, the use of hydraulic fracturing combined with horizontal drilling has facilitated the extraction of shale gas, which previously had not been economically viable.
- *reserves* correspond to proven resources that are readily exploitable using current technology. Their production, however, also depends on the evolution of market prices. Estimates of energy reserves fluctuate considerably. In fact, the amount of resources can decline, while reserves increase with the discovery of new recovery techniques. Figure 2.3 depicts this phenomenon for the case of coal.

45. Moreover, flows tell us nothing about the pollution they cause. We explore the question of pollution in the second part of this chapter by taking a closer look at one pollutant (among many others): greenhouse gas emissions.

46. For a more detailed presentation of natural resource stocks, see 4D (2013), from which some of the findings presented in this section have been taken.

Box 2.1.

Energy resources and units of measure

In this section, we present the stocks of energy resources using the reserves-to-production (R/P) ratio. This ratio, however, cannot reliably predict the number of years left before reserves become totally depleted given that the rate of consumption is changing, as is the pace of new discoveries. For several decades now, the pace of discoveries has been slowing down, while consumption has been increasing. Energy data are also presented in physical units of energy – here, in exajoules (EJ). The joule (J) is the standard energy unit used by the International System of Units, and an exajoule (EJ) is equivalent to a billion billion joules. In 2012, the world consumed 532 EJ. By way of comparison, a 100 W light bulb consumes 100 J a second or 360,000 J an hour, that is to say, the annual global consumption divided by a hundred million and then by a billion…

For hydrocarbons (oil, gas, coal) the values presented here correspond to the median of oil reserve estimates from seven organisations listed by 4D (2013). These include oil companies (British Petroleum [BP]), public and international institutions (United States Geological Survey [USGS], Institut Français du Pétrole [IFP], International Energy Agency [IEA], German Federal Institute for Geosciences and Natural Resources [BGR], World Energy Council [WEC]), and civil society bodies (Association for the Study of Peak Oil [ASPO]).

In 2010, the global oil R/P ratio stood at 47 years, or 9,090 EJ (cf. Box 2.1). *The R/P ratio was relatively stable from the end of the 1980s: oil consumption and production increased substantially from 1990 to 2010 but new discoveries helped to keep this ratio constant.*

3. OIL RESOURCES

The reserves-to-production (R/P) ratio indicates the number of remaining years of production if levels of reserves and production (and thus consumption) remain unchanged. However, this ratio is often misleading as, in fact, neither its denominator nor its numerator is stable over time. Reserves may vary due to new discoveries (even if, in a finite world, the amount of resources is limited) and, above all, the production and consumption rate is never stable–as was seen in the previous section.

Figure 2.4. Global oil reserves in 2010

(in years, at the current production rate)

	R/P (years)
Median	47
Mininum	37
Maximum	89

Source: authors' calculations based on 2010 production (IEA, 2011) and the reserves reported by the seven main organisations (ASPO, USGS, BP, IFP, IEA, BGR, WEC) cited by 4D (2013).

Oil reserves did, in fact, increase between 1990 and 2010 in the former USSR member countries

(+100%) and the OPEC countries (+40%). Venezuela revised its oil resources upwards, which almost doubled its own resources and thus explains the rise in OPEC reserves. OECD countries saw a fall in their reserves (-23%). Historically, the rate of oil discoveries hit its lowest level towards the year 2000 (Figure 2.5) after peaking in the mid-1960s.

Oil reserves are very unevenly distributed across the planet, with six countries (Venezuela, Saudi Arabia, Iran, Iraq, Kuwait and the United Arab Emirates) holding over two-thirds of the global reserves. The European Union used 16% of global production and imported 89% of its consumption.[47] In 2010, nearly 60% of EU crude oil imports were sourced from Russia, Norway and Libya. It should be remembered, however, that the EU possesses only 0.5% of the world's oil reserves.

Estimating oil reserves is a controversial subject at both the scientific and geopolitical level, which explains the wide range of uncertainty surrounding them. For instance, there is controversy among geologists concerning the presence of reserves in some types of reservoirs (mostly in the Arctic). These controversies on the location of resources are compounded by debates over reservoir performance, which depends on the characteristics (porosity, permeability, etc.) of the rock involved and is difficult to assess ahead of drilling operations. In future years, reserve amounts are more likely to be driven up by advances in extraction techniques able to step up the amount of oil extracted from already operating oil fields, than by the discovery of non-conventional deposits – which require technologies other than the traditional oil extraction techniques. Finally, some countries do not allow the international community to verify their reported data given the strategic nature of these reserves. This is notably the case for Venezuela, which has the largest oil reserves.

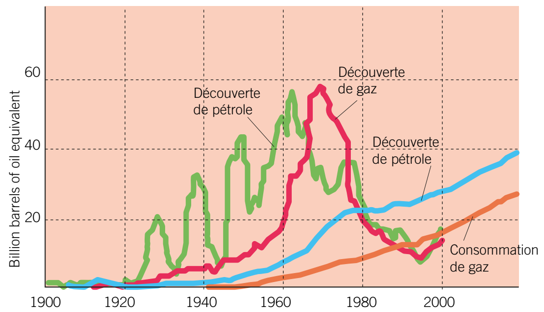
Shale oil reserves are estimated to add a further 10% to the amount of total proven oil reserves (EIA, 2013).

4. NATURAL GAS RESOURCES

In 2010, there were 51 years of natural gas reserves left worldwide, equivalent to 6,750 EJ. The range of uncertainty on the amount of available reserves is considerably higher for gas than for oil. This is because the IEA estimates also take into account shale gas and coal gas, which doubles the amount of reserves.

47. This percentage refers to net imports. The figures are taken from BP (2011).

Figure 2.5. Hydrocarbon discoveries and consumption (1900–2020)



Source: Exxon Mobil, 2002, cited by 4D (2013).

Figure 2.6. Global natural gas reserves in 2010

(in years, at the current production rate)

	R/P (years)
Median	51
Mininum	48
Maximum	213

Source: the authors' calculations based on 2010 production (IEA, 2011) and the reserves reported by five major organisations (BP, IFP, IEA, BGR, WEC).

The R/P ratio for natural gas remained relatively stable from the early 1980s on. As in the case of oil, the higher production levels were offset by new discoveries in the Middle East and Africa (+54% of reserves in non-OECD countries). European reserves dropped by 27% in the space of twenty years. The pace of discoveries also slowed down very sharply after the mid-1970s after peaking in 1974 (see Figure 2.5 above).

Global gas reserves are a little more evenly distributed across the planet than oil reserves: substantial amounts are found in Eurasia, the Middle East, Africa and North America. Nonetheless, two-thirds of the reserves are held by only ten countries, including Russia (24% of total global resources), Iran (16%) and Qatar (13.5%) – the distribution worldwide is thus very relative. The EU has 1.3% of global reserves, consumes 15% of world production and imports 65%[48] of its consumption. In 2010, almost three-quarters of EU imports came from Russia, Norway and Algeria.

The controversies surrounding gas resources echo those around oil: geological knowledge is under debate and the withholding of strategic information is an issue. However, identified non-conventional resources are probably larger for gas: at global level, shale gases have added an extra 47%

48. This percentage refers to net imports.

to conventional resources (EIA, 2013[49]). Shale gas resources are found across the five continents and more evenly distributed than conventional gas resources. According to the EIA, the European Union holds 6.5% of shale gas resources, mainly in Poland and France.

Figure 2.7. Geographical distribution of shale gases

(% of world shale gas resources)

China	15.3%
Argentina	11.0%
Algeria	9.7%
USA	9.1%
Canada	7.9%
Mexico	7.5%
Australia	6.0%
South Africa	5.3%
Russia	3.9%
Brazil	3.4%

Source: IEA, 2013.

5. COAL RESOURCES

The R/P ratio for coal is 96 years–twice the ratio for gas and oil, and equivalent to 20,120 EJ. The range of uncertainty for coal is relatively narrow, which indicates reasonably good knowledge of the geological sites and formations involved.

Figure 2.8. Global coal reserves in 2010

(in years, at the current production rate)

	R/P (years)
Median	96
Minimum	89
Maximum	124

Source: the authors' calculations based on 2010 production (IEA, 2011) and the reserves reported by five main organisations (BP, IFP, IEA, BGR, WEC).

Unlike gas and oil, the R/P ratio for coal decreased as from the mid-twentieth century. The ratio was over 200 years in 1980, but was halved in the space of thirty years. In fact, no new significant discoveries of coal deposits were made in the 1990s and 2000s. At global level, the reserves of bituminous coal, lignite and anthracite–the three main categories of coal–declined slightly over the last decade. There have nonetheless been major changes in the geographical distribution of coalfields, with a fall of reserves in the Asia Pacific region and Africa and a rise in Eurasia.

Three-quarters of the world's proven coal reserves are located in three regions: Asia (26% of global reserves), Europe (23%) and North America (21%). The European Union used 7.5% of world production and imported 42% of its consumption from the rest of the world. In 2010, 64% of EU imports came from Russia, Colombia and the United States. The EU has less than 6.5% of world reserves. The carbon market is relatively concentrated with two countries, China and the United States, accounting for over 60% of production and consumption.

6. URANIUM RESOURCES

The R/P ratio for uranium is 76 years for conventional resources, equivalent to 2.2 EJ.[50] Added to this are 47 years (1.4 EJ) of inferred reserves, or in other words reserves that have been identified but with a lesser degree of certainty (OECD, 2011), and 18 years of secondary resources, which are resources from recovered fissile materials and military stockpiles (0.5 EJ). Secondary reserves can cover a large share of production: in recent years, secondary resources have represented about 40% of requirements (Capus, 2007).[51]

Figure 2.9. Global uranium reserves in 2010

(in years, at the current production rate)

Conventional resources	76
With inferred resources	123
With Secondary resources	141

Source: IAEA, 2011.

Uranium reserves are scattered over the five continents: they are mainly found in Australia (23% of global reserves), Kazakhstan (15%), Russia (10%), Canada (8%) and Niger (8%). In addition, there is an abundance of uranium in the world's oceans but the concentrations are too low to extract it using current technologies.

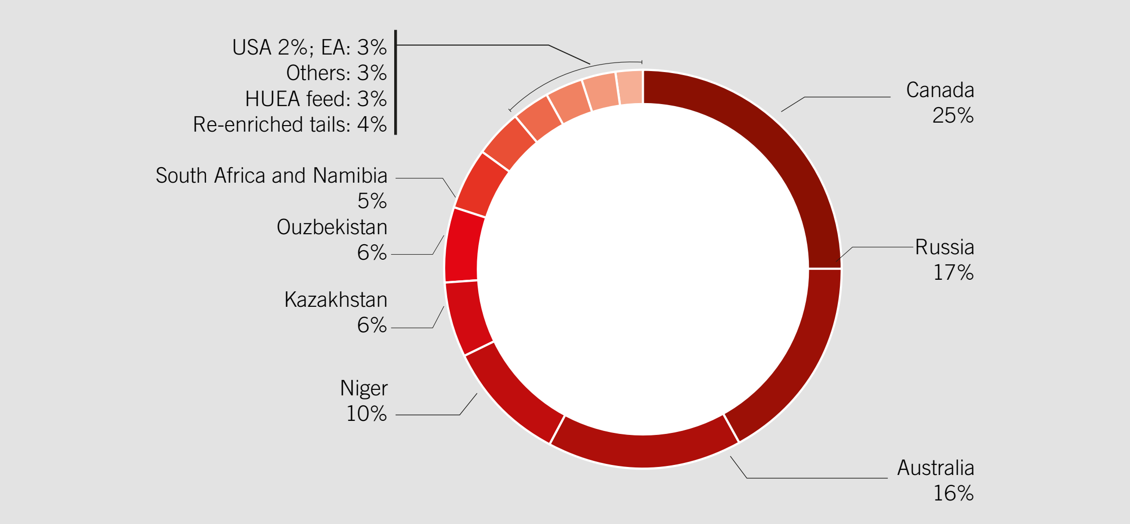
In 2008, the European Union used 33% of world

49. According to the Energy Information Administration, the inclusion of non-conventional gases (shale and coal gas) doubles the total amount of available reserves, which pushes the R/P ratio up to 213 years.

50. This is 4,000 less than for oil reserves. The EJ values correspond to the average primary energy (i.e. heat) extracted from a tonne of uranium in France (IAEA, 2011).

51. We do not include the stocks of other fissile resources, such as thorium, given that no current technology is able to use it commercially.

Figure 2.10. Geographical origin of uranium imports to the European Union



Source: IAEA (2008).

production, and imported 97% of its uranium consumption. Nearly 60% of EU imports came from Canada, Russia and Australia (Figure 2.10). The EU has less than 1% of world reserves.[52]

7. IMPORTED FOSSIL FUELS AND "GREY" ENERGY

Adding together the European Union's imports of each fossil fuel shows that Union imports almost 60% of its energy consumption (Figure 2.11).

Figure 2.11. Share of primary energy imports in 2005

	Share in primary energy production	% of fuel imports
Natural gas	18.8%	65%
Solid fuels	19.6%	42%
Nuclear energy	28.5%	97%
Crude oil	11.7%	89%
Renewables and other	21.4%	0%
	100%	59%

Source: Pourouchottamin *et al.*, 2013.

However, the EU also imports energy indirectly. Known as grey energy, this is the energy "hidden" in the goods and services that Europeans buy from the rest of the world. This means that on top of the 70 EJ of primary energy consumed by the European Union there is 37% of imported grey energy.[53] The energy dependency rate for the European Union thus reaches 70%.

At global level, China is the leading exporter of grey energy *via* the products that it manufactures for the rest of the world (Figure 2.12).[54] The gap between the grey energy imported by the United States and the direct energy that it consumes is small but reflects, in reality, a very high level of direct energy consumption and thus a relatively small proportion of imports.

8. CONSTRUCTION MINERALS

Minerals used for construction (sand, gravel, limestone and lime) are found in abundance on the Earth's surface and are relatively well distributed across the globe. Most of the construction minerals used in the European Union are thus produced locally and the depletion of stocks poses no problem for this type of resource strictly speaking.

However, there is the thorny issue of competing land uses. In European countries, urbanisation,

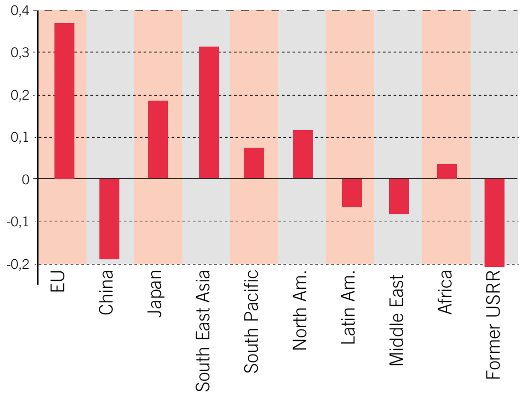
52. The thorium industry is sometimes cited as being able to provide an alternative to uranium for nuclear power generation. Thorium is three to four times more abundant than uranium and its use in fast-breeder reactors would produce fissile materials that are partly recyclable. Some studies highlight the potential of having several thousand years of reserves if fast-breeder reactors and thorium are used. However, the viability of this resource has not yet been demonstrated.

53. This figure is "net" insofar as the energy exported by the European Union in the goods and services that it sells to its partners has been subtracted (cf. Pourouchottamin *et al.* (2013) for the methodology).

54. The members of the former USSR are large exporters as they sell refined gas, which is counted as a processed product, not as a raw material.

Figure 2.12. Indirect energy imports and exports

(as a % of direct energy consumption)



Source: Pourouchottamin *et al.*, 2013.

road building, the demarcation of nature reserves and the protection of aquifers all limit the access to these resources. According to BRGM (cited by 4D, 2013), it is these indirect factors that substantially constrain construction mineral reserves in France rather than the limits of extraction techniques *per se*. The competition between different land uses is gradually pushing the production centres for construction minerals out to the periphery of the European Union, which drives up the related transport costs.

Worldwide, the current consumption of construction minerals is 28.3 billion tonnes against 0.67 billion at the beginning of the last century. The European Union consumes 5% of the global production of construction minerals, compared with 25% in 1950 (Schaffartzik, 2013).[55]

9. METAL RESOURCES

Global consumption of metals multiplied by 31 over a period of sixty years and Europe's share in world production dropped from 21% to 5% over the same period. Metals can be classified in four families (4D, 2013):

- Iron and ferroalloys (iron mixed with other elements such as manganese or chromium) are widely used to build infrastructures (roads, urban structures and factories). They are of pivotal economic importance and fairly evenly distributed across the planet. However, chromium reserves are a cause for concern, as their R/P ratio is under 15 years. The ratio for iron reserves stands at 70 years at the current rate of production.
- Non-ferrous metals[56] (e.g. copper, zinc and tin) are used for infrastructures as well as for the manufacture of industrial products (engineering, transport, energy sectors). Some of these metals such as zinc, tin, lead and copper have R/P ratios of less than 35 years. However, doubts remain as to the possibility of their production at current cost levels.
- Precious metals (gold, silver, platinum) used in more advanced industrial processes are relatively abundant except for gold and silver, which have proven reserve-lives of 19 and 20 years respectively at current consumption rates.
- Hi-tech metals (cobalt, indium, lithium, titanium, germanium, rare earths) are used in cutting-edge manufacturing processes for in the electronics, IT and telephony sectors. These metals are strategically important and, in many cases, their reserves are confined to a relatively small number of locations across the globe.
- Among these metals, the rare earth elements comprising an ensemble of seventeen metals,57 are important inputs for hi-tech industries. The amounts of rare earth resources are not very limited on a planetary scale but they are concentrated in a very small number of locations. China has taken up a strategic position vis-à-vis these resources since the 1990s and now controls 97% of production thanks to its leadership in extraction techniques and its low labour costs.

Supply risk and the economic importance of metals

The risk of metal supply shortages is determined by the degree of market concentration, the European Union's import-dependency rates and the amounts of proven reserves. For instance, the supply of antimony is raising serious concerns as its proven reserves are estimated at only ten years and the EU is totally dependent on a quasi-monopolistic source of supply (China). China also produces over 50% of magnesium, molybdenum, lithium, selenium, germanium and gallium resources (USGS, 2010).

