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Economic Challenges in the Anthropocene

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Abstract

The evolution during the Anthropocene is analyzed through the interaction between economic and technological development, characterized by the role of fossil fuels and by the progressive dominance of those with a higher energy and density power. The challenge is how to make the rising demand for economic growth, mainly coming from developing and emerging countries, compatible with the sustainability of the processes concerning the Earth system. Mainly by focusing on the energy-environment challenge, it is claimed that the required technological breakthrough will not be possible without an appropriate combination of environmental and innovation policies. The big size of the needed investments in a context of limited financial resources asks for a strong support and definition of precise priorities by the governments. A strong help will come from a cultural change able to determine a more sustainable demand for goods and services and a new system of social norms.

JEL-Code: O100, O300, Q400, Q500.

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Anthropocene and its stages

In 2002 the Nobel laureate Paul Crutzen (2002) proposed the term Anthropocene to define a new geological epoch and a new era in the Earth history, began almost two hundred and fifty years ago, and characterized by an unprecedented influence of human action on the rest of nature.

According to Crutzen, the Anthropocene started in the latter part of the eighteenth century, when analyses of the air trapped in polar ice started to show growing concentrations of carbon dioxide and methane.

With the Anthropocene the Earth system has left the interglacial state, the Holocene, began between 12,000 and 10,000 years ago, in which a big change in the human-environment relationship has been represented by the so-called Neolithic Revolution, characterized by the advent of the agriculture.

From the economic point of view, the beginning of the Anthropecene coincides with the industrial era. Classical economists as Adam Smith found in the interaction between the market and the division of labor the main factor behind the development of the industrial era. Another fundamental factor has been ignored by economic analysis: the energy bottleneck in the last pre-industrial period which was removed by the diffusion of fossil fuels.

In pre-industrial human societies the environment was affected by economic activity through hunting, gathering and, later on, agriculture. Labor was the primary energy source; its power was later increased by animals, water and wood. Energy was limited by the land available for crops and forage. Water and wind power were available only in certain locations. Market were predominantly local and trade was limited. Self-sufficiency and local independence in food supplies played an important role: cities were small. Craftwork characterized human manufacturing activity.

This framework could change in the industrial era due to the new sources of energy represented by fossil fuels. They were offering access to carbon stored from millions of years of photosynthesis, and supported the Industrial Revolution allowing new technologies such as iron and steel production, and later railways and land transport. Industrial societies use four or five times as much energy as did agrarian societies, which in turn used three or four times as much energy as did hunting and gathering societies (Steffen and al., 2007).

Two important examples of how scientific and technological progress allowed fossil fuels to remove the energy bottleneck are the invention of the steam engine by James Watt in the 1780s and the ammonia synthesis from atmospheric nitrogen pioneered by Fritz Haber (the Haber-Bosch synthesis) in the early 20th century.

Energy transitions during Anthropocene have been characterized by the passage from biomass (old green power, typical of Holocene) to coal, and then from coal to liquid fuels (oil and natural gas). Energy transitions have been to higher density power sources (energy per m2) which provided new economic benefits because of industrialization diffusion and urbanization (Scott Taylor, Moreno Cruz, 2012).

According to Steffen and others (2011), three stages have characterized the evolution of the Anthropocene. The first stage goes from the industrial revolution to the Second World War; the second stage has been defined as the "Great Acceleration" and goes from the end of Second World War to the end of twentieth century; the third stage is the present one, with an ineludible challenge to mankind for the sustainability of the Earth system.

From 1800 to 1950 world population tripled from 1 to 3 billion; from 1950 to 2000 it doubled from 3 to 6 billion. In 2050 more than 50% of the world population will live in urban areas. Urban size will grow. Today more than 20 cities have more than 10 million inhabitants and almost 500 have more than one million; the number of both is expected to increase.

From 1950 to 2000 world total real GDP increased from 7 to 35 trillion 1990 US dollar (a multiplier of 5). Motor vehicles grew from 40 million in 1945 to almost one billion now. In China car sales are now higher than in US.