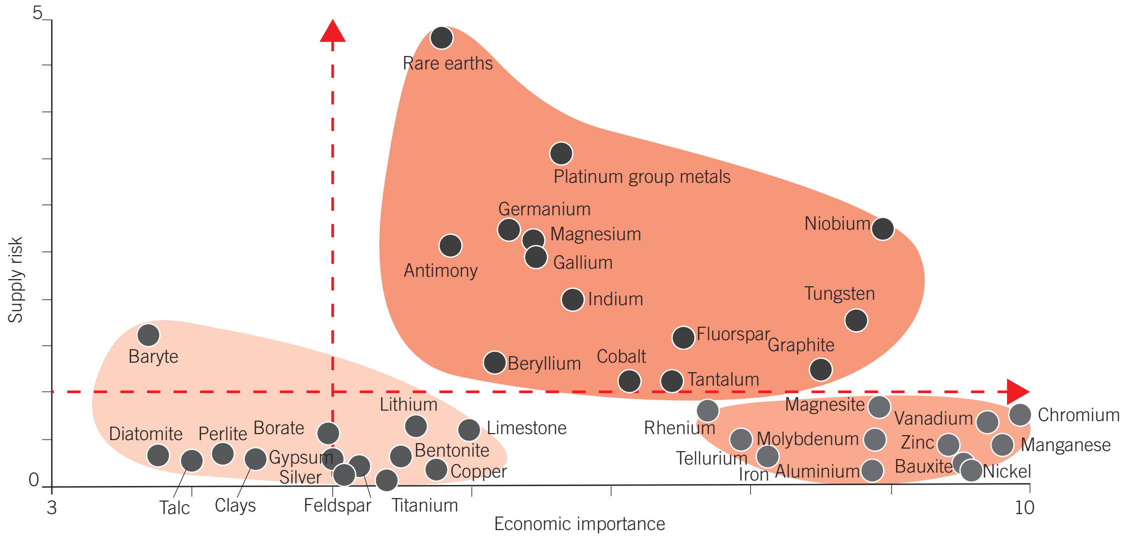
China also produces 97% of the world's supply of rare earths, 90% of antimony and more than 80% of tungsten. Certainly, as the European Union is poorly endowed with metal and mineral resources,

55. For want of available data, we do not give the indirect consumption of mineral and water resources.

56. Precious metals and hi-tech metals are also non-ferrous. We use this term for the sake of simplicity.

57. The main applications for rare earths include lasers (samarium), low-energy fluorescent bulbs (terbium), optic fibres (erbium), permanent magnets used in car batteries and wind turbines (neodymium).

Figure 2.13. Supply risk and economic importance for the European Union



Source: CGSP, 2013.

it will have to face rises in metal prices driven by increasing scarcity and heightened tensions in a context of market concentration.

The risks run by consumer countries do not stem from supply-side issues alone, but also from the economic and strategic importance of each metal. Chromium, manganese, vanadium, zinc and bauxite are vitally important for economic activity in the European Union. A cross-comparison of economic importance and supply risk enables us to assess the *criticality* of these metals (cf. Figure 2.13[58]). Metals such as niobium, tungsten, rare earths and magnesium are in the high criticality group. Certainly, the growing demand for these metals will certainly create economic or geopolitical problems for the European Union, if its consumption does not decrease or if it fails to find other sources of supply (particularly, through recycling).

10. THE CURRENT STATE OF WATER RESOURCES

Freshwater represents only 2.5% of the world's water resources.[59] However, most of this water is not in liquid form: 70% is in the form of snow or ice in mountainous and polar regions, 30% is found in groundwater reserves and only 0.3% in lakes and rivers.

Global freshwater consumption accounts for a little less than a tenth of global surface runoff (i.e. the flow of freshwater on the Earth's surface):[60] this runoff represents 42,000 km³, whereas annual consumption is around 3,900 km³. However, if extraction techniques and environmental constraints are taken into account, it is estimated that the equivalent of between one half and one third of renewable water resources[61] is withdrawn each year.

The volumes of available water and consumption levels are very unevenly distributed in space and time: a third of the continents receive only 2.5% of this flow (Sahara, Sahel, Gobi Desert) and precipitations within one region may fluctuate dramatically on account of monsoon events. Locally, therefore, water may be a scarce resource for which States are competing, as for example the dispute over the waters of the Nile.

Human activities generate two types of impacts on water resources. The first relates to the increasing scarcity of available resources caused by the drying-up of water courses, excessive water withdrawals that deprive ecosystems of the water they need, the overexploitation of aquifers and conflicts over resource uses. The second involves the pollution of these resources either through

58. Supply risk does not take into account the amount of remaining reserves and is limited to market geography.

59. Equivalent to 35 million km³ out of 1.4 billion km³.

60. Freshwater runoff is precipitation minus evaporation, which thus excludes groundwater reserves.

61. Renewable water resources are computed as the level ensuring replenishment of the resource, or in other terms, the annual flow of water that corresponds, in each catchment basin and each aquifer, to the level of precipitations from which natural evapotranspiration is calculated. According to the World Bank, renewable internal freshwater resources flows refer to "internal renewable resources (internal river flows and groundwater from rainfall) in the country."

organic pollution or pollution by heavy metals, fertilisers and other toxic substances, all of which make the water unfit for use. These two issues may be interlinked and exacerbate each other. Nitrate concentration, for example, becomes higher when the flow of water slows down.

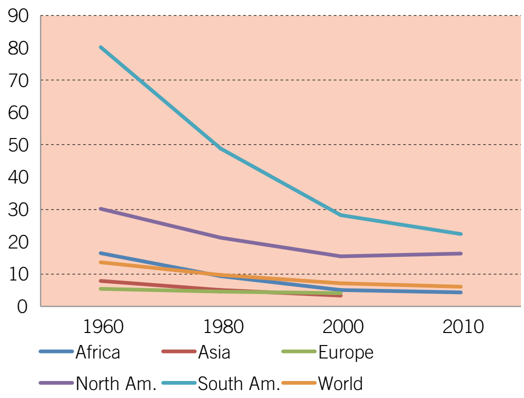
Water resources relative to the number of inhabitants have been declining in all world regions since the 1960s due to the effect of population growth. At global level, per capita water resources have been halved in forty years, whereas the population has doubled. By 2030, the WWAP (2012) estimates that 47% of the world's population will be living in regions suffering from water scarcity due to climate variations and demographic trends.

Europe is not an arid continent but the European Commission estimates that water scarcity affects at least 11% of Europe's population, a figure that has been rising over recent decades. According to the European Environment Agency, the ratio between water resource use and the reserves available at national level is deemed preoccupying in six European countries (Bulgaria, Belgium, Spain, Italy, Cyprus and Malta) (EC,2013). In the other European countries, water consumption has remained steady since the 1980s. Water use rose substantially in the 1970s to meet to the needs of the growing industrial and agricultural sectors, but there have been efficiency gains over the last thirty years owing to the decline of highly water-intensive industries such as the steel industry. In addition, it is estimated that water consumption in the European Union could be reduced by 20 to 40% if wastage[62] was eliminated (EC, 2013).

Depending on the climate scenarios for Southern Europe, requests are already beginning to appear for increased withdrawals for irrigation purposes, which will place additional stress on water resources and aquatic ecosystems in these regions. It seems reasonable to suppose that major increase in irrigation withdrawals will not be possible, and that these regions' agricultural production will need to rely above all on a more efficient use of water, as well as on production systems using crops adapted to local climate conditions.

In terms of water quality and pollution, polluting activities in the European Union are agriculture, the recycling of household effluents and industry. Nitrate pollution, which was on the rise until the mid-2000s, seems to have plateaued since 2004 in France. The reduction of what is termed "point-source" pollution (from factories, municipal landfills, etc.) seems to have been relatively effective over the past twenty years. But it seems that the

Figure 2.14. Global water resources per capita and by region (1960–2010, in m³/cap./year)



Sources: Shiklomanov, 1998; 4D, 2013; World Bank, 2013. Formatted by the authors.

objective of ensuring a "good ecological condition by 2015" (EU Water Framework Directive) will not be achieved in many regions chiefly because of non-point pollution (mainly from agriculture). In some regions, this pollution, especially when pesticides are involved, can constrain the availability of water for domestic use, as well as for some industrial uses that require a safe water quality – which both increases water scarcity and the cost of accessing the water resource.

11. AGRICULTURAL RESOURCES AND LAND-USE ISSUES

In the previous sections, we touched on the cross-cutting issue of competing land uses in connection with the different resources. It is nonetheless worthwhile to explore this competition as a separate topic. Worldwide, agriculture takes up a large amount of land (one third of the global utilised land area). Competition with other land uses is becoming all the more critical as world population has not yet reached a plateau and the average human diet contains an increasing share of meat,[63] thus requiring a larger land area to feed livestock (producing one calorie of animal protein for human consumption requires between three and seven calories of plant protein).

Between 1961 and 2009, the global volume of cultivated land increased relatively little (+12%) but over the same period world population soared by 130%. At the same time, agricultural productivity improved significantly, thus securing food supply

62. Inefficient water distribution networks, dripping taps, etc.

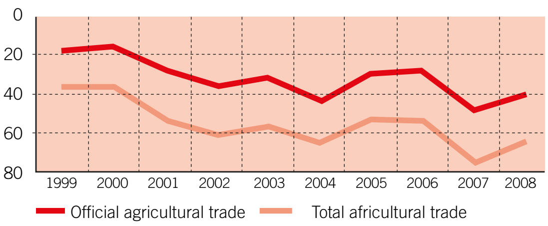
63. The production of animal products has increased fourfold since 1960, whereas world population has slightly more than doubled.

at the global level. In 1960, an average hectare of cultivated land was able to feed two people, three in 1980 and today four (FAO, 2011). Yet, this global increase in agricultural productivity has adversely impacted the environment in many regions of the world, particularly those where the green revolution has been the most effective in stepping up productivity: overexploitation of aquifers, pollution of water resources, soil salinisation, decreasing soil fertility, etc. All of these impacts tend to constrain long-run agricultural production capacities (Cassman, 1999).

At the global level, the area of arable land is still more than sufficient to feed seven or even nine billion people (FAO, 2011). The challenge is not so much to cultivate the entire potential area (which would be harmful to biodiversity), as to identify the technical models that could produce increased yields (the productivity of land) in regions where this is now very low, without endangering the state of the ecosystems, water resources and cropland underpinning agricultural systems. Yet, each year, between 0.8 and 1 billion people suffer from famine, even though today the global availability of agricultural products would be enough to feed all of humanity; and those experiencing food insecurity are still largely (and paradoxically) farmers or people living in rural areas in the poorest countries. The question of access to food and sharing out the available supplies among the different populations is thus at the heart of the question of agricultural resources. And it will be even more the case in the very near future, in a world where resources for agricultural production will be scarcer in some regions (water, urbanisation and land degradation, biodiversity loss, etc.). Much like water resources, agricultural resources are scarce in some regions and abundant in others. However, unlike water, the agricultural sector is more deeply integrated into global markets, which can be both a balancing force and a cause of imbalances (even if the share in volume of cross-continental trade in agricultural commodities relative to the agricultural production of each of these major regions remains small). Certainly, these markets help to cushion the climate shocks that impact some regions, but the efforts to regulate price volatility on international commodity markets still appear to be limited.

The European Union is the world's largest importer of agricultural commodities, just ahead of the United States (von Witzke *et al.*, 1999).[64] It

Figure 2.15. Agricultural product imports to the European Union, 1999-2008 (in millions of tonnes)



Source: von Witzke *et al.*, 2010

also ranks as the world's second largest exporter of agricultural commodities (in terms of value and volume) after the United States. In 2008, the EU imported 130 billion tonnes of agricultural commodities, while its exports totalled only 65 billion. The overall deficit was thus 65 billion tonnes.[65] The deficit has reached record levels since the late 1990s.

The deficit has worsened mainly due to the import of grain and soybean-derived products for animal feed. This trend reflects above all the intensification in Europe of livestock production, which uses a large share of the European-grown cereals, supplemented by imported protein crops (mainly soybean) The impact of the demand for biofuels, which is sustained by the obligation to mix a given percentage of biofuels with fossil fuels, is more difficult to estimate: there is a boom in colza to the detriment of other cereal crops and grazing land, and the use of co-products such as colza for animal feed oil cakes, ethanol imports, etc. Yet, it seems that these land use changes will likely heighten the EU's dependency on agricultural imports. The EU is a net exporter of meat but the trade balance for this sector has narrowed over the past ten years due to a fall in its exports.[66]

As we have seen in the case of energy, it is possible to convert the consumption of agricultural imports into agricultural resources consumed in third countries – here in the form of virtual imports of land. The European Union has about 100 million hectares of farmland but, to satisfy its food requirements, it also utilises 35 million hectares in third countries. This means that the EU imports a third of its arable land (an area equivalent to the size of Germany) from the rest of the world. And this figure is on the rise: in 2008 imports were up

64. For a description of the methodology used, see von Witzke *et al.*, 2010. The authors cover not only the two most often included categories of agricultural commodities (food and live animals, beverages and tobacco) but also the Standard International Trade Categories 4, 22, 263 and 268 (animal and vegetable oils, fats and waxes; oil-seeds and oleaginous fruits; cotton; and wool).

65. The monetary deficit is 45 billion dollars per year.

66. Mainly pork exports.

40% over 2000, representing an increase the size of Hungary and Poland combined. This increase is mainly explained by a higher consumption of soybean-derived products. Although these figures may be subject to discussion, they give an idea of the order of magnitude of this dependency.

The scarcity of resources required for agricultural production cannot be characterised without taking into account the type of production system, consumption patterns and the trajectories of technological progress that can be implemented.

Although climate change will most likely increase the amount of arable land worldwide (mainly due to the melting of permafrost), it will probably have mixed consequences at European level, with an increase in arable land in the north of the EU and fewer arable areas in the Mediterranean latitudes. In all cases, a rapid rise in temperatures will require significant changes in production methods and raises the question of the adaptive capacity of agricultural practices – at both global and European level (see Olesen *et al.*, 2002).

12. FROM PHYSICAL DATA TO SOCIO-ECONOMIC DYNAMICS

What can be concluded from the data and trends presented in this section? Firstly, the resources used in economic activities are finite and although there is uncertainty as to the exact amounts of some resource stocks, it is clearly physically impossible to increase consumption levels indefinitely. But what does this imply for the economy and growth? Physical data *per se* do not provide the answer to our initial question: what are the limiting factors for economic activity?

In fact, even setting aside the price of resources, consumption dynamics and advances in extraction techniques, transport and consumption, it is not possible to go beyond a generalising discourse on how resources impact economic activity.

Yet, what the study of physical quantities does is give us a framework (one that is constantly changing as we discover new reserves and burn others). To understand the complex changes happening inside this framework, we need to go through an economic modelling exercise.

PART B. ENERGY, CLIMATE AND GROWTH: A MODELLING EXERCISE

For most economic activities, fossil resources are essential factors of production, which introduces a direct link between growth pathways, the pressures on such non-renewable resources and the CO_2 emissions associated with their use. However, to get a clearer picture of the challenges raised by long-term energy constraints and climate policy, it is also useful to take into account the possible breaks in the link between energy and economic activity caused by profound changes in consumption patterns, production structures and technologies. To analyse these interactions, it is also useful to use adapted modelling tools able to capture these dynamics.

The second part of this chapter aims to take these interactions into account so as to answer, if only in part, the question: what impact do increasing energy scarcity and climate policies have on growth pathways?

In Section 1, we show why it is better to use models that are more complex than a "Kaya equation", and why standard economic models have important shortcomings that need to be addressed. For this study, we chose to use a model from the family of integrated assessment models – the IMACLIM model – which attempts to fill these gaps.

In Section 2, we describe the simulation exercise carried out using IMACLIM. Given the uncertainties about energy resources, changes in renewable energy prices or the future mobility needs of transport users, we trace 432 different possible development trajectories. By comparing these scenarios, and by setting or not setting them the objective of stabilising global warming at under 2°C, we can discuss:

- a. the macroeconomic impact of increasing energy scarcity and climate policies, and its sensitivity to the assumptions used;
- b. the relative importance of the different assumptions and thus, to some extent, the key factors for decoupling growth/energy and CO_2. More specifically, we isolate the assumptions related to lifestyles in order to foreground those aspects that we feel are too often sidelined in the debate. Public authorities have some leverage for action with respect to these assumptions: this is a call to activate them.

1. STANDARD ECONOMY-ENVIRONMENT MODELS

The most conventional method for analysing the links between economic activity and ecological impact (be it the use of oil or CO_2 emissions) is known as the "Kaya identity".[67] This identity decomposes the determinants of the impact *I* into three factors through the equation $I=A*e*c$ where:

- *A* is the level of economic activity measured by *GDP*,
- *e* is the energy intensity of production (i.e. the amount of energy needed to produce one unit of GDP) measured by *Primary Energy/GDP*,
- *c* is the impact intensity of the energy used (i.e. the amount of resources used or the number of CO_2 molecules emitted by a unit of consumed energy) measured by *Impact/Primary Energy*.

The Kaya identity makes it possible to quantify the link between the dynamics of ecological impacts and the three determinants and, more specifically, to identify the conditions under which continuing growth (an increase of *A*) is compatible with the mitigation of ecological impacts (decrease of *I*). Using this methodology, concurring studies have shown the magnitude of the underlying technical challenges to continuing growth in a world under environmental constraint.

A direct calculation shows that the continuation of growth pathways at global level is only compatible with the CO_2 reduction needed to limit global warming to 2°C if carbon intensity – *that is to say, the amount of CO_2 emitted per unit of production* – decreases by more than 5% per year over the entire twenty-first century. However, this rate of technological progress outstrips everything that has been observed in the past. In fact, the decarbonisation rate of recent growth pathways has reached no more than an annual 0.8% since 2000 at the global level (0.7% in 2011). On the basis of this widely shared diagnosis, two kinds of conclusion can be drawn. On the one hand, the author Tim Jackson argues in his book, *Prosperity without Growth* (2009), that GDP degrowth (i.e. negative growth rates) is inevitable if ambitious climate targets are to be met. On the other hand, the PWC study, "Too late for two degrees?" (2012), concludes that the 2°C target is unattainable and that priority should thus be given to preparing the economy for higher levels of global warming. These contrasted conclusions reflect different views about the relative importance given to environment and growth in socio-economic and political priorities: the first view expounds the primacy of environmental constraint, whereas the second sets priority on economic growth as a factor of development.