The global-scale transformation of the environment has been particularly evident in the atmosphere. The range of Holocene variability of CO2 concentration was between 260 and 285 ppm. In 1750 it was 277 ppm. ; in 1850 it moved to 285 ppm; in 1950 it jumped to 311 ppm.; in 2000 to 369 ppm. , arriving to 395 ppm. in 2011 (Steffen and al., 2007, 2011).

Anthropocene, technological change and economic growth.

The most important characterizing factor of the industrial era has been economic growth. Angus Maddison (2007) estimates that world GDP per capita (measured in 1990 USD) was only $450 in year 1000. In 1820 it arrived at $667 with an increase of 50% in eight hundred years. World GDP per capita (in 1990 USD) arrived at $2,113 in 1950 and to $6,516 in 2003, ten times the level at the beginning of the industrial era.

According to the traditional economic theory, growth in GDP derives from physical capital (that increases through investment), labor (that increases because of population growth and greater labor force participation), productivity growth (due to technical change).

More recently, economic theory has emphasized the role of human capital, i.e. the degree of labor's skillness, improved through investment in education. Productivity growth has been related to investment in R&D, learning by doing and economies of scale. A better health, and hence investment in the health system, also has a role in improving labor productivity.

Focusing on the relation between economic growth and technological progress leads to identifying three technological revolutions in the Anthorpocene considered as the era of energy based on fossil fuels (Smil, 2010; Gordon, 2012).

The first technological revolution was the Industrial Revolution (1750-1830). Coal replaced wood as main energy source. Steam engines and cotton spinning were invented. The high energy density of coal facilitated its use in transportation. Communications improved through early railroad and steamships.

The second technology revolution lasted almost one century (from 1870 to the late 1960s). It can be divided in two phases. The first phase went from 1870 to the First World War. Oil and gas replaced coal and wood. Power density strongly increased, favoring large plants, large grids and market power in energy production. This phase was characterized by great radical innovations: electricity; internal combustion engines; chemistry and chemical engineering; running water, central household heating; telephone, telegraph, radio. They set the roots for the technological transformations of the second phase.

The second phase went from the end of the First World War to the 1960s. It was characterized by incremental innovations based upon the first phase radical innovations: road means of transport, durable consumption goods, electronic computers, new systems of communication and entertainment (motion pictures,TV).

In the 1970s the benefits of the second technological revolution faded (the US were characterized by a period known as “productivity slowdown”). Energy crises started, characterized by sudden huge increases in oil price. Higher oil and fossil fuels prices provided an incentive to developing alternative forms of energy. Nuclear power increased its contribution to energy supply; renewable energies, particularly wind and solar technologies, started to receive governmental support (Newell, 2009).

In this framework the third technological revolution developed, based upon Information and Communication Technologies (ICTs); it reached its maximum expansion in 1990s. This has also been the period of economic globalization, with many examples of technological «leapfrogging» in emerging economies. Incremental innovations developed in communication and entertainment (Ipod, smart phones, tablets, Ipad).

In 2001the ICTs bubble started bursting; this was also the year of the “twin towers” terrorist attack. Growth continued to be supported, particularly in US, through an expansion of private debt: this produced housing and financial bubbles; with their bursting, the financial crisis exploded which rapidly became a global economic crisis, still impairing future growth perspectives.

In the years immediately before the global economic crisis, oil and natural gas prices raised sharply because of the expanding global demand. Governments and the private sector responded with increased investments in the energy-related sectors. But later the fall in global demand brought by the global crisis also led to a fall in energy prices. The effort of linking governments' recovery program to renew the energy system was clearly inadequate. Problems of government budget and debt, and of credit crunch, reduced the incentives to government and private investments in energy and environment.

The result is that the present heritage of the technological development in the past 250 years is a world with serious problems concerning economic growth, but also with serious problems concerning the impact of humans on the Earth system.