While these "Kaya-style" approaches indeed shed light on the magnitude of the challenge to be met – a colossal challenge in the case of climate change – they are limited when it comes to dealing with the question of decoupling in the long term as they encounter two main obstacles. First, the Kaya equation talks only about the past and not the future as these analyses involve extrapolating future trends on the basis of pathways observed in the past. This is, in fact, the only way of reasoning that can be followed given the highly aggregated representation of the technical dimensions, which are captured by only two aggregate parameters (energy intensity and carbon intensity), with no details on the underlying socio-economic components. In this approach, it is impossible to explicitly envisage changes in production processes, consumption patterns and technologies likely to drive necessary breakthroughs in technical trajectories. Secondly, the Kaya equation is based on the simplified assumption that economic and technical determinants are independent, which thus implies disregarding the effects of economic activity on the economy's resource intensity and the rebound effects that stimulate economic activity and consumption in response to technical improvements.

Integrated assessment models have been developed in the area of climate and energy in order to provide a view articulating the economic, technical and environmental dimensions. They notably aim to respond to the twofold challenge of giving a detailed representation of technical change and integrating its complex interactions with the socio-economic system. Based on the representation of the environment-related constraints core to economic interactions, these tools analyse the complex interplay between changes in resource prices, consumption and production dynamics, technical changes and socio-economic trajectories. A special effort has been made to incorporate into the macroeconomic interactions a detailed representation of technologies and the behaviours that determine their adoption.[68] A large number of models with diverse specifications have been developed on the basis of these principles and are used to analyse the long-term socio-economic issues relating to energy and climate.[69] This is the main type of

67. This identity is named after the Japanese economist who made it widely known, Yoichi Kaya. It was, however, developed by P. Ehrlich and J.P. Holdren; cf. Ehrlich *et al*. (1971).

68. See the debate on hybrid modelling, which combines "bottom-up" technical and "top-down" macroeconomic approaches, as summarised by Hourcade *et al.* (2006).

69. For example, the World Energy Model (used by the IEA for the World Energy Outlook), the Linkages model

model used in the reports of the Intergovernmental Panel on Climate Change (IPCC) to assess the costs of mitigating climate change.

Yet, some assumptions conventionally adopted by this type of model limit its potential to analyse questions related to decoupling economic growth and energy.

The first limitation lies in the approach used to introduce energy into macroeconomic assessments. The approach is based on compact models that aggregate all non-energy sectors and consider energy simply as an additional production factor. In the economic literature, this methodological choice is supported by the fact that the energy sectors account for only a small share of GDP (a few per cent), which justifies viewing energy as having very little influence on growth pathways and treating it at the margin of macroeconomic issues.[70] This view, however, becomes highly questionable when one considers *(i)* future energy scenarios in which steep rises in energy prices can cause a sharp increase in the share of energy in GDP[71] and *(ii)* the heterogeneity of the productive sectors in terms of energy use and the fact that a deep structural change (for example, one brought on by a strong environmental constraint) is likely to modify the linkage between economic activity and energy.

A second limitation relates to the ways that behaviours are represented, which often assume that individuals are all-knowing and have perfect foresight, thus allowing optimal pathways to be defined for a given objective (maximising consumption, well-being, etc.). This assumption nonetheless seems problematic for concrete policy prescriptions concerning long-term energy/climate issues because imperfect foresight is an essential component due to the uncertainties about future economic signals (relative prices, final demand, profitability of investment), to "noises" from sources other than the energy sector but which interact with it (informal economy, real-estate prices, etc.) and to the non-economic determinants of public policy decisions that integrate dimensions other than pure economic efficiency (equity, urban planning, budget constraints, etc.).

(developed at the OECD), the MESSAGE, AIM, GCAM and IMAGE models (used to construct the carbon emissions trajectories for the assessments of the 5th IPCC Report) or the PRIMES and GEM-E3 models (used by the European Commission for the Energy Roadmap to 2050).

70. An argument dubbed metaphorically as the "elephant and rabbit stew", developed by Hogan and Manne (1977).

71. See, for example, the analyses of the macroeconomic impact of the first oil shock by Hamilton (2008).

Finally, these *standard* integrated assessment models describe a world in which economic adjustments are perfectly flexible, production factors are used to the full (maximum use of production capacities, no cyclical unemployment) and monopoly market situations generating economic rents do not exist. This type of approach basically assumes *i)* complete short-term substitutability of production factors (i.e. a worker can easily be replaced by a machine), *ii)* no long-term inertia on the renewal of capital stock (i.e. the stock of installed infrastructure is flexible insofar as its characteristics are not fixed but adaptable to the economic context) or on changes in behaviours (i.e., agents' preferences determine, for example, the size of their house; their mobility needs are adjustable) and *iii)* the absence of any market power resulting from the privileged ownership of a production factor (i.e. owners of fossil fuel resources have no possibility of influencing the market prices of the resource). However, these fundamentals need to be questioned when considering long-term energy issues.

2. AN INTEGRATED ASSESSMENT MODEL FOR ANALYSING DECOUPLING: IMACLIM

The IMACLIM model developed at the Centre International de Recherche sur l'Environnement et le Développement (CIRED)[72] belongs to the family of integrated assessment models. It combines a dynamic description of the major macroeconomic aggregates (GDP, productivity, etc.) and a detailed technical representation of the energy sectors and their possible developments. Specific efforts have been made to explicitly represent technologies in key sectors such as power generation (15 different technologies, including coal-fired facilities, nuclear power stations and renewables), fuel production (distinction between oil refining, biofuels and coal-to-liquid), transportation (5 types of vehicles, including descriptions of hybrid and electric vehicles) and buildings (the model differentiates between energy-intensive and low-energy buildings).

To open up what could seem like a "black box" given the complexity of the model, we have included different appendices to explain IMACLIM's technical details. Technical Appendix A provides a technical description of the model's overall structure, Technical Appendix B gives the details of the model's variables and equations, Technical

72. UMR *ParisTech/ENPC/CNRS/EHESS, 45bis av de la Belle Gabrielle, 94736 Nogent sur Marne, France*

Appendix C details the representation of technical changes in the different economic sectors and Technical Appendix D discusses some of the model's numerical assumptions.

The IMACLIM model attempts to overcome the shortcomings of the standard integrated assessment models described above. To begin with, IMACLIM adopts a detailed multi-sector structure in which different types of activities are explicitly distinguished: agricultural/agri-food activities, material- and energy-intensive industries (e.g. steel, aluminium, cement) and manufacturing industries or services requiring more moderate amounts of materials. This level of sector detail makes it possible to represent the structural changes that influence the dematerialisation of the economy depending on how demands change in response to socio-economic dynamics (income, prices, preferences).[73]

Moreover, the simulation approach used by IMACLIM, unlike standard models, makes it possible to represent the fact that, at a given date, agents have very little information about the future and can only base their decisions on an extrapolation of past trends through adaptive foresight. This means that technical choices are made on the basis of imperfect anticipations regarding future technological and economic conditions.

Finally, the description of economic adjustments in IMACLIM differs from the standard assumptions on market adjustments as it represents certain specifics that are crucial for energy issues. The production function of each sector is thus designed to represent short-term rigidities, as it is assumed that production factors are not substitutable in the short term and that adjustments operate through the utilisation rate of production capacities and labour. The flexibility of longer-term adjustments depends on the technical choices for new production capacities, but long-term substitutability remains limited and depends on the rate at which capital stock is renewed (modifications to capital stock characteristics are made at the margin via the new capacities installed each year, as the characteristics of installed capacities are considered as fixed), on the emergence of new technologies and on the finite availability of investment capital (investment is subject to the constraint of available capital, which itself depends on household savings and exogenous flows of international capital). Finally, market powers are represented by introducing a profit rate that increases in line with the scarcity of the good produced (as measured by the utilisation rate of installed production capacities) and makes it possible to represent the emergence of economic rents.

Through the methodological choices discussed above, the IMACLIM model aims to offer a consistent vision of growth and its physical and technical content or, in other words, to ensure that the projected economy is supported by a realistic technical background (in the engineering sense) and, conversely, that the projected technical systems correspond to realistic economic signals. To make this twofold vision operational, IMACLIM relies on the dual accounting of monetary and physical flows. Thus, contrary to the standard economic models used by the advocates of "green growth",[74] IMACLIM does not presuppose that natural resources are fully convertible into euros or dollars. The environment is not completely "monetisable" in the IMACLIM model, in which resource stocks can constitute limiting factors when they are almost totally depleted. Yet, in IMACLIM, the representation of the world is not just "physical". It also captures the evolution of prices and thus consumption patterns and possible rebound effects,[75] as well as organisational, technological and structural changes. In other words, IMACLIM incorporates economics, whereas Kaya does not. It also takes into account the physical reality of the world, whereas standard economics shows no or too little interest in this aspect.

The IMACLIM model enables economy and energy trajectories to be simulated in yearly time steps following different sets of assumptions on what determines the economic, energy and technological trajectories. These sets of assumptions define different scenarios whose results are compared in order to identify the key mechanisms operative in the question being studied. This is the general methodology used in the rest of this section to first assess the issues of increasing constraints on energy. Then, in a second step, we introduce climate policy.

73. In particular, the model reproduces widely observed stylised facts such as the declining share of agricultural and industrial goods in favour of services as incomes increase. Moreover, this kind of sector detail also allows the representation of interdependencies between different types of activity, as for example, between the development of renewable energies and the needs of energy- or material-intensive industries (e.g., cement for wind turbine construction, materials for solar panels).

74. See, for example, the model developed by Acemoglu *et al*. (2009), which has the shortcoming of vastly oversimplifying the environmental question, as it only identifies two economic sectors (environment-friendly activities and polluting activities), in a world where there is no behavioural, political or technological brake on green sector development.

75. That is to say, the increase in consumption induced by a decrease in the price of a resource.

3. METHODOLOGY

The simulation exercises undertaken in this study using the IMACLIM model aim to:

1. give quantified elements to inform the debate on the possibilities for growth in a world faced with increasing energy scarcity and the need to drastically reduce its greenhouse gas emissions;
2. provide information on the key factors that drive the decoupling of growth and environmental impact (use of energy resources and/or CO_2 emissions).

The methodology chosen for the study involves (i) identifying the dimensions thought to play a role in this decoupling, (ii) defining the variation ranges for the related parameters in order to screen the uncertainties associated with each of them and (iii) defining the scenarios that combine the assumptions on each of the dimensions.[76]

(i) Identifying the dimensions that drive the decoupling of growth and energy consumption

The main uncertainties surrounding the energy sector concern resources, with technical factors determining end-uses (costs, availability, ultimate potential for diffusion) and lifestyles determining energy demand (mainly characterised by surface area of dwellings in m²; mobility needs in passenger-km). For resources, we distinguish oil/gas from coal on account of their very different characteristics; for the technical dimension, we make a distinction between the assumptions on energy efficiency and those that exclusively involve low-carbon technologies for both energy producers and consumers. We finally obtain 5 dimensions of uncertainty for the energy sector:

- a. The availability of oil and gas, defined by the assumptions on the amount of reserves and their geographical distribution, the geological inertias impacting the rate at which these reserves are extracted, and the strategic behaviours of countries and companies. These assumptions define both the pace at which the constraints on oil availability appear and the type of economic effects that accompany a stagnating or declining supply.
- b. The availability of coal, considered as sufficiently abundant in all scenarios, depends on the sensitivity of international coal prices compared to other fuel prices and on the availability of technologies using coal-based fuels at a competitive cost (notably, coal liquefaction as a substitute to oil refining).
- c. Energy-efficiency in production processes, depending on the rate at which energy intensities converge through learning processes or technology transfers. This dimension has an important direct effect on companies' competitiveness as it affects the energy intensity of production, especially in major energy-importing regions, such as Europe.
- d. The availability of low-carbon technologies, which are explicitly represented on both the supply side (renewables, carbon capture and sequestration, nuclear) and demand side (vehicles, electric vehicles). This availability is a function of learning rates and the potential for these technologies to penetrate the market. They are above all important for decarbonising power generation, as well as for the transport sector, where electric vehicles offer alternative solutions to oil-dependent modes of transport.
- e. Lifestyles and behaviours, defined as household preferences (square metres of living space, motorisation rate, structure of the demand), companies' modes of organisation (particularly, the transport intensity of production/distribution processes) and spatial organisation (urban planning). These dimensions are key determinants of an economy's degree of energy-dependency and thus govern its level of vulnerability to energy supply.

For each of these five dimensions, we define counterfactual visions that are translated into parametric assumptions. For the sake of clarity, Appendix D describes the different numerical assumptions for the availability of energy resources, technological advances and their costs, and lifestyles.

For the assumptions on labour productivity, which is a core exogenous parameter of the model, we adopt the assumption of a "convergence" paradigm, i.e. developed countries experience moderate growth, while emerging economies are characterised by faster growth so as to catch up the absolute productivity levels of the leaders (Barro & Sala-i-Martin, 1992). The median assumption results in an average growth rate for labour productivity of around 1.2% per year in Europe (1.5% at global level)

In addition to these energy variants, we also test the effect of contrasted assumptions on labour productivity growth (it should be remembered that this assumption is exogenous to the model) by considering different levels of convergence.[77]

76. We consider that the assumptions on each of the dimensions show no incompatibilities, which means that they can be combined without producing a scenario that is *a priori* unrealistic.

77. The assumptions examined remain within a moderate growth paradigm, but more extreme scenarios could be

ii) Defining the scenarios

For each of the six dimensions defined above (five energy dimensions plus productivity), we define contrasted scenarios and translate these into parametric assumptions (see Appendix D). A scenario corresponds to a set of assumptions on all of the dimensions listed above. By combining the different assumptions, we obtain 432 scenarios enabling us to screen a huge ensemble of possible futures at the 2050 time horizon in terms of economy, energy and climate.

Figure 2.16 below describes the range of these possible futures, integrating the constraints linked to an increasing scarcity of fossil fuel resources but without any measures to limit carbon emissions. Each scenario is characterised according to its average growth rate, its cumulative energy consumption and its total cumulative carbon emissions for Europe over the period 2010–2050 (in both graphs, a scenario is represented by a point).

Looking at the scenarios built according to the labour productivity assumption, we can see that this assumption causes most of the spread in the scatter plot and defines three distinct regimes in terms of growth and energy. It can be clearly seen that an acceleration of growth due to labour productivity gains translates into a parallel rise in environmental impacts, as shown by the shift of the point cloud toward the upper right for the scenarios with the highest productivity. In fact, higher labour productivity growth frees up production potential but has no effect on the resource intensity of economic activity, which depends on structural and technical changes; the highest level of production thus goes hand in hand with an increase in adverse environmental effects.

Moreover, it can be seen that, regardless of the parallel shift in growth and average environmental impacts, all the regimes show similar trends, which suggests that determinants other than productivity can be studied independently of the labour productivity assumption. This is how we will proceed for the rest of the study by limiting our analysis to a given regime (identical assumption on labour productivity), with no loss of generality.[78]

constructed in order to test, for example, the effect of stagnating productivity, which would lead to regimes closer to degrowth.

78. Note that this observation makes it possible to extend the mechanisms identified in the following sections to a broader range of growth rates than the one considered here and, in particular, to weaker growth rates caused by the assumption that labour productivity gains will stagnate.

Box 2.2.

Representations of the future and integrated assessment models

***"All models are wrong, but some are useful"* George E. P. Box**

Quantitative modelling is called on when the complexity of the mechanisms at play precludes an analytical approach. IMACLIM-type models are developed in order to account for complex interactions that cannot be understood *a priori*. When it comes to studying how the energy constraint affects the economy, there are too many variables for the human mind to grasp and visualise all of the interactions operative over the long term. Models are thus powerful tools to further our understanding.

It is very tempting to draw conclusions about our capacity to grow in a "finite" world: will the model teach us that we are condemned to degrowth or that decoupling is possible? What will our future growth rates be? Here, however, we treat the quantitative results from the modelling exercises with the utmost caution, given all their limits. Moreover, a modelling exercise like the one proposed in this section cannot answer questions formulated like those above, as they refer to absolute growth rate values. In fact, these growth rates will depend not only on the internal structure of the model defining the adjustment mechanisms adopted, but also on the parametric hypotheses, both of which are dimensions characterised by high uncertainties that do not allow a predictive interpretation of the results. Here, we can take the example of labour productivity. In Chapter 1, we not only saw that this is a key determinant of growth pathways, but also that a great deal of uncertainty exists about how it will evolve in the future As an analysis of this dynamic is far beyond the objective of an energy-economy model, the labour productivity variable is set exogenously (see the discussion above).

To overstep these limitations, the results of the model are used for a relative analysis, which means comparing two scenarios that differ only in one given dimension. This type of comparative methodology makes it possible to control for the structural and parametric effects in order to identify what effect the assumption that varies (notably on oil resources or on carbon emissions) has on the growth pattern, and hence to assess their differential effect. The model thus permits us to answer a question formulated in the following way: "What is the differential effect on growth of constraints linked to resources and/or climate?"

The purpose of the IMACLIM model is thus not to predict future trajectories. It is conceived rather as a tool for dialogue allowing us to test alternative visions of the future in economic, policy, technical or environmental terms. It thus provides us with a tool for assessing the mechanisms and uncertainties at play. It should nonetheless be noted that this dialogue takes place within the bounds of a certain view of the world, as indicated above. Instead of focusing on the numerical results of the modelling (that is, on the precise impact on growth of a particular policy intended to control energy consumption or carbon emissions), our primary interest is to examine the conditions under which the results have been obtained. And this is indeed why models are useful: instead of closing doors, they are able to inform and broaden the scope of the public debate as they describe the conditions needed for a transition pathway to succeed. This is the approach we follow in this report.

4. ECONOMIC GROWTH AND ENERGY RESOURCES

Our analysis of these scenarios is always carried out within the framework of trajectories that have no specific measures to limit CO_2 emissions in order to isolate the impact of energy resource constraint on growth. This analysis makes it possible to classify the determinants according to their impact on the growth pathways. But before discussing the relative importance of the assumptions on energy resources, technologies or lifestyles, what do the above figures teach us about the future of growth?