Economic growth and its limits.

We are now in what Steffen e al. (2011) has called the third stage of the Anthropocene, characterized by a growing awareness of human impact on the Earth system, particularly through the energy-environment issue, in which a commitment is needed to build systems of global governance because of the globalization of the problems, and in which special care should be given to the relation between economic growth and the human impact on the Earth system.

Worldwide economic growth has brought great benefits which have resulted in improved living standards and substantial reduction in poverty. However, inequality has substantially increased in recent decades not only in emerging countries, but also in US and most of Europe. Moreover, the experience of the last 250 years shows a negative impact of economic growth on the environment, particularly in the first stages of the take-off process.

Some scholars claim that prosperity should not be identified with economic growth (Jackson, 2010). De-growth supporters claim that economic growth should be reduced to maintain environmental sustainability. According to Herman Daly (Daly, 1996), the economy should aim at a "steady state" keeping constant the flow of "throughput" (the lowest feasible flows of matter and energy from the first stage of production to the last stage of consumption).

These positions have been recently reinforced by the conclusions of Rockstroem and other scientists (2009) that human activity is going beyond a safe operating space, identified with nine "planetary boundaries". Planetary boundaries are threshold levels that, once crossed, may create potentially disastrous consequences for important sub-systems of the Earth system. The nine identified planetary boundaries are: climate change; rate of biodiversity loss; interference with the nitrogen and phosphorous cycles; stratospheric ozone depletion; ocean acidification; global freshwater use; change in land use; chemical pollution; atmospheric aerosol loading. According to Rockstroem and others (2009) three Earth system processes (climate change, rate of biodiversity loss, interference with the nitrogen cycle) have already crossed their boundaries.

At the world level economic growth cannot be growth of matter: this would conflict with the first law of thermodynamics. Economic activity cannot make matter growing, it can only transform it: to be sustainable this process of transformation must maximize recycling potential and minimize entropy (energy losses). Hence economic growth does not refer to an increase in matter, but is measured by an increase in values of the output of the transformation process; moreover, an increasing share in this output is represented not by material goods, but by services and immaterial goods. If the process of transformation in the economic system develops according to sustainability requirements, there is no reason to exclude that economic activity as real value of produced output can grow over time.

Some scholars argue that beyond a certain threshold of the average income per capita, further economic growth does not give rise to greater well-being because its social costs overcome its social benefits. However, this argument does not hold for the majority of developing countries whose average income per capita is much lower than that threshold. Between one and two billions people still do not have access to electricity, clean water and sanitation. These dramatic problems cannot be solved without economic growth.

However, the demand for economic growth at a global level, particularly by developing countries, will imply additional relevant pressures on the environment. Fulfilling the worldwide increasing demand for economic growth by using the same growth model experienced in the past 250 years in the now mature economies would lead to unsustainable outcomes.

The need to combine economic growth with preserving a clean and safe environment has led to the concept of “green growth”.

Is green growth a feasible perspective for the third stage of the Anthropocene?

Many claim that “greening” economic growth may make it compatible with the challenges of the third stage of the Anthropocene. The idea of “green growth” is an operational way of specifying the wider objective of “sustainable development” made popular in the late Eighties by the well-known Brundtland Report, by concentrating on the economic dimension.

“Green growth” recently found a relevant place in official statements of international institutions dealing with sustainable development issues, mainly World Bank and OECD. According to the World Bank (2012), green growth is a model of economic growth efficient in the use of natural resources, clean in that it minimizes pollution and environmental impacts, resilient in that it accounts for natural hazards and the role of environmental management and natural capital in preventing physical disasters. In the World Bank's vision, inclusive green growth aims at operationalize sustainable development by reconciling developing countries' need for growth and poverty alleviation with the need of avoiding irreversible and costly environmental damage.

According to OECD (2011) green growth means fostering economic growth and development, while ensuring that natural assets continue to provide the resources and environmental services on which our well-being relies.