4.1. Macroeconomic impacts

First of all, each growth regime in Figure 2.16 above shows a downward trend, which is to say that, for a given labour productivity, there are determinants that together tend to decrease resource consumption and foster growth. We thus see that the most energy-efficient growth trajectory, in a given regime, has an annual growth rate of more than 0.2 percentage point higher than the least energy-efficient trajectory. The trajectory that shows that the highest growth – annual growth as high as 0.5 percentage point – is by no means the most energy-intensive.

To understand this result, it is useful to remember that resource constraint is a key determinant of growth pathways over the 2010–2050 time horizon, given that the increasing scarcity of the energies involved (chiefly oil) translates into substantial price rises that adversely impact economic activity over the same period. Thus, a decrease in energy intensity fosters growth as it helps to make economic activity less dependent on scarce resources. The overall effect on the amount of energy consumed thus depends on the order of magnitude of the rebound effect (in other words, the use of less energy-intensive technologies and practices leads to a higher demand for energy services such that the absolute consumption of energy does not necessarily decrease); the absolute decrease of energy consumption at higher growth rates thus suggests the existence of determinants that enable significant improvements in energy intensity and, at the same time, more effective control over the magnitude of the rebound effects.

4.2. The relative importance of decoupling factors

To deepen this analysis and identify the determinants driving these trends, we use a technique[79] that allows us to classify the five dimensions defined in Section 2.B.3(i) by order of importance for both of the observed variables, that is to say, the growth rate and the cumulative amount of energy consumed.

A first finding from our analysis involves the role of lifestyles and behaviours (determinant e), which appears to be crucial in explaining the results related to growth and energy. This parameter is a key determinant of both the economy's resource dependency and its vulnerability to energy break points. Certainly, the assumption on lifestyles and behaviours has a significant effect on the share of energy in household bills (size and type of housing, motorisation rate, and preference for manufactured goods) and on the production processes of companies, who curb their use of energy and make decisions about the associated production costs (vertical and horizontal integration, specialised production units, just-in-time processes). Thus, the adoption of more virtuous modes of consumption and production inducing a reduced demand for energy services is beneficial for both growth and energy consumption. This result is mainly due to the fact that the related rebound effects (notably, the extra consumption driven by the decreasing share of energy in household budgets) remain moderate.

The technical assumptions that lead to a reduction of energy intensity in production (dimension c) or define the potential for technology diffusion (dimension d) have less impact on average growth and cumulative resource consumption than the above-mentioned parameters. One of the main reasons for this relates to the rebound effect, which is particularly important for technological progress insofar as the absolute reduction of energy consumption is limited by the increased use of a new technology.

Finally, the assumptions on energy resources (dimensions a and b) have little impact on average growth rates over the 2010–2050 period. This finding may seem surprising but it masks high variability in the time profiles. In particular, a comparison of two scenarios that differ only in their opposite assumptions on the amount of reserves reveals that the variations in growth are relatively moderate over the period 2010–2050, but correspond to very different time profiles: if reserves are low, annual growth rates are about 0.5 percentage point lower over two decades.

To illustrate the importance of the time profile, we analyse the growth profiles in two scenarios characterised by dimensions that are identical except for the amount of reserves (high or low). The gap in average growth is moderate (about 0.1 percentage point) but the trajectories are very

79. This analytical method, known as the "CART algorithm" was introduced by Breiman *et al.* (1984).

different with an annual growth rate of around 0.5 percentage point lower during two decades if oil reserves are low (Figure 2.17). In fact, low reserves lead to peak oil production, which drives steep price rises that have adverse impacts on the European economy, as shown by the slackening of growth rates around 2015; on the contrary, more abundant reserves stave off these effects and curb their magnitude giving rise to much smoother growth pathways. In the longer term, one also sees that limited oil reserves translate into an economic upswing after 2030, which partly offsets the flat growth rates over the 2010–2030 period.

In addition to the amount of oil reserves, the extraction rate for this resource also significantly affects the growth profile.

5. ECONOMIC GROWTH AND CLIMATE

In addition to the energy constraint, we now introduce the question of climate change by examining a carbon emissions policy along the lines of an international climate agreement prolonging the Kyoto Protocol. The discussion here will look at how the scenarios can inform the debate on the possibility of continuing growth despite the climate "constraint", and on the relative importance of the key factors that drive decoupling.

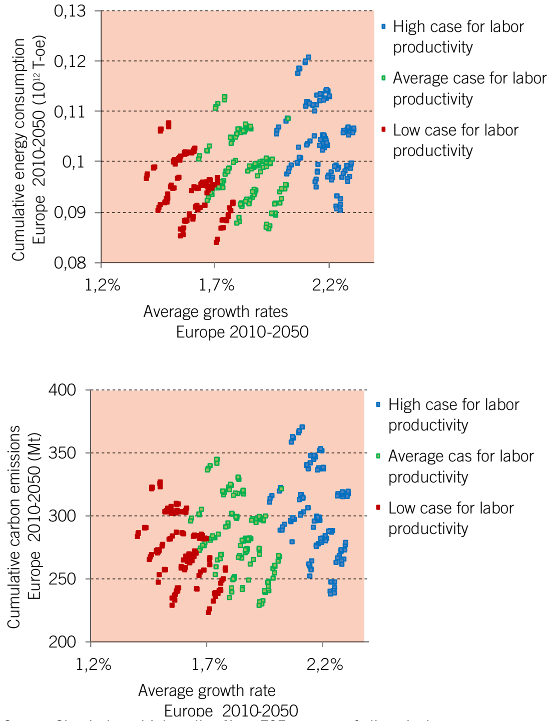
In the IMACLIM model, climate policy is introduced as an exogenous path defining, for each year, the maximum amount of carbon emissions authorised at global level for energy uses. The climate target corresponding to this assumption – mainly in terms of temperature increases relative to the pre-industrial era – is discussed in Box 2.4.

5.1. Macroeconomic impacts

The model makes it possible to analyse the relative effects of climate policy on growth pathways by measuring the GDP variations between the above set of scenarios with no climate policy (business-as-usual scenarios – BAU) and the same set of scenarios under the constraint of stabilising the increase in emissions and respecting the carbon emission path given in Figure 2.18 through the introduction of a carbon price.

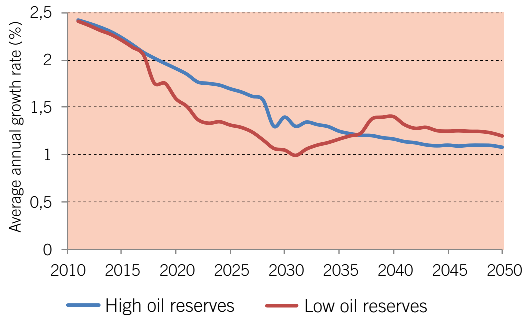
Figure 2.19 (left-hand panel) compares global GDP in all of the stabilisation scenarios with their BAU counterpart (the bold black line shows the average), and the profile of the carbon price (right-hand panel) that would be required to satisfy the carbon constraint. Figure 2.20 gives the corresponding time profile of the growth differentials or, in other words, the variations of the average GDP growth rate for the BAU scenarios compared to the stabilisation scenarios over each of the periods. The whole analysis is conducted at global level given that all of the world regions incur mitigation costs with dynamics similar to those shown in the figure above.[80]

Figure 2.16. The range of modelled futures



Source: Simulation with Imaclim. Note: TOE = tonne of oil equivalent

Figure 2.17 Impact of oil resources on the economy



Source: Simulation with IMACLIM.

80. In this modelling exercise, all countries pay the same carbon price. Countries with a high dependence on energy and low labour costs (such as emerging emerging) will be relatively more impacted than others. Introducing global differentiated emission patterns more favourable to developing and emerging countries would increase the costs of climate policies for industrialized countries and hence the impact on EU GDP growth rates.

Box 2.3.

Carbon emission paths and temperature increases

At policy level, climate objectives are usually formulated in terms of temperature increases relative to pre-industrial levels, with +2°C as a benchmark target in the case of a vigorous climate policy. There is obviously a link between the increase in temperature and carbon emissions from the energy uses considered in the modelling exercise. But, two major sources of uncertainty must be taken into account when translating CO_2 emissions into temperatures.

First, although the carbon from energy accounts for most of the greenhouse gases caused by human activity (about three-quarters for Europe; see the figure below), the future emissions of the other major gases responsible for climate change (non-energy carbon, nitrous oxide, N20 and CH_4 methane) will significantly impact the final rise in temperature. Furthermore, the link between the rise in temperature and greenhouse gas emissions is clearly establish. But the intensity of this link is a matter of uncertainty due to the complexity of the physical and chemical interactions in the climate system that determine the sensitivity of the climate and the magnitude of climate change in reaction to a certain level of greenhouse gas emissions

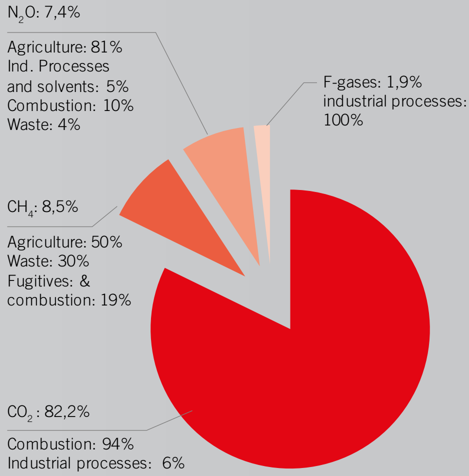
To relate the carbon emission scenario of our modelled analysis to the +2°C target, we refer to Rogelj *et al*. (2011). In their survey of the literature, these authors analyse a large number of scenarios to assess the probability that a carbon emission trajectory will reach the +2°C target, taking into consideration the two types of uncertainty mentioned above. On the basis of their analysis, they define ranges of values for three parameters that must be satisfied by the emission trajectory in order to reach – with a certain level of probability – a temperature increase below +2°C compared to pre-industrial levels. We consider more precisely the characteristics of the emission scenarios that "probably" (i.e. with a probability above 66%) lead to a temperature rise of less than +2°C with respect to pre-industrial levels by comparing them with the emission scenario used in our study.

		Date of peak emissions	Total greenhouse gas emissions in 2020 ($GtCO_2eq$)	Rate of reduction after the emission peak (% of the 2000 emissions/year)
(Rogelj *et al.*, 2011)	Median value*	2010	44 $GtCO_2eq$	2.7%
	Minimum*	2010	21 $GtCO_2eq$	1.5%
	Maximum*	2020	48 $GtCO_2eq$	3.4%
Present study		2017	48 $GtCO_2eq$ **	2%

*The median, minimum and maximum values refer to the set of values observed over the scenarios considered in Rogelj et al. (2011)

**The calculated value assumes a constant proportion between CO2 and other greenhouse gases.

We observe that the scenario under consideration is compatible with all of the criteria and can thus be considered to "probably" lead to a temperature increase of 2°C compared to the pre-industrial period.



Source: EEA, 2013

Figure 2.18. Global carbon emissions, under climate policies ($GtCO_2$) climatiques (2010-2100)

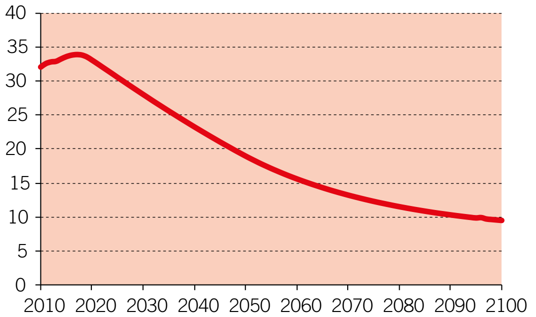
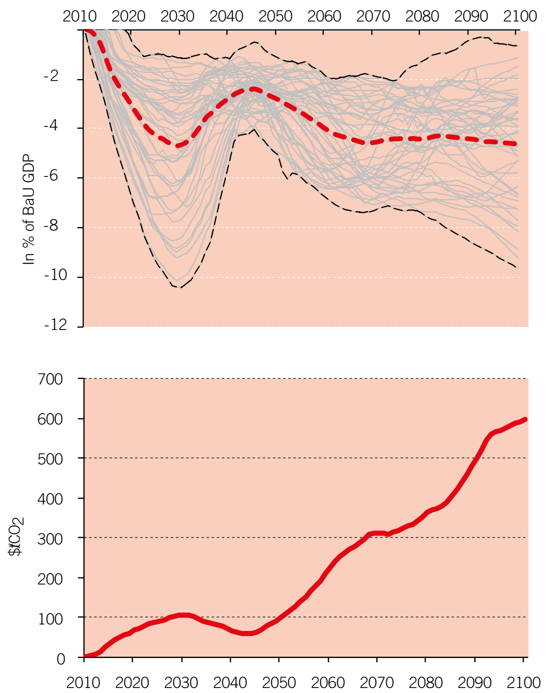


Figure 2.19. Impact of the 432 scenarios on GDP and the associated carbon price



Note: the right-hand panel shows the gap between each scenario and the BAU scenario. The right-hand panel indicates the carbon price that policy would need to be implemented to limit emissions. Source: Simulation with Imaclim

Figure 2.20. Average differentials between the climate policy scenario and the BAU scenario

(in percentage points of annual growth)

2010-2100	2010-2030	2030-2050	2050-2070	2070-2100
-0.05	-0.23	0.10	-0.11	0.00

Before looking at the timing of the macroeconomic effect of climate policy, we should first insist on the huge uncertainty linked to this cost.

At the 2030–2050 horizon, some development trajectories see their annual growth rate drop by nearly half a percentage point, whereas others are barely affected.[81] Clearly, climate policies have less impact on the trajectories or futures in which technology progresses swiftly to ensure its profitability or consumers consume more services and fewer material goods. And, according to the IMACLIM results, they are significantly less impacted.

But, beyond this variability, the growth trajectories show a similar time profile in all the variants under consideration and this reveals four distinct phases that prove robust to parameter uncertainty:

- *Substantial transitory losses (2010–2030),* with significantly lower growth rates than those in the BAU scenario (in the average scenario, annual growth is 0.2 percentage point lower and 0.5 lower in the most pessimistic scenarios). These costs are associated with a sharp increase of the carbon price, which drives up production costs for companies and slows down increases in purchasing power. The magnitude of the effects can be explained by the inertias limiting the rate at which production structures and infrastructure are decarbonised.
- *A medium-term catch-up period (2030–2050),* during which growth rates are higher under a climate policy. This result illustrates the beneficial effects of climate policy on the expectations of increasing energy prices. The introduction of carbon pricing has made the use of oil more costly and enabled the economy to anticipate oil scarcity by adopting less oil-intensive pathways. This type of economy is more resilient to peak oil than an economy that has failed to implement change.
- *A second phase of significant GDP loss from 2050 to 2070*, associated with a second sharp carbon price increase. In fact, at this time horizon, all the potential measures for low-cost reductions of carbon emission have been exploited and the bulk of the remaining emissions is due to transport, a sector where the energy transition is the most complicated.[82]

Finally, for the post-2070 period, interpreting forecasts is even more problematic. One can however say that, even if the carbon price continues to rise, the economy will have adapted to climate policy requirements, which no longer "nibble away" at growth.[83]

81. This does not mean, in absolute terms, that the trajectories least impacted by climate policies have growth rates higher than the trajectories that are much less impacted.
82. Contrary to the residential sector, industry or electricity generation, the transport sector is non-sensitive to price signals and a hefty increase in carbon prices is needed in order to change behaviours in any significant way.
83. It should be remembered that, here, we are not projecting a bifurcation under a climate policy regime, which

5.2. The relative importance of the factors driving decoupling

The role of the technical dimension is analysed by comparing the results of two variants: a variant where the potential for energy efficiency is high and where low-carbon technologies (renewables, electric vehicles, Carbon Capture and Storage) are rapidly and massively deployed (grey line) and a variant where this potential is more limited (black line).[84] The short-term losses are significantly lower under an optimistic assumption (a GDP 3% lower than the scenario without a climate policy, compared to 7% under the pessimistic variant). This shows how important it is to adequately anticipate technical adjustment processes in order to diffuse them rapidly and prevent them from hampering growth. In the long term, the costs are basically determined by the race between mobility needs and decarbonisation of the transport sector, which largely depends on the assumption on the final potential for diffusing electric vehicles. Under the assumption that a vast portion of the vehicle fleet can be electrified, losses decrease (about 2% in 2100), but this does not radically change the trends.

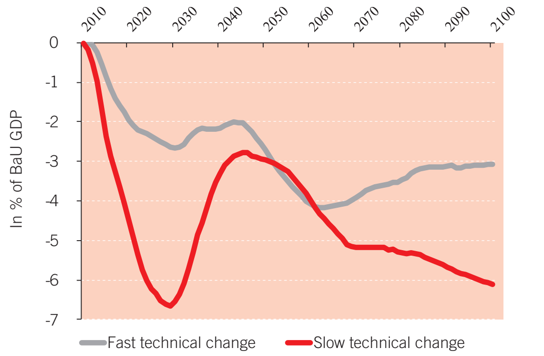
The role of lifestyles and behaviours is analysed principally through two groups of scenarios that differ with respect to the ways space is occupied, the choices of infrastructure and logistical systems. We compare the BAU scenario, which reflects a continuation of the trends for this dimension (black lines), to a scenario (grey lines) in which urban forms depend less on individual mobility (smaller distances, public transport infrastructures)[85] and logistical systems are less freight-intensive (integrated production processes, a moderation of just-in-time processes). A reduction in mobility needs for passengers and freight, as well as a transition towards low-carbon transport modes, makes it easier to control emissions in the transport sector. This also means that the same climate objective can be achieved with a moderate rise in the carbon prices and negligible losses in the long term. Here, we can see an illustration of the effect of complementary infrastructure policies as an instrument for limiting the carbon price increases needed to attain a given reduction of carbon emissions.

would likely create substantial differences for productivity trajectories.

84. These assumptions combine the assumptions on the evolution of the cost of technologies and their diffusion in terms of penetration rate and final potential (see Appendix D).