UNEP (2011) focuses on the wider concept of "green economy" as one that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities.

According to the traditional economic theory, growth in GDP derives from physical capital (that increases through investment), labor (that increases because of population growth and greater labor force participation), productivity growth (due to technical change).

More recent growth theory has emphasized the role of human capital, i.e. the degree of labor's skillness improved through investment in education. Productivity growth has been related to investment in R&D, learning by doing and economies of scale. A better health (hence investment in the health system) also has a role in improving labor productivity.

Growth theory has largely ignored that environment, as natural capital, can be an important factor of production, contributing to economic growth (S.Smulders and C.Withagen, 2012). Protecting the natural capital is important to maintain and increase economic production, because natural capital is required to sustain human life.

To preserve the stock of natural capital the absolute flow of ecological resource use should be kept within the regeneration capacity of the biogeochemical natural cycles. This requires that the intensity of ecological resource use per unit of GDP declines over time, at a rate higher than, or at most equal to, the rate of positive growth of GDP. This is what is defined as "decoupling" economic growth from its pressure on natural resources.

The pressure of economic activity on the environment depends on the scale of the economic activity, on the composition of economic structure (which depends on the evolution of the structure of final demand), and on the dynamics of sector coefficients of environmental impact per unit of output (which depends on sector technical progress).

Economic growth makes the scale of the economic activity larger and larger. This "scale effect" would have negative effects on the environmental sustainability of the growth path. However, the scale effect can be compensated, or more than compensated, by an evolution of the structure of final demand towards less environment intensive goods and by a prevailing role of the sectors in which declining coefficients of environmental impact per unit of output take place.

As a matter of fact, the interaction between the various factors necessary to achieve "decoupling" is so complex that there is no automatic guarantee that it will effectively take place.

The historical experience teaches that in the initial stages of development the scale effect dominates (as population and output per capita both grow), that there is a negative composition effect (because of the increasing weight of polluting industries), that a weak environmental regulation prevails (as growth is preferred to environmental preservations). Hence economic growth and environmental quality are inversely related in the initial stages of development.

In mature economies, on the other hand, rates of growth usually do not persist as very high, which reduces the scale effect; the weight of less polluting sectors (services, immaterial productions) increases; the technique effect starts acting in a positive way. With an increasing income per capita, people's environmental awareness increases: this produces a more effective environmental regulation.

Hence in advanced economies there exists a possible positive relation between growth and environment. As a matter of fact, local air or water quality indicators seem to show a positive relation with income per capita, but no evidence of such a relation exists for global pollutants (CO_2) and for hazardous wastes and toxic chemicals.

Evidence from high-income countries also does not support the idea of "grow now, clean-up later": cleaning-up later may become too costly. It is more efficient to prevent pollution at early stages of growth than to incur higher clean-up costs at later stages, crowding out other types of expenditures which may be more socially useful. Future clean-up costs may become very high because existing technologies and infrastructures "lock in" high-carbon and polluting economic outcomes (World Bank, 2012).

<u>Environmental policies for a green growth</u>.

The negative effects of economic growth on the environment depend on the fact that the market does not provide the right incentives to economic agents to take an environment friendly behavior.

When profit maximizing firms release untreated pollutants in the environment, there are social costs in terms of environmental damages (such as health damages or in terms of reduced environmental services), unaccounted by the market: they are negative environmental externalities which make net social benefits of production lower than private profits.

On the other hand, environmental assets have a public good nature: they provide non rival and non excludable services. Their services are non rival because one person's enjoyment of the environmental service does not prevent other persons from enjoying the same service. They are non excludable because there is no way to exclude somebody from enjoying an environmental service.

Non rivalry and non excludability of the flow of services provided by the stock of environmental resources are the reason why individuals do not have incentives to contribute to providing environmental quality: they can enjoy it even if others, and not themselves, contribute; moreover, those who contribute do not appropriate all the benefits from their contribution.