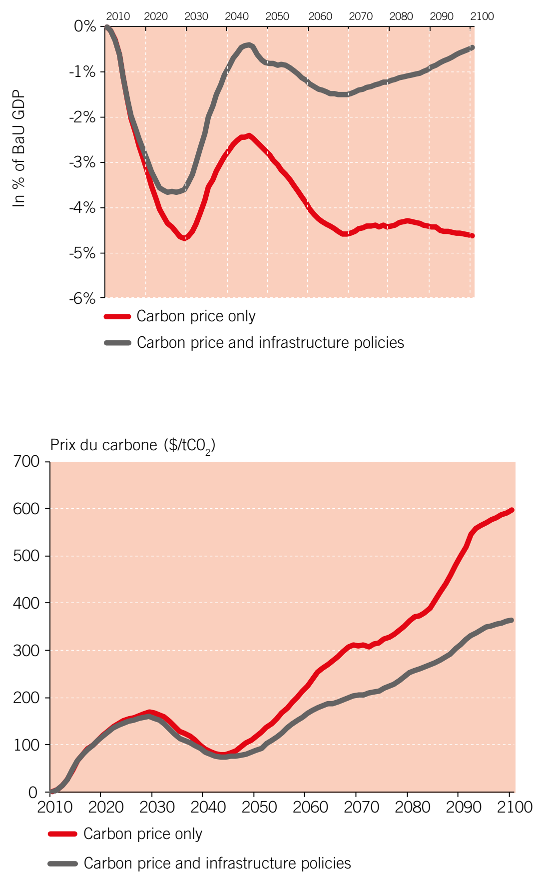
85. We adopt the simplified assumption that investment is redirected to developing public transport infrastructures, with a decrease in the amount of investment for building roads.

Figure 2.21. The cost of transition and diffusing new technologies



Source: Simulation with IMACLIM

Figure 2.22. The cost of transition and changing behaviours



Source: Simulation with IMACLIM.

One conclusion might be that, in the short term, it is important that the promises proffered by technology come to fruition in order to limit the macroeconomic impact of climate transition but that, in the longer term, changes in lifestyles are crucial. We can pursue today's unsustainable lifestyles and place our trust in technological innovation alone: but this "strategy" could have a particularly high macroeconomic cost.

6. CONCLUSION OF THE SECOND CHAPTER

Does environmental constraint put a brake on economic growth? In this chapter, we proceeded in two steps. The first involved listing the stocks of energy, mineral, agricultural and water resources in order to identify the main issues linked to these resources.

The issues vary depending on the resource: proven fossil fuels resources are almost exhausted; they are often in limited quantities and highly concentrated geographically in the case of hi-tech minerals such as the rare earths; land is in competition with other resources and water resources are particularly vulnerable to local pollution…

The European Union is particularly badly placed when it comes to accessing the resources: the EU's energy dependence rate is in excess of 70%, the Union has no rare earths and is the world's main consumer of arable land in third countries. If the current trends of natural resource consumption continue, without any new discoveries or technological and behavioural changes, the European Union and the global economy will experience severe shortages. There is nothing new in this observation – but a reminder of the hard figures has the merit of underlining the urgent need for a metamorphosis of our societies.

Will this kind of metamorphosis imply foregoing economic growth? We have seen that to answer this question, it is not enough to study the future quantities of available energy reserves. What also needs to be taken into account is the complex interplay between society, the economy and the environment. For this, we have used CIRED's economy-energy-climate model, also used by the IPCC, to model the impact of the growing scarcity of energy resources and climate policy on the economy.

The IMACLIM model was used to imagine 432 different possible growth trajectories according to the amount of energy resources still available, the evolution of low-carbon technology costs and lifestyle changes. By comparing these scenarios and setting or not setting them the objective of stabilising global warming at under 2°C, it appears that:

- 1. Although the energy and climate constraint can have a significant macroeconomic impact in some case, it does not lead to a drop in economic activity… at least as long as we assume that productivity increases, at the same time, at the "normal rates" observed in the past. In fact, the absolute growth rates in the scenarios depend primarily on the rate at which productivity evolves independently of the energy and climate problems (cf. Chapter 1).
- 2. The low assumption on energy resources nonetheless leads to a drop of around 0.5 percentage point of annual GDP growth over the long run, compared to the more optimistic assumptions.
- 3. For a given labour productivity, there are determinants that together tend to foster growth due to a reduced consumption of energy resources. The trajectory that shows the highest growth – up to 0.5 percentage point of annual growth in both the short and medium term – is relatively energy-efficient. Growth and energy are not correlated at 100%.
- 4. The macroeconomic cost of climate policies can nonetheless reach 0.5 percentage point of annual growth, at least during a transition period (until 2030), under the most pessimistic assumptions. Once again, this cost is substantial in a period of already low growth.
- 5. In the medium term, the cost of the climate policy decreases mainly thanks the co-benefit of climate transition in a context of increasing energy scarcity. This makes it possible to smooth the energy transition by generating higher growth rates than under the BAU scenarios between 2030 and 2050.

- 6. In the long term, the cost depends mostly on lifestyles, which determine the dependency on fossil energies, and on the policies that accompany carbon pricing and are designed to control carbon emissions from the sectors that prove weakly reactive to price signals (notably transport).

When considering the above findings, it is important to keep in mind the framework within which the results of the modelling exercises are to be interpreted and, in particular, the fact that quantified assessments must not be viewed as predictions but as orders of magnitude enabling us to identify the main issues involved in the energy transition.

More generally, IMACLIM, like all models, is not constructed in order to predict whether or not we can grow despite the constraints related to energy scarcity or climate policy. They are there to explore different possible development trajectories and their economic and environmental consequences. They shed light on the choices that we can make so as to cushion the energy and climate constraints – change our urban forms, invest or not in Carbon Capture and Storage – and on the choices that are not ours to make – the energy reserves that are actually available, the arrival of technological break points. In this sense, the models are tools for dialogue.

So, while the political and media debates on energy and climate issues often seem to focus on new technologies for producing and consuming energy, what appears even more crucial is that we change our lifestyles in order to respond to these environmental challenges and minimise the macroeconomic cost of action. Indeed, the simulation exercise shows that we can continue today's unsustainable lifestyles and place our trust in technological innovation alone: but this "strategy" could have a particularly high macroeconomic cost – if only because it is more sensitive to the rebound effect.

It is thus incumbent on policy makers and decision makers to implement the necessary infrastructures for more energy-efficient and low-carbon lifestyles (low-carbon public transport for long and short distances, innovative financing tools to upgrade the energy-efficiency of housing), standards to reduce wastage and built-in obsolescence, as well as policies to inform and incentivise a shift in preferences towards products with low-energy content (i.e. local supply chains).

Some transition pathways can at the same time foster growth and reduce energy consumption and carbon emissions, whereas on other pathways the two will be at odds. There is little certainty as to our collective capabilities to engage on one pathway rather than another. A serious approach to dealing with these uncertainties would be to ask ourselves if and how we can "build a cohesive society" in a context of structurally weak, or even stagnant growth.

CHAPTER III – PROSPERITY WITHOUT GROWTH?

In the first chapter, we saw that growth could be heading for relatively weak levels compared to those experienced by developed countries in the twentieth century. This downward trend could also be exacerbated by climate and energy resource constraints, as described in Chapter 2. New technologies may, of course emerge, increasing productivity gains and possibly transforming climate efforts into a winning solution: this is the gamble of the "green industrial revolution".

In this report, however, we take a precautionary stance. We need to prepare for a broad range of possible economic futures, and one of the questions that arises is whether or not societies can adapt to inherently weaker GDP growth. Adam Smith, in *The Wealth of Nations*, argued that the well-being of a country and its people exists only when growth is in "a progressive state" (Figure 3.1). This modernist view is still widely held today – particularly in times of economic crisis – and the prospect of sluggish growth over the coming years musters little enthusiasm.

Figure 3.1. Extract from Adam Smith's *The Wealth of Nations* (1776)

"It deserves to be remarked, perhaps, that it is in the progressive state, while the society is advancing to the further acquisition, rather than when it has acquired its full complement of riches, that the condition of the labouring poor, of the great body of the people, seems to be the happiest and the most comfortable. It is hard in the stationary, and miserable in the declining state. The progressive state is in reality the cheerful and the hearty state to all the different orders of the society. The stationary state is dull; the declining, melancholy."

We nonetheless need to ask ourselves whether a "progressive state" of growth refers to actual GDP growth, or whether the ideal of progress (from the Latin *progressus*, which means "advance") can be achieved in some other way. In his forward-looking essay "Economic Possibilities for our Grandchildren", Keynes (1930) imagined a world in 2030 where life's material necessities would be fully satisfied allowing people to devote their time to art and culture, to family and community life, without having to worry about improving their income. In this kind of world, people would work for just three hours a day – with productivity levels ensuring that "essential" material needs would be more than satisfied.

Figures 3.2. Extract from J.M. Keynes' *"Economic Possibilities for our Grandchildren",* (1930)

"I see us free, therefore, to return to some of the most sure and certain principles of religion and traditional virtue – that avarice is a vice, that the exaction of usury is a misdemeanor, and the love of money is detestable, that those walk most truly in the paths of virtue and sane wisdom who take least thought for the morrow. We shall once more value ends above means and prefer the good to the useful. We shall honor those who can teach us how to pluck the hour and the day virtuously and well, the delightful people who are capable of taking direct enjoyment in things, the lilies of the field who toil not, neither do they spin. But beware! The time for all this is not yet. For at least another hundred years we must pretend to ourselves and to everyone that fair is foul and foul is fair; for foul is useful and fair is not. Avarice and usury and precaution must be our gods for a little longer still. For only they can lead us out of the tunnel of economic necessity into daylight."

But is this world simply Utopian? Have industrialised societies reached the level of opulence enabling them to surpass the need for material enrichment and reach "daylight", to reprise Keynes' expression?

Many studies have foregrounded the disconnect between the level of wealth and self-reported happiness in rich countries (Jackson, 2009). Others (Lachaize, 2013) argue that it would be better to leave GDP aside, as this statistical aggregate is no longer adapted to current problems. Certainly, there are very good grounds for criticising this indicator and the way it is used.[86]

Yet, if many political actors view economic growth as a prerequisite of prosperity, it is not simply because they are not yet acquainted with these studies. If the "myth" of growth persists in political, media and civic discourse, it is also–perhaps–because growth is an effective tool to successfully achieve certain objectives.

To go beyond the "myth" of growth, in this third chapter we look at *some* aspects of well- being, and identify the mechanisms linking them to short- and long-term GDP growth, in order to propose a fresh view of the challenges raised by a low-growth regime.

The chapter presents a survey of the economic literature that explores the ways in which happiness, employment, inequalities and social protection link up with growth. These four dimensions correspond to the public policy areas frequently cited by European citizens in opinion polls[87]. Moreover, from our discussions with policy makers, it became clear that they establish close, but sometimes confused, links between growth, employment, inequality and social protection financing that could well do with some clarification.

Once again, we are not predicting the future here: high growth *may* occur in the future. But whatever happens, it is well-advised to consider how the social contract can be made to evolve in a world where the accumulation of economic wealth is slowing down.

1. GROWTH AND HAPPINESS: "CAN'T BUY ME LOVE"?

Does growth bring happiness? In contrast to a view commonly found in standard economics whereby happiness is synonymous with rising incomes, in 1974 Richard Easterlin expounded a paradox: while income levels explain happiness relatively well in the short term within and across countries, the same does not hold true over the long term. Easterlin's theory can resumed in four main points (Senik, 2005):

- (i) Short-term macroeconomic fluctuations correlate strongly with self-reported happiness (Figure 3.3). The relationship between short-term growth and unemployment certainly seems to support this observation (see section 3.2).
- (ii) In cross-country comparisons, self-reported happiness depends on income (Figure 3.4): the inhabitants of rich countries report a higher level of happiness, on average, than those in poor countries (Inglehart *et al.*, 2008). However, there is a sharp slowdown, if not a disconnect, in the growth of happiness as average income per capita increases.
- (iii) Income levels within a country also predict the level of happiness between individuals. The self-reported happiness of the wealthy is greater than that of the poor. This is a relatively well-established fact both within rich countries and less economically developed countries, and it is stable over time.[88]
- (iv) Over the long term, however, no correlation is observed in rich countries between average income per capita and happiness. Although happiness does vary in the short term in line with the economic conjunctures in these countries, over the long run the self-reported level of satisfaction remains steady. The same trend is seen in Europe, the United States and Japan (Easterlin, 1995; Clark *et al.*, 2008; Easterlin *et al.*, 2007).

Easterlin thus points up a threshold beyond which wealth no longer increases happiness of the average individual. In some respects, he concurs with the intuition of Keynes (1930), who believed that people would lose interest in money once their material needs were satisfied. This threshold hypothesis is confirmed by the British economist Richard Layard (2005): "once a country has over $15,000 per head, its level of happiness appears to be independent of its income per head".

To explain why well-being stagnates over time, two main arguments are usually called on.

First, well-being in rich societies does not depend on what we can do or buy with a given level of income, but on the difference between our own purchasing power and that of those around us–and consequently on a society's inequality.[89] When average income increases and inequality also rises, as

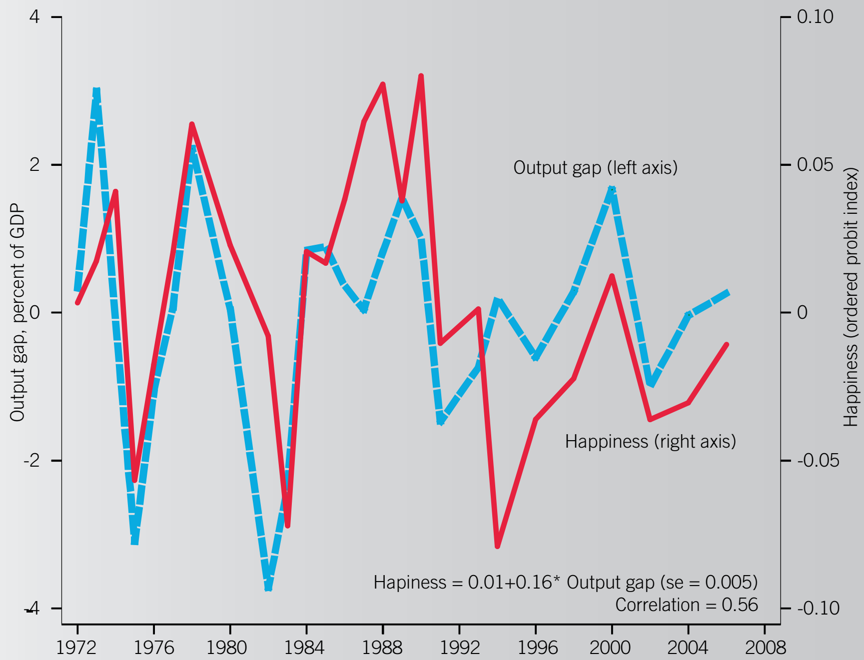
86. See particularly Stiglitz *et al*. (2009) and Meda (2013).

87. See notably the *Eurobarometer* Europe-wide opinion polls, EC (2013).

88. For details at a national level, refer to the German Socio-economic Panel, the British Household Panel Survey, the Swiss Household Panel, the Australian Household Survey, the French Household Survey, the Indian Consumer Budget Survey, etc. For details over time, refer to the five waves (1981–2008) of the World Value Survey, covering 105 countries.

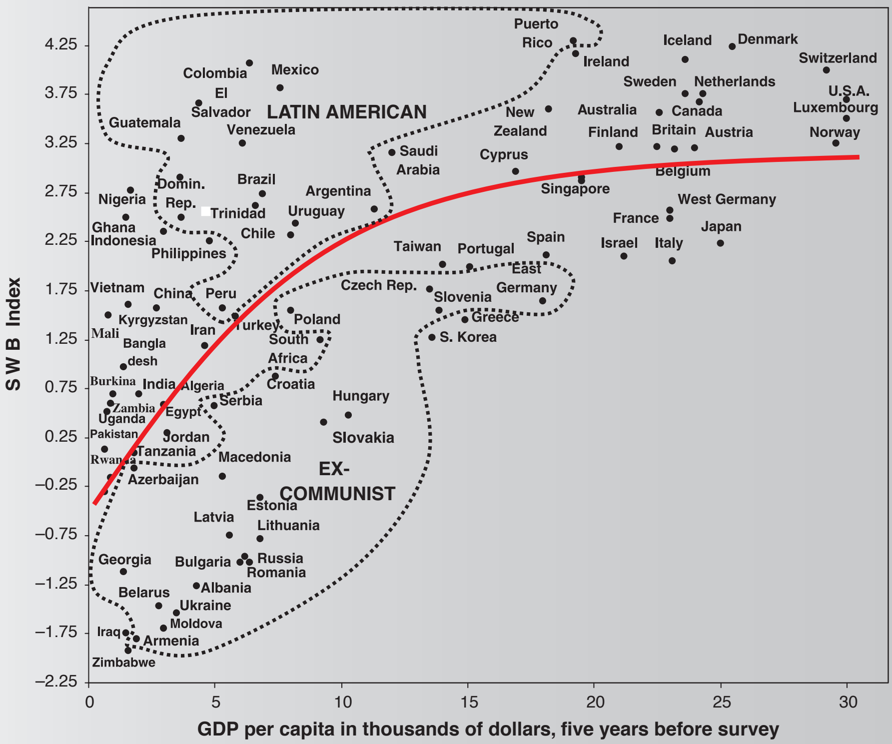
89. The literature shows that Europeans compare themselves first of all with their work colleagues and then with friends or family. Southern Europeans are an exception, however, as they compare themselves more with their family. It is worth noting that comparisons with colleagues are less often associated with a decrease in well-being than comparisons with family. If a colleague has a given level of income, attaining this same level is easier for an individual than attaining the income level of a family member in a different profession (Senik & Clark, 2010).

Figure 3.3. Gap between potential growth and self-reported happiness



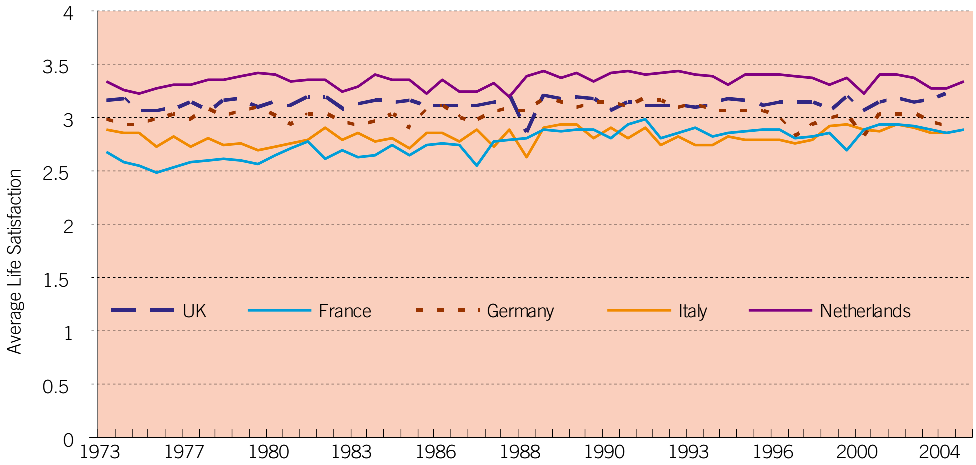
Note: the potential growth gap (or output gap) correlates very well with the trends in the unemployment rate (cf. Section 3.2 on employment). Source: Stevenson *et al.* (2008)

Figure 3.4. Average income and self-reported happiness



Source: Inglehart *et al.*, 2008.

Figure 3.5. Changes in self-reported happiness over time



Source: Clark et al. 2007, taken from Senik (2013)

has been the case in rich countries since the 1970s, overall subjective well-being appears to stagnate. Studies by McBride (2001) and Card *et al.* (2012) have shown empirically that income comparison strongly influences subjective well-being.

The second argument relates to how individuals adapt to novelty or shifts in preferences: an increase in income that opens up access to new goods or services for an individual is satisfying for a while, until they become used to their new situation, which then becomes their norm. Plug (1997) and Van de Stadt *et al.* (1985) have shown that the minimum income deemed necessary for a person to "make ends meet"[90] without incurring debt increases as he or she earns more.[91] This is the "extra room" syndrome experienced by new homeowners, who are satisfied with their new home until they feel the need for a little more room…

However, whether or not this satiation point exists is a subject of controversy. According to Stevenson and Wolfers (2008), the data used by Easterlin were patchy and, more to the point, the absence of proof linking well-being and growth does not signify proof of its absence.[92] Drawing on new data, the authors concur that growth leads to an increase in self-reported well-being. The table below shows different studies that reach different conclusions on the linkages between growth and happiness over the long run.

Figure. 3.6. Correlation between happiness and level of income

No correlation	Easterlin (2005b); Easterlin *et al.* (2009); Easterlin *et al.* (2010); Brockman *et al.* (2009); Layard (2005).
Weak positive correlation, but unsystematic	Hagerty and Veenhoven (2000); Inglehart *et al.* (2008); Kenny (2005); Layard *et al.* (2010); Di Tella *et al.* (2008).
Positive and systematic correlation	Helliwell (2002); Stevenson *et al.* (2008); Veenhoven *et al.* (2013); Deaton (2008); Blanchflower (2008)

Yet, a more fundamental critique can be levelled at the Easterlin paradox, namely, that the scale of happiness measured by the studies is bounded. Respondents are asked to rate their well-being on a scale of 1 to 10 – by definition, measured happiness cannot therefore increase indefinitely. Moreover, any historical interpretation of the relationship between growth and happiness would be meaningless, as individuals are not comparing their happiness to the happiness of previous generations, but instead base their reasoning on the world as they know it (Senik, 2013).

More recently, studies have revisited Easterlin's work (Stevenson *et al.*, 2008; Clark *et al.*, 2012) and shown that, hidden behind the stability of happiness measured over the long term, some striking changes have taken place: in the rich countries inequality in individual happiness has narrowed over the last four decades. What would explain why the wealthiest have become more dissatisfied and the less wealthy more satisfied? Today, owing to globalisation, the most well-off compare themselves more than before to the rich in other countries and therefore may no longer find themselves at

90. To use the expression employed by researchers.

91. More specifically, an individual who is given a €100 raise one year will, after two years, estimate the income that (s)he deems necessary for decent living standards at €60 higher than in the year of his/her raise. See also Kahneman *et al.* (1979) and Easterlin (2001).

92. These authors consider that happiness increases, but less than proportionally.

the top of the income pyramid. As for the poorest, they now have more access to public goods than before (social protection, improvements in education, increased life expectancy, political rights and gender equality). Here we should point out that, unlike Senik's (2013) interpretation, these explanations refer less to growth and more to inequality in the broadest sense (i.e. not simply economic inequality).

In summary, we have shown that, in the short term, growth is effectively correlated with subjective well-being and that this relationship can be explained more particularly through unemployment: recessionary periods correspond to job losses (cf. below) and thus to high levels of dissatisfaction. Over the long term, the relationship between well-being and growth is more controversial once a certain standard of living is attained. Comparing oneself with other people may be a more important factor for self-reported satisfaction than income growth. Finally, we need to look further than the question of income, as access to public goods such as health care or education is a powerful factor in increasing well-being for the less wealthy.[93]

In other words: rather than focussing on growth and waiting for its arrival in the hope that this will make people happy, it would be better to meet their demands for employment, income equality and equal access to public goods.

2. EMPLOYMENT, GROWTH AND PRODUCTIVITY: A GORDIAN KNOT?

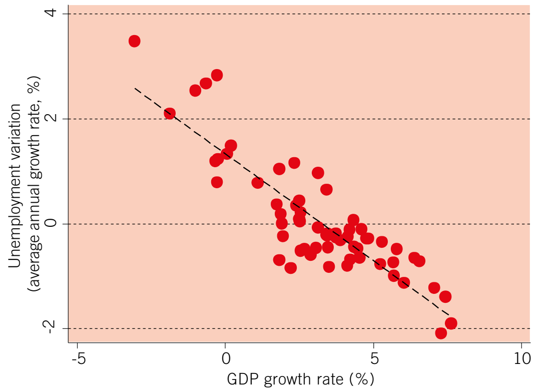
Without growth, no jobs? At least, this is the view held by politicians, most economists and public opinion. To shed light on this controversial issue, we need to pinpoint the different effects linking the unemployment rate with GDP growth in both the *short* and *long* term, along with the various possible *causes* for a decline in the growth rate.

In this section, we focus on three cases: the linkage between growth, unemployment and productivity in the short term (2.1), the impact on employment of an intentional and prolonged drop in consumption (2.2) and, finally, the impact of declining productivity gains on the rate of unemployment over the long run (2.3).

3.2.1. Employment, growth and productivity in the short term.

"Okun's Law: fit at fifty?" In a recent article, Ball *et al*. (2012) examined the relevance of what is known as "Okun's Law", according to which the

Figure 3.7. Unemployment rate and GDP growth in the United States (1951–2012)



Source: BLS (2013)

unemployment rate can be predicted in function of the GDP growth rate. "Okun's Law" was formulated in the 1960s (Okun, 1962) and establishes a relationship between unemployment and growth in the short run.

Figure 3.7 shows the relatively strong link between GDP growth and variations in unemployment levels in the USA since 1950. Ball *et al*. show that this law has had a strong predictive power in many countries over the last fifty years.

According to Okun's Law, variation in unemployment levels is a function of the gap between real growth and "potential" growth, which is defined as the growth that could be achieved if the economy utilises its production capacities to the full (i.e. all of its factories, workers and available technical capabilities[94]). The simplified version[95] of Okun's Law is expressed as:

Variation of employment rate = real GDP growth – potential GDP growth

This law means, therefore, that there is a growth threshold below which the economy destroys more jobs than it creates, and a level of growth above which more jobs are created than are destroyed. This threshold, as a function of potential growth, depends on two main factors: productivity growth and demographic growth.

One possible critique of Okun's Law, however,

93. See section 3.4.2.

94. In other words, everything made possible by its technical advances.

95. More precisely, Okun's Law is expressed as: $U-U^{*}=ß(g-g^{*})+u$ where U is the estimated unemployment rate, U^{*} is the level of long-term unemployment, g is GDP growth, g^{*} is the level of potential GDP growth, ß is Okun's coefficient and u is an error term.

is that it translates above all an accounting-based reality and gives no indication of the *directionality* of the relationship between growth and unemployment. Is it growth that creates jobs or *vice versa*? Broadly speaking, this question reflects the debate between the proponents of "supply-side policies" (reducing labour costs to boost employment and therefore growth) and the proponents of "demand-side policies" (i.e. increasing wages or public-sector employment[96] to stimulate growth and employment across the entire economy).

The accounting-based relationship identified above has also been criticised: for some authors, it is unstable (Meyer & Tasci, 2012), and even totally inoperative for others (Gordon, 2011; NPR, 2011), who point up cases of a strong recovery following an economic recession with no fall in the unemployment rate. In Europe, the link between unemployment and GDP growth in the short run is much less mechanical than in the United States. In Italy, Germany, Austria and Switzerland, Okun's Law explains the variations in unemployment levels for just half of the last thirty-two years, and sometimes even less (Ball *et al*., 2011). The predictive power of the relationship is therefore far from foolproof.

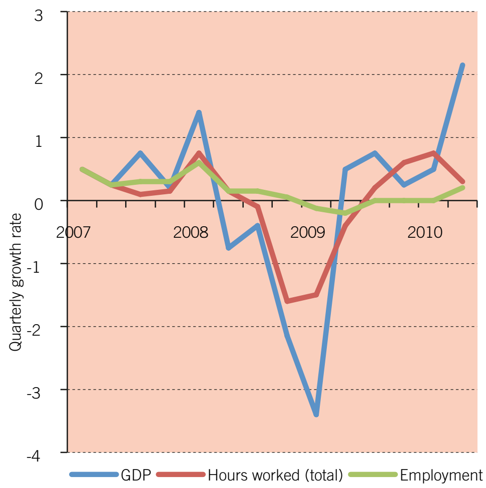
This is particularly true in the case of Germany during the last economic crisis. In 2008 and 2009, the recession was severe, but the employment rate remained at a relatively constant level. This trend may be for several reasons, including demographics (many young people extended their studies instead of entering the labour market [Duval, 2013]), but more importantly, companies decided to reduce working hours (with or without a drop in income), as shown in Figure 3.8.

Therefore, even though the GDP growth–unemployment linkage is considered to be "automatic" by some, it cannot consistently indicate whether it is weak growth that creates unemployment or *vice versa*. Moreover, this relationship is not infallible: measures such as reducing working hours can be taken to curb unemployment during periods of recession.

3.2.2. Employment and persistently weak growth: the case for reducing consumption.

As we saw in Chapter 2, some authors (Jackson, 2009; Victor, 2008) argue that greenhouse gas mitigation targets can only be achieved if individuals significantly reduce their overall amount of consumption, *i.e*. if there is a stagnation or degrowth of GDP. We can then ask what issues an extended period of weak growth would create for employment.

Figure 3.8. Employment, growth and hours worked in Germany (2007–2010)



Note: Quarterly growth rate. Source: Dietz *et al.,* 2011. Formatted by the authors.

Jackson (2009) points out that if consumption decreases while productivity gains and associated job losses are high, the economy will destroy jobs. This line of reasoning was described in the previous section: if working hours remain unchanged and GDP growth is weaker than productivity growth, the economy's new sectors cannot absorb the jobs destroyed, as demand is too low. What makes the difference here is the length of the low-growth period (i.e. years vs. decades). Dietz *et al.* (2013) hold that, in this type of scenario, sharing work time can help to tackle a significant rise in unemployment.[97] In this case, note that although policies in favour of a redistribution of wealth (between wages or from capital to labour) can be implemented to increase or maintain income levels for some population groups, a reduction in work time cannot maintain wage levels for all workers.

Note, however, that the "degrowth" authors consider that reducing working hours is not only a way of avoiding an increase unemployment during a period of generalised decrease in consumption (Entropia, 2007). It is also a way of driving down consumption. The system of reduced work time is thus seen as a means to produce less and consume

96. In this case, public authorities have to create budget margins, print money or borrow funds pending a return to growth. This was the course followed by American President F.D. Roosevelt during the New Deal from 1932 on; it is also the wager of the French Government's *contrats d'avenir* (contracts for the future), introduced in 2012.

97. The authors also argue that jobs funded by the public sector can also reduce the unemployment rate. It remains to be defined how these jobs will be funded (higher taxes, borrowing, money supply).

Box 3.1.

Weak growth and unemployment in Japan

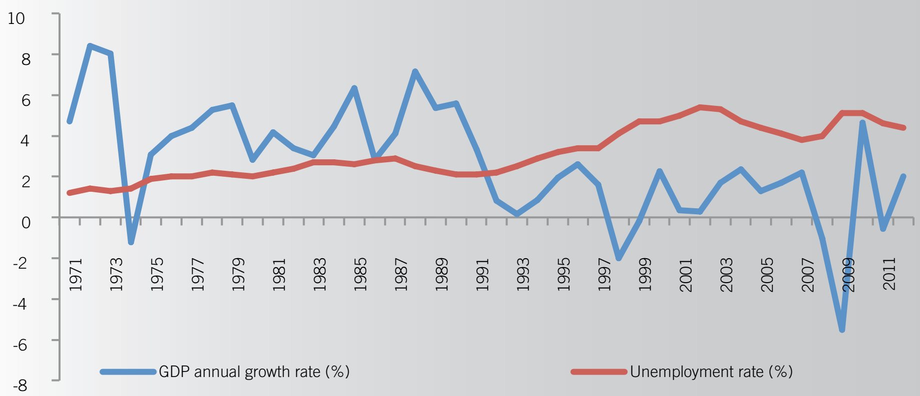
Japan is an interesting case in point because it is a rich country that has experienced a decade of sluggish growth whilst maintaining a low unemployment rate. This obviously does not involve an intentional reduction in consumption as discussed in section 3.2.2, but neither is it a passing crisis (see section 3.2.1).

When the housing bubble of the early 1990s burst, the Japanese economy then grew at an average rate of 1.1% per year until the 2007 crisis, whilst hourly productivity increased on average by 1.9% over the same period. Japan thus combines both subdued demand (households lack confidence in the future and prefer to save, thus slowing GDP growth) and low productivity gains compared with previous decades.

During the fifteen years that followed the 1991 crisis, the Japanese unemployment rate rose from 2.1% to 5.4%, falling to 3.8% before the 2007 crisis. However, although this was a steep rise (the rate doubled), the absolute level was kept in check: Japanese unemployment did not exceed 6%, which is a level that many European countries would envy. Moreover, before the 2007 crisis, the level of unemployment had started to fall again, despite a lack of sharp improvement in growth.

How is it possible that such a long period of weak growth – lower than productivity growth – did not lead to an explosion of the unemployment rate? Two reasons can be advanced, which paradoxically relate to two employment policy prescriptions normally at odds with each other. Firstly, Japan is known for its job-for-life culture. Companies rarely lay off their workers and prefer to implement company reorganisations, along with part-time work and ongoing training. Secondly, the Japanese labour market was deregulated during this period (1991–2007) with the introduction of short-term contracts and more flexible redundancy procedures. This drove an increase in social inequalities, particularly between young people entering the job market and older people who were already employed (Lechevallier, 2011).

Figure 3.9. Growth and unemployment in Japan (1971–2012)



Source: Conference Board (2013) and OECD (2013). Formatted by the authors.

less. Here, of course, there is a strong assumption that individual and collective consumption can be reduced as desired.

3.2.3. Employment and weak growth in the long run: the case of declining productivity gains

Okun's Law was not devised to explain the links between unemployment rates and the transition to weaker growth regimes triggered by a slowdown in productivity gains, but rather to model short-run trends in unemployment and GDP. To answer our original question, we need to call on other theories that focus on the relationship between long-term economic growth and unemployment rates. In this sub-section, our interest is on declining growth induced by lower productivity gains, and not the negative feedback effects of unemployment on productivity or growth, although this also warrants detailed analysis.

The decline in productivity gains observed since the late 1960s in OECD countries may be intuitively associated with higher unemployment rates. Productivity gains in Europe have fallen more sharply than in the United States, and the rise in unemployment is greater in Europe than in North America.

i) The transition from a strong-growth to a weak-growth regime

One possible explanation for rising unemployment due to lower productivity gains is wage inertia. According to Blanchard and Wolfers (2000), when economic actors have grown accustomed to a period of high growth, they also become used to rapid rises in income. During a transition to lower levels of productivity growth, wage increase expectations may be rigid. Wages thus increase more quickly than the economy's ability to produce, which automatically drives up the real cost of labour and may lead to a rise in unemployment. Conversely, this "rigidity" effect may work in favour of employment when productivity gains increase. This is what Aghion and Howitt (1994) call the "capitalisation effect", whereby higher productivity gains lead to more profitable employment.[98]

Although this "rigidity" effect plays a part in the initial phase of slower productivity gains, Blanchard nonetheless shows – by regressing variations in the unemployment rate on the changes in productivity gains and other factors[99] – that the decreases in productivity gains in OECD countries between 1968 and 1980 are not reliable predictors of the growth in unemployment rates for all of the period.

ii) Creative destruction and problems of job matching

Aghion and Howitt (1994) also argue for a Schumpeterian view of the relationship between growth and employment, according to which high productivity gains are indicative of a rapid renewal of the economy's productive base. Job destruction is high in the least productive sectors, but the creation of new jobs in the more productive sectors is also high. A booming economy thus sees a higher job *separation* rate[100] and *turnover* rate than does an economy experiencing sluggish growth.

In a society where individuals are all-knowing and able to switch easily from one job to another, a higher job separation rate has no effect on the unemployment rate. But in a labour market constrained by poor levels of job matching, information or training (Pissarides & Mortenssen, 1994), the higher the separation rate, the higher the rate of unemployment. Productivity growth is thus associated with an increase in the unemployment rate. Lower productivity has the opposite effect: it reduces the equilibrium rate of unemployment.[101]

This view is supported by the findings of Davis and Haltiwanger (1992), who show that periods of high unemployment are also periods of high labour turnover. However, these results are not valid for all countries.

iii) Creative destruction and rigidities: which effect prevails?