Improving environmental quality is the opposite task than reducing negative environmental externalities. Therefore the market mechanism leads to excessive negative environmental externalities and to under-provision of environmental quality as a public good. Environmental policy must to provide the incentives needed to correct negative environmental externalities and underproduction of environmental quality.

Economic instruments of environmental policy may be price and quantity instruments. Price instruments aim at ensuring that prices paid for goods and services reflect full social costs, including negative environmental externalities.

A typical price instrument is an environmental tax. Firms paying a tax on pollution incur in higher cost to produce polluting goods and they are discouraged from producing them. On the other hand, the price of polluting goods on the market will be higher because of the higher production costs (including environmental taxes). Consumers will be discouraged from buying polluting goods by their higher prices.

Hence the effect of environmental taxes will be to discourage both production and consumption of polluting goods. How much effective this will be on the level of pollution depends on the elasticity of consumers' demand with respect to prices. If consumers are reluctant to react to a higher price with a lower consumption (their demand is very rigid), a very high price increase of the polluting good is necessary to reduce pollution. This is typically the case of gasoline.

Environmental taxes produce revenues to the government. These revenues can be used in various ways. One way is to compensate those that are more heavily hit by the taxes, i.e. the poorer segments of society. Another way is to support environmental innovations, which can be done directly, by greening public expenditure; or indirectly, by financing firms' research efforts. The two ways of using revenues from environmental taxes (redistribution and support to innovation) are in conflict. Solving this conflict is up to political decisions.

One problem with using environmental taxation is that it is very difficult to evaluate environmental costs on which they are based. Information may be very difficult to acquire; this is a source of errors in determining the right level of environmental taxes. Moreover, often there are “threshold” levels in the amount of pollution in a given area: this requires that an “ambient” pollution standard is defined.

The problem then arises of how to achieve that standard without a waste of resources; which is obtained by minimizing the cost to achieve it. This result in turn requires that the polluting sources with lower (marginal) abatement cost should abate more, while those with higher (marginal) abatement cost should abate less.

This outcome can be achieved by using a market for tradable emission permits (also called “cap and trade” systems): a cap is fixed by the regulator on the aggregate quantity of emissions; emission permits (whose sum is equal to the “cap”) can be exchanged across firms. Firms with high marginal abatement costs will prefer to purchase pollution permits from firms with low marginal abatement costs. The first would save abatement costs; the second would get a net gain from selling permits.

The market for pollution permits will provide a pollution price as does an environmental tax. This should not surprise as quantity constraints always imply a price. However, the equivalence between tradable permits and environmental taxes depend on the way permits are initially allocated. They can be allocated for free (grandfathering) or they can be sold through an auction. Only when they are auctioned, they fully correspond to environmental taxes, because they give some revenue to the government.

One problem with environmental policies is that there may be short run trade-offs between them and economic production. Expenditures to abate pollution may affect negatively production in the short run. A negative effect can derive from early retirement of physical capital embodying old polluting technologies. Consumers may react negatively to higher prices of polluting goods (e.g. gasoline)

These short run trade-offs are one of the main reasons why it is difficult to implement environmental policies. Policies may be organized in a way that makes them more acceptable. A lot of care must be given to the way information is provided. Disclosure of information about firms’ environmental performance and regulatory violations can support environmental policy, as firms are more likely to react to the “watchdog” pressure of public opinion.

It is also important that environmental policies are considered as a part of a larger social goal. By framing environmental protection as a social project, policy makers can help individuals in thinking in terms of social and collective goals.

A change in the social norms of behavior is required to shift the consumption model and the structure of final demand in an environment friendly direction. These social norms cannot be imposed through a paternalistic approach. They should be the result a cultural change freely accepted by the large majority of the persons in a society.

Some claim that this change of behavior should imply the adoption of a model of lower consumption and more frugality. But more than reducing the quantitative level of consumption, the issue at stake is that of changing the quality and the nature of the consumption model.