For Aghion and Howitt, the negative impact of growth on the unemployment rate (linked to creative destruction and job matching issues) prevails up to a certain threshold, beyond which the rigidity effect prevails. The left hand side of the curve in Figure 3.9 is dominated by the creative destruction effect while the right hand side is dominated by the rigidity effect.

Flipping the analysis around to address our original question, in this scenario a slowdown in productivity gains could initially have a negative effect on employment: the rigidity effect would thus take over. Once past this threshold, a prolonged slowdown in productivity gains could instead lower the equilibrium rate of unemployment.

While this model opens up some interesting avenues of reflection that could bring a deeper insight into our question, its main weakness lies in the dearth of empirical tests for this kind of scenario. In fact, an analysis of the trend of average unemployment rates over five years and the average productivity growth rates over the same period shows no correlation between the two (Figure 3.10). In other words, the level of growth in the medium term does not appear to be linked with the rate of unemployment at a five-year horizon. Neither does there appear to be a long-run relationship.

In summary, over the short term, a decline in growth correlates with a rise in the unemployment rate – which is hardly surprising. However, Okun's Law says nothing about the directionality of the relationship between unemployment and growth – which remains a subject of lively debate. Thus, for a large swathe of the related literature, it is not so much growth that creates employment but employment that creates growth. And this is even more the case in the long term. The return to growth is seen as resulting from policies that successfully curb unemployment through better strategic positioning on world markets, improvements to the labour market, public-sector employment, etc. In other words, for these authors of very different persuasions, there is no need for short-term growth to create employment. The need is more for policies that boost… employment.

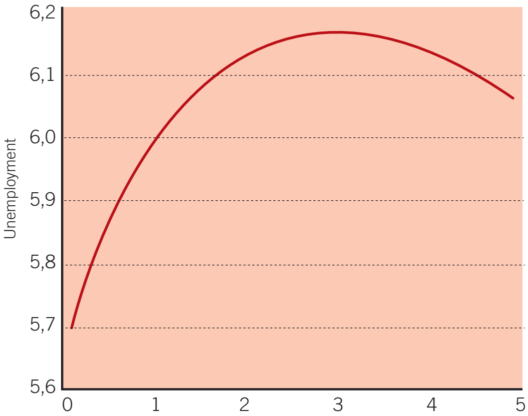
98. Aghion and Howitt's capitalisation effect is actually more complex but, in their model, the assumption used to explain the positive relationship between productivity growth and employment growth is that wages remain constant.

99. Such as the share of capital in aggregate income, cf. Blanchard, 1998.

100. The job separation rate is defined as the number of people that move from employment to unemployment divided by the number of employed.

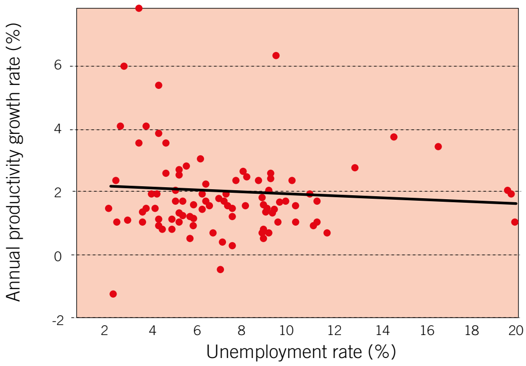
101. This result only holds true if technological changes and productivity gains *destroy* jobs while at the same time creating new ones. If there is no creative destruction, and instead employment is maintained, the unemployment level remains constant. This underlines the importance of the way in which productivity gains are recycled.

Figure 3.10. The matching effect *vs.* rigidities



Source: Aghion and Howitt (1994).

Figure 3.11. Link between unemployment and mid-term growth



Source: Cahuc *et al.* (2014).

Amongst the currently debated employment policies, work time reduction is foregrounded by some "degrowth" authors as the solution to a durable and intentional decrease in consumption, even if productivity continues to rise. The economic debate is intense between those who think that reduced work time creates jobs, those who think that it does not and those who think that this job creation is only possible if accompanied by a decrease in wages. Yet, there may be a consensus on the fact that reduced work time is necessary if consumers effectively begin to reduce their consumption "voluntarily": is reduced work time thus the pathway to degrowth rather than a tool for creating jobs in a no-growth situation?

3. GROWTH AND INCOME INEQUALITY

3.3.1. Income inequality and growth in the short term

Is weak growth compatible with reducing economic inequality? The past five years of recession with little or no growth have also been a period of rising income inequality in a large majority of European countries. Figure 3.11 illustrates the rise in market income inequality (i.e. income from labour and capital before redistribution) and disposable income inequality (household "take home" income) in OECD countries since the onset of the crisis.

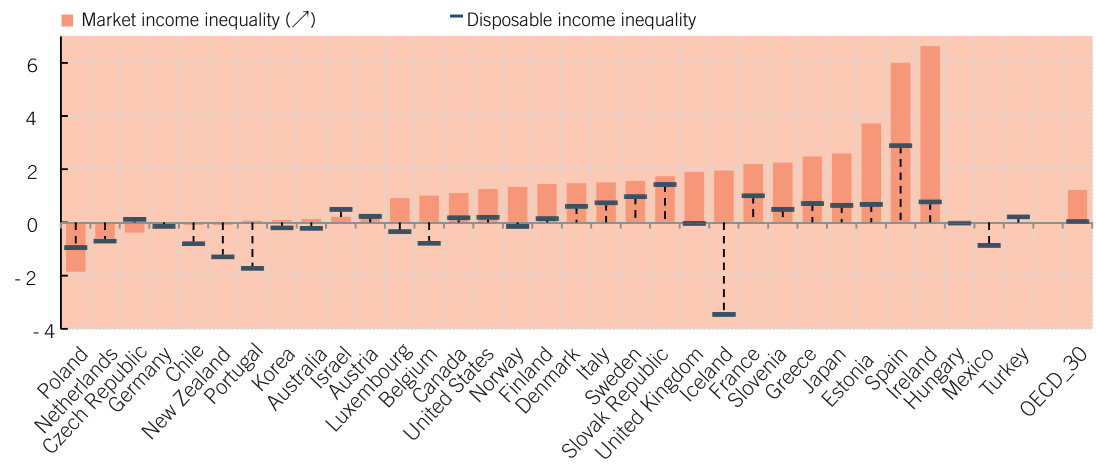
Market income inequality has increased in almost all Western countries. By and large, disposable income inequality has also increased, with a few exceptions (Iceland, Portugal and Belgium).

During the crisis, bank failures and declining economic activity caused a drop in income from labour and capital. Workers at the bottom of the social ladder were hit particularly hard by layoffs and saw their income decrease (both in absolute terms and proportionally) more than other household categories in which individuals are often more highly qualified, better integrated and thus less likely to lose their job. Moreover, the incomes of the wealthiest begin to recover more rapidly than the incomes of the poorest, with the rapid recovery of capital assets markets (OECD, 2012)

However, disposable income inequality rises less steeply than market income inequality. In fact, in crisis situations, governments put income support mechanisms (e.g. unemployment benefits) into action and create new redistributive tools through taxation or social transfer programmes, as in the case of Iceland or Portugal. Changes in economic inequality are indeed not determined by growth alone, but rather by an ensemble of social, economic and political factors.

In times of recession, market income inequality tends to increase. Yet, here again, we need a better understanding of the reasons for this "correlation". What exacerbates short-run income inequalities is not so much growth as unemployment and the level of social protection for the unemployed. There is no need to call on growth as the key to a reduction in inequality. To boot, periods of relatively sustained growth may well be associated with a sharp rise in inequality, as has been the case in the United States over the last twenty years. It is thus better to implement effective employment and redistribution policies to support the most vulnerable members of society. We saw earlier that one can to some extent separate growth and employment, but we will see below that separating growth and better social protection is no easy matter at policy level.

Figure 3.12. Rise in inequalities, 2007–2010



Note: The Y-axis shows % variation in GINI coefficient. The GINI coefficient measures inequality levels: a rise in the coefficient represents an increase in inequality. Source: OECD, 2013.)

3.3.2. Inequality and growth over the long term

Dynamics of capital accumulation and weak growth

How does inequality evolve during extended periods of sluggish growth? To answer this question, we need to look at the relationship between the fluctuations of returns to capital (i.e. interest, rents, dividends, etc.) and changes in earned income growth rates. In fact, household wealth is not determined by wages alone but also by assets, which grow over time when invested.

Whereas the growth rate of earned income is almost equal to economic growth over the long run, the rate of return to capital may differ significantly from the economic growth rate. When return to capital is higher than economic growth, capital holders increase their wealth more quickly than those who receive only the fruits of their labour, and so the inequality gap widens. It only takes a small difference between the growth rate and the return to capital, after several decades, to create significant disparities between rentier incomes and labour incomes. Conversely, when the economic growth rate is higher than the capital growth rate, labour income increases more quickly than rentier income, which thus narrows the inequality between wage earners and capital holders (Piketty, 2013). Logically, therefore, weak growth with an unchanging rate of return to capital widens the gap between capital and labour, and results in greater inequality.

Lessons from economic history

Before the take-off of economic growth described in Chapter 1, return to capital was historically around 4 to 5% a year and exceeded economic growth rates by as many percentage points. While capital accumulated year after year, labour income stagnated to the point that the Ancien Régime was characterised by huge inequalities between the nobility and the peasantry. When growth took off during the nineteenth century, the gap between return to capital and earned income narrowed. New professions emerged and became comparatively more profitable than rentier incomes. The inequality gap thus narrowed.

However, the main lesson to be learnt from history is that the dramatic twentieth-century decrease in income inequality relative to previous centuries is not a direct consequence of sustained growth. The mechanics described above were also impacted by various political, military and social factors. In fact, the reduction in inequality was primarily the result of the disaster brought on by two world wars, which also ruined rentier incomes by destroying factories and machines. Generous redistribution mechanisms, nationalisation policies, decolonisation and progressive taxation regimes established after the 1929 crisis and in the aftermath of the Second World War reinforced the trend that levelled out the distribution of wealth in European societies. The post-war golden age of growth helped to maintain a certain equilibrium.

Recent decades, characterised by lower growth rates and a lesser dependence on taxation and redistribution mechanisms, have seen the return of inequality in Western societies. In the USA, the inequality gap has widened even during periods of relatively high growth. Between 1993 and 2007, the American economy grew at an average rate of 3.4%. However, the majority of this increase was to the benefit of the wealthiest: the average income of the richest 1% grew by an average 10% per year, whereas the income of the poorest 99% increased by only 2% per year (Atkinson *et al*. 2009).

We have thus pointed up a strong economic trend: lower growth tends to increase income inequality between wage earners and rentiers. However, society has the appropriate tools (except during wartime) to react to this trend: taxation, social protection and legal means. These instruments are the result of intense political struggles, but globalisation is making their implementation more complicated, as capital is a great deal more mobile than the work force. Moreover, some authors are concerned about the negative impact that these redistributive instruments may have on the economy. But once again, there is no clear-cut answer to this question.

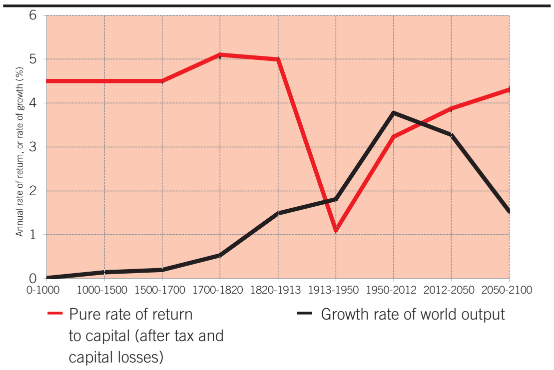
Effects of inequality on growth

In traditional economic thinking, inequality is often perceived as a sort of incentive and consequently a positive factor for economic activity. Inequality in companies is seen as conducive to improving worker productivity as it can act as a stimulus for employees eager to progress to a higher level of pay. A more equal distribution of income could, on the contrary, discourage workers from producing more (Mirrlees, 1971). Yet, studies into experimental and behavioural economics (Cohn *et al*., 2011) have shown that perceived unequal treatment may have a negative impact on company productivity[102] – over and above the detrimental social consequences that this inequality may induce.

Another line of reasoning, as Kaldor (1960) argued, holds that the better-off save and invest a greater share of their income. Consequently, a more unequal society would invest a greater share of its overall wealth and thus enjoy higher growth rates in the long term. But, as social reality shows, a ruling elite may not be inclined to fund public goods (education, health, safety, transports, etc.) as it already benefits from these services (Stiglitz, 2012). Any such lack of funding for public goods would weigh on both society as a whole and on future growth.

Empirically, there is no compelling macroeconomic study proving a temporally and spatially consistent causal link between redistribution policies and growth (Banerjee *et al*., 2003). Over the last fifty years, Western countries have followed different trajectories with respect to inequality, but by and large their growth rates have been similar

Figure 3.13. Growth and return to capital



Source: Piketty, 2013.

(Atkinson, 2013). The economic impact of redistribution thus depends on the tools used, the international context and the social compromise underlying their implementation. There is no systematic relationship between a reduction in inequality and growth.

In conclusion, we have seen that, in the very long term, weak growth tends to increase inequality between workers and rentiers. If growth remains weak while at the same returns to capital remain high, as has been the case in the past, then there is a strong trend towards greater economic inequality.

In a weak-growth society, the main focus should thus be on reducing inequality. Twentieth century history shows that the level of income inequality in society is determined above all by political, historical and social dynamics, as for example, progressive taxation. This is why reforming taxation systems (cf. Piketty *et al*. 2011) and coordinating them at the international level is all the more crucial in a world of weak growth in order to counter rising income inequality. In addition to taxation and "*ex-post*" redistribution, the democratic underpinnings of the corporate world are also a powerful factor for smoothing out wage inequalities, much like the practices of many co-operative organisations.

A final point to be remembered is that the question of inequality is not limited to income. Better access to public goods (education, culture, social protection) is another way of reducing inequality related to well-being. In the following section, we turn to the impacts of weak growth on the health sector, which is one example of a public good that can help to reduce inequality.

102. To cite the sadly well-known example of the tyre manufacturer Bridgestone, where new working conditions and a 30% drop in wages for new hires led to a number of manufacturing defects, which in turn caused hundreds of fatal accidents.

4. GROWTH AND SOCIAL PROTECTION

We define social protection as the public policy instruments that protect individuals against a range of individual risks (e.g. health, unemployment, housing) and provide them with retirement pensions. Social protection is the result of social and political struggles, but it has also been facilitated by economic growth given that, from a historical perspective of the economy, this has freed up an increasing share of income for spending on "higher" needs.[103]

Here, we focus on the two main components of social protection in most European countries, in terms not only of budget but also of citizens' concerns – namely, the pension system and the health system.[104] Over the last fifty years, the proportion of spending on health care and retirement has been increasing steadily in most developed countries. In the early 2010s, social protection expenditure accounted on average for 30% of GDP in the eurozone, compared with around 15% in the late 1950s. Looking ahead, the European Commission expects social protection spending to reach almost 35% of GDP by 2050 in eurozone countries.

These forecasts are obviously based on growth assumptions for the coming years. Broadly speaking, growth of one percentage point below standard forecasts[105] would mean social protection spending would take up 50% of GDP in 2050. What consequences would this level of social protection spending have on our economies? In fact, weak growth affects pension systems and health systems differently.

4.1. Weak growth and pension systems

A pension is a form of income paid out in the future – income that employees save during the course of their working life. This may be a collective type of saving scheme in which the pension is paid by the State via the social protection system. In this case, the State deducts contributions from the wages earned today so as to pay the pensions of yesterday's workers – this is referred to as the state pay-as-you-go pension system. Pension savings may equally be on an individual basis and a retiree's pension will then be paid by dividends from market-based funds. This is known as the privately managed, funded pension system.

In funded pension systems, the pension paid depends on capital market returns. If these are higher than the level of growth, then pensioners will see their pensions outstrip wage earners' incomes. If the returns are lower than growth, then earned income will grow faster. This system is thus not built on the principles of intergenerational solidarity. Moreover, funded pensions are particularly sensitive to economic crises that can quickly wipe out invested capital and severely slash pensions.

In the state pension system, the level of pensions depends primarily on the level of labour productivity (or average earned income), on the average rate of workers' contributions and on demographics (the ratio of the number of wage earners to the number of pensioners). This relationship is summarised by the equation for the "equilibrium" of the pension system:

Resources = Expenditure
Number of wage earners x Average earned income x Average rate of contribution = Average pension x Number of pensioners

In an economy where the ratio between wage earners and pensioners is stable, and where the average pension tracks the average salary (which, in turn, is supposedly index-linked to productivity), financial equilibrium is assured regardless of productivity gains. However, this only holds from a theoretical standpoint. In many European countries, pensions are not index-linked to productivity gains and the ratio between wage earners and pensioners is changing due to shifting demographics.

When the number of pensioners increases relative to wage earners (for example, due to the retirement of "baby-boomers" or rising unemployment), it then becomes necessary to leverage growth in earned income driven by productivity gains,[106] or step up contribution rates, or reduce pension levels relative to wages. An increase in productivity gains always seems to be the "easiest" solution – or hope – for governments to secure the financial equilibrium of their social protection systems – especially as this does not require difficult reforms.

In France, the equilibrium of the pension system is very sensitive to long-term forecasts of productivity growth. According to government estimates,

103. In the seventeenth century, a peasant was unable to set aside money for retirement or welfare because his income barely covered his subsistence needs.

104. Pensions and health care account for 80% of social protection expenditure in a country like France. The level of pensions and the quality of the health system count among the main preoccupations of European citizens: 15% of Europeans ranked social security and pensions as their two most pressing concerns, after rising prices and unemployment (EC, 2013).

105. That is, 0.7% growth instead of 1.7% (cf. Chancel *et al.*, 2013).

106. Or through a new capital-labour distribution to the benefit of labour.

a 0.3 percentage point drop in annual productivity growth, compared to the baseline scenario, would cause public pension expenditure to rise by 1 percentage point of GDP and the long-term public deficit would increase by 0.5% (Chancel *et al*., 2013). Moreover, a change in the unemployment rate would have a multiplier effect.