Innovation policies for a green growth.

Pricing environmental externalities is likely to lead firms to adopt more environment friendly *existing* technologies in their production processes and to produce cleaner goods.

For this to happen, environmental regulation should be consistent and persistent over time: this will convince firms to use more environment friendly *existing* technologies in order to avoid the higher expected costs of future, possibly stricter, regulation.

Environmental innovation can also be promoted through the demand-side of environmental policy. The public sector is one of the largest consumers and therefore a key source of demand for firms. Hence an innovation-oriented government expenditure and public procurement rules help fostering markets for green products and services and promoting green innovation.

However this is likely not sufficient to promote *new* technologies: to achieve this target environmental policy should be accompanied by an explicit “green innovation” policy (Jaffe, Newell and Popp, 2010; Popp, 2012).

An innovation policy is in general justified by a market failure deriving from the public good nature of new knowledge. A firm that invests in research and is successful in implementing a new technology creates benefits for others who do not bear any cost. This gives firms less incentives to invest in research and new technologies. An additional reason for firms not investing enough in research is the uncertainty associated with the returns to investment in innovation.

Uncertainty proves particularly relevant for environmental innovations whose profitability may turn out to be very risky because of the uncertainty concerning the existence of a demand large enough to absorb them. This is particularly the case for radical innovations shifting the technological regime, which are fundamental in achieving absolute decoupling of environmental impacts from economic growth, by transforming entire economic sub-systems like the energy system and the transport system.

A green innovation policy is therefore necessary. The prevailing opinion from both theoretical and empirical studies is that environmental and green innovation policies work best together. Using only environmental policy is likely to lead to excessive reduction in current production and consumption (also because of adjustment lags), and to inadequate dealing with the research externalities. Environmental policy tools should be accompanied by additional instruments (R&D subsidies or profit tax on the dirty sectors) able to direct innovation towards clean technologies to increase future production. Environmental and technology policies can also be combined by using revenues from the first (from environmental taxes or auctioned permits) to promote environment oriented innovations.

Is the world ready for a new green technological revolution?

Green economic growth is implemented through some kind of technological breakthrough. The main question that the mankind faces in third stage of the Anthropocene is whether this technological breakthrough is a realistic perspective.

The model of economic growth based upon fossil fuels has documented risks of being unsustainable. What is the real reason for this unsustainability?

Some people claim that it lies in the fact that the world is running out of fossil fuels. There is no evidence of this. Although there are increasingly serious problems, particularly environmental ones, in further exploiting them, the world is not running out of fossil fuels.

There are a lot of reserves of fossil fuels and they are becoming increasingly exploitable, particularly because of new unconventional sources. Until recently, deposits of oil and gas contained in shale rocks could not be unlocked due to the lack of technologies to split and fracture the rocks, often at very great depths. Due to the new technologies that have been developed, exploiting these unconventional resources is now easier. There are however serious environmental problems concerning water and chemicals added to improve the rock fracking process.

Other people claim that there is a security problem with fossil fuels, due to the geographically concentrated political power of the oil producers and gas suppliers. Political instability in fossil fuels producer countries adds to this concern.

This is a real concern; but it is not clear how the situation will develop. If producer countries restrict supply to show their power they should aware that this has a price effect, which encourages alternative supplies. Moreover they are sooner or later likely to react by increasing supply as they need funds to finance investments required by an expanding share of domestic population asking for a better level of life.

The main challenge to the growth model based upon fossil fuels is represented by the problem of climate change with its damaging effects such as increased weather variability, more frequent and intense extreme events, greater exposure to coastal storms and flooding, loss of glaciers and rising sea level.

Emissions of greenhouse gases responsible for climate change strongly depends on fossil fuels. It is important to recognize that different types of fossil fuels emit different quantities of carbon. Natural gas has a lower content in terms of emissions; hence switching to gas may be very important as a transitional response in the process of moving to a low carbon energy system based on alternative energy sources to fossil fuels (Helm, 2012).