A fall-off in productivity gains thus needs to be offset by increasing the average contribution rate, which would mean either extending the effective contribution period or reducing retirees' pensions relative to the incomes of the economically active population. Another lever, of course, would be to reduce unemployment.

These options can be commingled or implemented separately, and each has its flaws: extending the contribution period needs to take into account the system's ability to factor in the arduous nature of some careers or the fact that, despite increasing life expectancy, healthy life expectancy has stagnated (or even fallen) in many industrialised countries (Jagger *et al*., 2008). An increase in contribution rates lowers wage earners' relative standard of living and drives up labour costs. Reducing pensioners' incomes relative to wage earners' incomes raises the issue of intergenerational equity.

4.2. Weak growth and health systems

The last fifty years have seen health care expenditure rise faster than income: in France, spending has risen by 7.3 percentage points of total GDP. There has been a similar trend in Germany, the UK, Switzerland, the USA and Japan (Figure 3.13).

Figure 3.14. Changes in total health expenditure as a share of GDP (1960–2006)

Pays	1960	2006	Variation
France	3,8	11,1	+7,3
Germany*	6	10,6	+4,6
United Kingdom	3,9	8,4	+4,5
Switzerland	4,9	11,3	+6,4
UNITED STATES	5,1	15,3	+10,2
Japan**	3	8,2	+5,2

Source: Dormont, 2009. Country – 1960 – 2006 – Change. France, Germany*, UK, Switzerland, USA, Japan** *Germany: 1970-2006. **Japan: 1960-2005

In France, if these trends in income growth and health sector spending were to continue along broadly the same lines, the latter would represent a quarter of the economy by 2050. If the economy were to grow by one point less, health care would represent ten percentage points more, that is to say, more than a third of total expenditure. In countries that have opted to manage a large part of their health sector collectively, especially for reasons of equity, the increased "burden" on GDP raises the question of how health care is to be financed in the long run. Is it advisable to have such high levels of health care spending? And is it possible to keep the accounts balanced at such levels?

To answer the first question, we must first look back at why health expenditures have increased over the last fifty years. The hike in health care spending is above all a result of medical progress, which benefits all age groups by providing better quality treatment; the main driver is thus not ageing-related expenditure, which would be "constrained" spending. Although higher spending in certain areas has not produced positive outcomes – for example, antidepressant treatment – it has generally yielded significant gains in terms of well-being and prolonging life. Some studies have however shown that healthy life expectancy has stagnated over the past ten years, despite the continued rise in spending (Jagger *et al.*, 2008). The debate over whether or not spending hikes are advisable is inconclusive, but there are clearly many new treatments still to be developed (Alzheimer's disease, cancer, etc.).

What can be done when health care spending outstrips growth in rest of the economy? Several options that are not mutually exclusive can be envisaged:

- The first involves raising the contribution rates. Historically, this is the option chosen by France: for the last thirty years, compulsory contribution rates have been increased to maintain a constant rate of reimbursement for treatment costs (roughly three-quarters of treatment costs are reimbursed).
- Another option is to gradually reduce reimbursement rates and pass the cost on to the private health insurance sector. While this solution may help to balance public health finances, it would mean transferring the burden of expenditure to individuals. This would have major implications for equity as the lowest income households would be disadvantaged.
- A third option is to improve the efficiency of the health system: provide the same service at a lower cost. The "soft" option would be to discourage treatment considered unnecessary.[107] In the "hard" version, the health system would be made more efficient by shifting from a curative to a preventive approach. This new approach

107. Currently, in France, some prescription drugs judged to be ineffective are continue to be reimbursed at a lower rate of 15% (but not 0%), and health insurance companies still cover even excessive overruns of medical fees to avoid losing customers.

Box 3.2.

Weak growth, inequality and the health system

One way of improving a country's health outcomes regardless of growth levels or its arrangements for funding its health system seems to be by reducing income inequality. For Wilkinson and Pickett (2009), in *rich countries,* the health system's performance is not related to levels of income or the GDP growth rate.

Conversely, the degree of income equality is strongly correlated to life expectancy, mental illness and obesity outcomes. One explanation for this is the fact that stress raises the likelihood such illnesses occurring. In addition, stress levels appear to be closely linked to the level of economic inequality. Interestingly enough, in unequal societies, the life expectancy of the wealthiest is lower than in more equal societies.

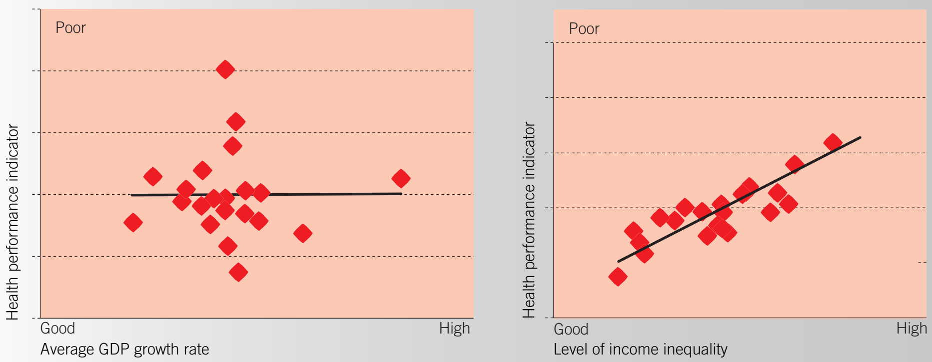
Figure 3.14 shows the links between average growth rates over the last forty years in the OECD countries and an index of health and social problems.[1] The higher the index value, the higher the extent of the problems. If we shift our focus to the link between health and overall national wealth rather than the average growth rate, this produces a scatter plot similar to the one in the left hand panel.

The indicator represents health outcomes in 2006. The higher the indicator value, the lower the health outcome.

For public policy in a post-growth economy, these findings herald both good news and bad news. Good news because the healthcare outcomes do not appear to be correlated with a country's level of growth,[2] but are strongly correlated to inequality. Bad news because we have shown that inequality tends to increase in a world of weak growth. But there are ways to limit the widening of the inequality gap.

1. This index includes life expectancy, infant mortality and obesity, among others (cf. Wilkinson *et al.*, 2009). For each of these dimensions taken individually, there is also a strong correlation with the level of a country's inequality and no relationship with income level or average growth rates in the recent or distant past.
2. Note however that none of the countries studied report an average annual growth rate of income per head lower than 0.9%.

Figure 3.15. Health, growth and inequality



Source: equalitytrust.co.uk and TED (2013). Formatted by the authors. Note: Each red diamond-shape represents an OECD member country.

would involve the medical community (preventive medicine) as well as measures to combat stress and physical strain at work, reduce exposure to toxic substances, promote a balanced diet, etc. It is extremely difficult to assess *ex ante* the impact of such changes.

To sum up, weak growth makes social protection reforms all the more necessary and all the more difficult. State pension systems, which in many countries are facing demographic shocks such as an ageing population, need growth or reform to secure their funding: increase social contributions, lower retirement pensions relative to wages, extend working lives. Public health systems, like private health systems, are expanding, which means that weak growth imposes a rise in compulsory contributions in relation to GDP, or different levels of reform (e.g. a transition from curative to preventive medicine or reducing stress upstream by narrowing the inequality gap).

Weak growth also makes reforms more complicated. It is easier to accept a decrease in pensions *relative to* wages when pension increases remain substantial. Or to pay higher taxes to finance public services such as health when one can also consume an increasing amount of other goods and services. Weak growth is a cake that is getting bigger less quickly than before, which makes it all the more difficult to change how it is shared out. How much should each receive, how much should go to the consumption of smart pads, leisure or health?[108]

Weak growth makes social protection reforms all the more necessary and all the more difficult: less growth demands more policy. Should we be looking for the reason why many governments find it hard to gain acceptance for income tax increases or reforms to their social protection systems in the current weak-growth environment? Perhaps. Can we change how we share out a cake that is growing less? How can we make this change easier in spite of weak growth? There are a few options on the table: a more transparent and more progressive tax system and higher quality collective services, implemented through an ongoing reform or adaptation process to ensure that the contributions and their utilisation are perceived as legitimate. Unfortunately, in many countries, citizens seem to be increasingly disenchanted with their tax regimes and collective services. Weaker growth exacerbates these tensions.

108. This holds true for the private social protection systems, except that instead of managing this "schizophrenia" collectively, it is managed individually. Today, everyone has to choose between their income and their pension, between leisure and health. In the state systems, this schizophrenia is "managed" collectively… notably through the tax debate.

5. CONCLUSION TO THE THIRD CHAPTER

Can we "build a cohesive society" in a world of weak growth? In this chapter, we considered whether the growth-oriented focus of political discourse – where growth is presented as the solution to economic and social problems, in the short and long term alike, to the right and left of the political chessboard – is based on a myth or on mechanisms evidenced by the social sciences. The question we need to ask ourselves is whether a society evolving in a low-growth context is condemned to backslide economically and socially… or not.

To do so, we review the literature and the linkages between growth and four public policy objectives: self-reported well-being, employment, reduced income inequality and social protection. If unemployment, social protection and economic inequality regularly head the list of priorities for public action in opinion polls, we note that this is an open-ended list that can be expanded in line with the priorities of each and thus calls for further research.

This chapter has shown that above a certain level of national wealth, *already exceeded in the European Union countries*, growth does not determine the level of happiness. In fact, over the long run, this depends more on the level of inequality than on income. In the short run, on the other hand, the evolution of GDP growth is linked to the evolution of unemployment, and through this to variations in self-declared happiness.

We now come to unemployment: is growth necessary to create employment? In the short term the two are linked, but the directionality of this relationship is a matter of controversy: it is difficult to know which comes first, the "chicken of employment" or the "egg of growth". For economists of different persuasions, it is employment policy in the broad sense (support for demand in crisis periods, positioning on international markets, labour market reform, public-sector jobs, reduced work time, etc.) that stimulates growth rather than the reverse. While the transition towards a weaker growth regime could drive up unemployment for a time, this effect is disputed and, over the long run, no link is observed between the growth rate and unemployment rate.

Some "degrowthers" on the other hand underline that an intentional decrease in consumption and thus in growth, while productivity is increasing, calls for a reduction in work time in order to avoid a burst of unemployment. This reduction goes hand in hand with a drop in income. Nonetheless, reduced work time appears to be more a means of carrying out this *intentional* decrease than a response to the problem of unemployment.

Our review of the literature reveals the absence of a causal link between growth on the one hand

and happiness and employment on the other. Growth is not necessary to achieve these objectives. They can and must be treated as such by effective employment policies or the reduction of inequality. However, the links between growth, long-run inequality or social protection are much more tenuous.

As for inequality, weak growth tends to increase inequality between wage earners and rentiers in the long term, and yet inequality appears to be a key determinant of self-reported happiness as well as the effectiveness of health care systems. In area of social protection, weak growth implies the need for more reforms and more trade-offs – which are also more difficult to implement – in order to guarantee a certain level of health care or pension. However, whether the objective is to reduce inequality or secure social protection, weak growth does not prevent these objectives from being achieved: on the other hand, it does make achieving them more difficult at policy level.

We have thus shown that the links between growth and prosperity are much weaker than generally imagined. This is good news for public actors, who have been struggling to return to growth for several decades now. Other tools, such as inequality reduction measures or employment policies, now need to take over from the "growth objective" in political discourse and–it is perhaps already the case–in the practical implementation of public policy. We don't need to wait until growth arrives to attain prosperity, we just have to work at making prosperity happen.

We have, however, also shown that weaker growth complicates the task of reducing inequality, and this change is essential to self-reported happiness and effective healthcare systems. A low-growth society must thus redouble its efforts to redistribute wealth or improve access to essential services such as education, health and pensions. Likewise, weak growth reinforces the need to reform social protection systems in order to secure their funding.

Unfortunately, a weak-growth environment puts a powerful brake on policy, whether the goal is to reduce inequalities or reform the social protection system. Since the cake is not growing as fast as it used to, it is more difficult to modify the distribution of wealth between wage earners and rentiers, active and inactive workers, or to choose – individually and collectively – for example, between health services (and thus taxes in the case of public health systems) or plasma screens… A weaker growth regime requires more trade-offs and, ultimately, more policy action.

In a nutshell, our analysis shows it is not so much a society's economic growth that matters for prosperity, but rather the economic and social regime that creates more or less prosperity. The level and growth rate of GDP are simply the outcome of this "regime". This conclusion may appear trivial to some, but it is nonetheless fundamental. Many political discourses make a "detour" *via* GDP growth to reach the destination of prosperity, but in many respects this seems pointless and–after decades of weak growth–outdated.

CONCLUSION

The report, "A post-growth society for the 21st century", deals with two questions. Is there a future for economic growth in the developed world? And can a society prosper in a context of weak or stagnant growth? To answer these questions, we have studied the economic literature, organised seminars bringing together practitioners, policy makers and experts[109] and carried out a modelling exercise to investigate the links between the energy-climate nexus and the economy.

1. IS THERE A FUTURE FOR ECONOMIC GROWTH IN THE DEVELOPED WORLD?

Growth rates exceeding 1% a year are a recent phenomenon in the history of humanity and those seen in Europe during several decades following World War II are something of an exception. Growth is the result of complex mechanisms that can be linked up with factors such as the composition of the economy (tertiarisation), the diffusion of new technologies with a strong transformative potential, energy and the social compromise. However, economists are clearly quite unable to establish robust forecasts covering several decades.

For the last forty years, economic growth has been on the decline in the rich countries, and a weak-growth environment could well persist or even worsen. In fact, it is not inconceivable that today's new technologies turn out to be less "radical" than those that propelled the industrial revolution, or that the tertiarisation of the economy underway in industrial countries is durably slowing down productivity gains, particularly in those countries that have opted for development models based on education, healthcare, caring for the elderly and, more generally, on "personal" services.

On top of this, there is the challenge of growing energy resource scarcity and reductions in global greenhouse gas emissions. Here too, we find a great deal of controversy. While some consider economic degrowth to be inevitable, others believe that these environmental challenges present a tremendous opportunity to return to growth, start a new industrial revolution. As we have seen, the current state of natural resources is sometimes worrisome. Yet, to understand the possible macroeconomic impact of energy resource scarcity or emissions reduction, it is necessary to call on an economy-energy-climate model such as the CIRED model that we use. Our findings show that, while the most pessimistic scenarios are confirmed (for energy resources, trends in the cost of low-carbon technologies and lifestyles), the macroeconomic impact may be several tenths of a percentage point of annual growth or even stronger during the transition period spanning the next twenty years. Moreover, if growth is already weak, this represents a substantial drop. It should be noted that the modelling exercise presented in this study does not take into account the economic impact of environmental policies going beyond the "climate-energy" dimension, such as biodiversity protection.

There is thus "radical" uncertainty about the future of economic growth. Our future policy choices and the technologies that we may invent in the coming years are uncertain. This opens up a large range of possible economic pathways with an equivalent number of growth outcomes. And the eventuality of low growth rates, floundering around 1%, stagnation or worse, is not to be excluded.

109. The findings of this report are in part the result of the "Growth and Prosperity" seminars organised by Iddri, in partnership with the OFCE, CIRED, the Nicolas Hulot Foundation and the Institute Veblen.

2. CAN WE PROSPER WITHOUT GROWTH?

In political discourses, growth and prosperity are often synonymous. Yet, it would appear from this report that adapting to very low growth rates does not mean abandoning the objectives pursued by public authorities to reduce inequalities in wealth, secure social protection and improve life satisfaction.

The links between growth and prosperity are much weaker than is generally supposed. There is, in fact, no correlation between happiness and long-term growth in the richest countries, any more than between employment and long-term growth. Employment and growth appear to be strongly correlated in the short term, but many economists contend that it is not so much growth that drives employment as employment that helps restore growth: no need for growth in order to create employment, but rather a tautological need for "employment policies" (labour market, industrial strategy, wage policy, public-sector employment, etc.). Likewise, although happiness and growth are strongly correlated in the short term, this is primarily due to employment: what people need to feel happy is not so much growth as jobs. In the political discourse, the detour *via* growth is very often unnecessary.[110]

On the other hand, the links between growth, long-term inequality and social protection are much more tenuous. Weaker growth deepens income inequality over the long term, and yet greater equality seems to be crucial for self-reported happiness and the effectiveness of health care systems. A low-growth society thus needs to redouble its efforts as far as redistribution is concerned.

Similarly, we observe that weak growth complicates decisions about the trade-offs required to secure the financing of the state pension systems: without growth, there is all the more reason to step up contributions and/or work longer and/or decrease pensions *relatively*. The same holds for the health sector: with a rising demand for health care in a low-growth context, the need arises to increase contributions and/or cut expenditures and/or radically reform the system. Ultimately, without a "bubble of oxygen" from growth, we need more reforms, more political action.

Unfortunately, a weak-growth context puts a powerful brake on policy, whether the policy goal is to reduce inequalities or reform the social protection system. Since the pie is not growing as fast as it used to, it is intuitively more difficult to modify the distribution of wealth between workers and rentiers, active and inactive workers, or arbitrate collectively between public and private health services. A weaker growth regime thus imposes more arbitration and renders them even more politically sensitive.

By way of conclusion, we give a brief reminder of what has been outlined above. The analysis shows that it is not so much society's economic growth that matters, but rather the individual and collective choices that we make: whether or not to adopt a development model based on "personal" services, whether or not to reach our climate objectives. These choices will lead to different levels of prosperity and economic growth. The level and growth rate of GDP are above all the outcome of our choice of development paths – they are not what determines the prosperity of the industrialised countries. This conclusion may appear trivial to some, but it is nonetheless fundamental. Many political discourses make a "detour" *via* GDP growth to reach the destination of prosperity but in many respects this seems pointless and – after decades of sluggish growth – outdated.

It is now time for policy makers to take a fresh look at growth, accept the radical uncertainty surrounding its future and construct, first of all, a positive narrative for the future that bears no reference to growth and, then, a society that is able to concretely free itself of the shackles of growth: a post-growth society. We hope that this report has given policy makers some food for thought so that they can make themselves heard once again by the generations born after the post-war boom. We also hope that we have been able to encourage researchers to deepen the questions that have been left open: post-growth macroeconomics still remains to be built.

110. This detour is made in the discourses, but is it made in reality?

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