There is no hope of achieving a global target of CO2 emission reduction without some significant carbon price. Some steps have been made in that direction. For example the European Union has decided to use tradable CO2 emission permits. The system was welcomed with great hopes, but it revealed at least two drawbacks.

First, the system covers CO2 emissions from the larger sources in the power and heat sector, oil refineries, and other big material producers; but it does not cover small emitters such as those in transport, housing, agriculture and waste. Hence a lot of carbon emitting sources are not covered by the system.

Second, the lack of coordination among EU governments led to a too high cap, and the market was subject to business cycles and speculation. As a result the price of permits that had reached almost 30€ per ton. Before the global crisis in 2008, collapsed to 6€. Moreover the initial allocation of permits was free and they did not provide revenues to governments.

A carbon tax seems to be preferable to a permit system, but we must be very realistic about its practical implementation possibilities. Not only it is difficult to achieve coordination between sovereign countries to fix a carbon tax. But it is also difficult to organize it so that it provides the right incentives. On problem is that the right incentive would be to tax carbon consumption, not only carbon production. But this means taxing not only the carbon content of domestic production, but also the carbon content of imports.

However, carbon border taxes are objected as it is claimed that they amount to protectionism. The truth is that not having these taxes would distort trade since it would correspond to subsidizing polluting exports. On the other hand, border carbon taxes would be a powerful incentive on carbon exporters to introduce their own carbon tax or permit scheme (Helm, 2012)

Pricing carbon is necessary, but not sufficient. Energy efficiency can be stimulated by a higher energy price; and in fact this was the case in many countries. However experience also tells that the market has difficulties in organizing how to respond to a higher energy price. Energy saving companies should emerge in the market to help households and firms to undertake current investments to allow energy saving in the future. But they are not developing as expected; thus public policies continue to be required to support these energy saving investments.

Besides promoting energy efficiency, it will be necessary to improve the use of renewables energy sources (wind, both onshore and offshore; solar, as rooftop solar panels and large scale solar installations; bio-energy, as biomass and fuels). There is a lot of optimism on this perspective; but it would not be wise to ignore some current problems.

Wind requires a large scale of land to deliver significant electricity supplies; moreover, because of intermittency, extra back-up capacity must be provided by conventional technologies.

Solar energy also has an intermittency problem, although less relevant because its peak arrives in the middle of the day when demand also tends to be very high. There exist ambitious plans for large-scale solar thermal plants whose power can be transferred to be used abroad; but this requires long-distance transmission networks with very high costs.

Solar photovoltaic (PV) has been encouraged, especially in Europe, by generous feed-in tariffs; this however produced so high costs for electricity that in some countries (Italy for example) subsidies had to be cut; as a matter of fact, reducing subsidies has also been encouraged by falling solar PV costs.

Biofuels also require enormous land areas, a lot of water and huge subsidies. At the world level, the constraint of agriculture on biofuels will become more serious in the future because of the pressure on increasing population.

Risks of a catastrophe, of weapons’ proliferation and connected to waste treatment, still keep the majority of the public opinion against nuclear energy; moreover, there is the problem of the large capital costs; a direct government intervention is required or, to convince private investors, long-term contracts should enforced by the governments. But governments are not in a credible position to act in this direction because of political reasons.

Technological opportunities for the energy system will come from applying the new information and data technologies to a radical change in markets and systems for energy and transport. The energy industry has difficulties in allowing for energy storage and demand does not have enough flexibility; this this is why it is dominated by large vertically integrated utilities, that need excess margins of generation, and by rigid grids.

Smart technologies (smart meters and smart grids) will help decentralized generation to meet intermittency problems; they will help also consumers to use electricity more efficiently and system operators to better manage demand; they will support the many opportunities in the required revolution in transport means and infrastructure.

The effort towards new technologies to build a “low carbon economy” is enormous. People and government have to be aware that it will require a lot of big size investments to find out new technologies and make them deployable. According to most recent energy technology perspectives of the International Energy Agency (IEA, 2012) additional total investment needs to move from a business-as-usual scenario to a 450 Scenario (linked to an increase in temperature not large than 2°) amount to 36 trillions USD from 2010 to 2050. Transport will be the leading sector (more than 40%); the residential sector (buildings) follows with 30% and power with 20%.

Decarbonizing the economy will provide future benefits but in the transition limited financial resources for low carbon investments may imply lower rates of growth, although these investments may provide new jobs.

There should not be too much optimism about the costs of the transition to a decarbonized economy. The technological revolution required to decarbonize the economy will be fundamentally different from the past technological revolutions. What all the past technological revolutions had in common was a virtuous circle between innovations and market demand. Innovations aimed at widening market demand, particularly for consumption goods; larger market demand allowed increasing profits to support further investments in R&D and new products.

The technological progress to permanently decarbonize the economy will only partly be supported by private demand, even if the required cultural change takes place. The prevailing demand for a low carbon economy will be for a public good. Hence governments cannot be absent in this strategy, introducing a carbon consumption price, removing subsidies to fossil fuels, supporting R&D, supporting public procurement of low-carbon products and services, education, training and public information.

Moreover, as the share of the required investments will relatively increase in developing countries, a lot of international technology cooperation among governments will be required.

References.

P. Crutzen, Geology of Mankind: the Anthropocene, Nature, 415, 2002, p. 23.

H. Daly, Beyond growth, Beacon Press, Boston, Mass., 1996.

R.Gordon, Is U. S. economic growth over? Faltering innovation confronts the six headwinds , NBER, WP 18315, august 2012.

D. Helm, The Carbon Crunch, Yale University Press, New Haven 2012.

IEA (International Energy Agency), WEO (World Energy Outlook), Paris, 2012

IEA (International Energy Agency), ETP (Energy Technology Perspectives), Paris, 2012.

T. Jackson, Prosperity without Growth, Sustainable Development Commission, 2010.

A, Jaffe, R. Newell, D.Popp, Energy, the Environment and Technological Change, in Handbook of Economics of Innovation- Vol-II, Burlington: Academic Press, 2010, pp.873-938.

A. Maddison, Contours of the World Economy, 1-2030 AD, Oxford University Press, Oxford, 2007.

R.G. Newell, The Energy Innovation System: A Historical Perspective, in Accelerating Innovation in Energy: Insights from Multiple Sectors, R.H. Henderson and R.G. Newell, eds., University of Chicago Press, 2009, pp. 35-47.

OECD, Inclusive Green Growth. For the future we want, june 2012

D. Popp, The role of Technological Change in Green Growth, NBER WP n.18506, November 2012.

J. Rockstroem e al., A safe operating space for humanity, Nature, 461, 2009, pp. 472-475.

V. Smil, Energy Transitions. History, Requirements, Prospects, Praeger, Santa Barbara, Ca, 2010.

S. Smulders, C.Withagen, Green Growth. Lessons from Growth Theory, Policy Research Working Paper n.6230, World Bank, 2012.

W. Steffen, P.Crutzen, J. McNeill, The Anthropocene: Are Humans Now Overwhelming the Great Forces of Nature?, Royal Swedish Academy of Sciences, Ambio, vol.36, n.8, December 2007, pp. 614-621.

W. Steffen, J. Grinewald, P.Crutzen, J. McNeill, The Anthropocene: conceptual and historical perspectives, Philosophical Transactions of the Royal Society, 369, 2011, pp. 842-867.

M. Scott Taylor, J. Moreno Cruz, Back to the Future of Green Powered Economies, NBER WP 18236, 2012.

UNEP, Towards a Green Economy, 2011.

UNEP, Geo-5, Global Environmental Outlook, 2012.

World Bank, Inclusive Green Growth, 2012.