POLITECNICO DI MILANO

Scuola di Ingegneria Civile, Ambientale e Territoriale

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Master of Science in

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GREENHOUSE GAS MITIGATION : QUANTIFYING THE EFFORT NEEDED TO REACH A PRESCRIBED CO_2 EMISSION TARGET WITH SIX AVAILABLE METHODS

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ABSTRACT

The management of greenhouse gas emissions appears to be an issue of great importance and therefore the search for solutions is essential.

The current status of different technologies and solutions available to mitigate the negative effects of different human activities could lead to a reduction of the emissions.

The PolyGame project, designed by Stefano Caserini, Giulia Fiorese and Renato Casagrandi, aims at reducing 100 million tonnes of CO_2 equivalent ($MtCO_2$-eq) for Italy within 20 years, using 20 different wedges, chosen from the solutions already concretely realizable.

This thesis is composed as follows:

- Introduction
- Waste management
- Deforestation control
- Geothermal energy
- Reduction of car use
- Biofuels
- Electric cars
- Conclusions

For each chapter, except for the introduction and conclusion, informations will be given on the topic of the relative chapter, the relationship between the wedge and the emission of greenhouse gases, its historical evolution, current state of technology and its relative spread and the potential development. Moreover, it will be shown how to reduce the Italian emissions by about 5 Mt CO_2 eq. .

ABSTRACT

La gestione delle emissioni di gas serra risulta essere un problema di grande rilevanza e di conseguenza la ricerca di soluzioni per affrontarlo è fondamentale.
Lo stato attuale delle tecnologie e delle differenti soluzioni a disposizione per mitigare gli effetti negativi delle differenti attività antropiche potrebbe consentire una riduzione delle emissioni.
Il progetto PolyGame, ideato da Stefano Caserini, Giulia Fiorese e Renato Casagrandi, ha l'obiettivo di ridurre le emissioni italiane di 100 milioni di tonnellate equivalenti di CO_2 ($MtCO_2$-eq) entro 20 anni, grazie a 20 cunei, scelti tra soluzioni già concretamente realizzabili.
Il seguente elaborato è suddiviso nei seguenti capitoli:

- Introduzione
- Gestione dei rifiuti
- Controllo della deforestazione
- Energia geotermica
- Riduzione dell'utilizzo di auto
- Biocarburanti
- Auto elettriche
- Conclusione

Per ogni capitolo, fatta eccezione per l'introduzione e la conclusione, verranno date informazioni sull'argomento stesso, sul rapporto tra il cuneo e le emissioni di gas serra, la sua evoluzione storica, lo stato attuale della tecnologia, la sua diffusione ed il suo potenziale sviluppo, verranno inoltre mostrati dei calcoli relativi al PolyGame, che consistono nell'individuare lo sforzo necessario, utilizzando la tecnologia opportuna, a ridurre le emissioni italiane di 5 Mt CO_2 eq. .

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1.

INTRODUCTION TO CLIMATE CHANGE AND GHG EMISSIONS

1.1. Climate change

1.1.1. Earth's climate

The climate system is a complex, interactive system consisting of the atmosphere, land surface, snow and ice, oceans and other bodies of water, and living organisms. The atmospheric component of the climate system most obviously characterizes climate; climate is often defined as 'average weather'. Climate is usually described in terms of the mean and variability of temperature, precipitation and wind over a period of time, ranging from months to millions of years (the classical period is 30 years). The climate system evolves in time under the influence of its own internal dynamics and due to changes in external factors that affect climate (called 'forcing'). Forcing include natural phenomena such as volcanic eruptions and solar variations, as well as human-induced changes in atmospheric composition. Solar radiation powers the climate system. There are three fundamental ways to change the radiation balance of the Earth:

1) by changing the incoming solar radiation (e.g., by changes in Earth's orbit or in the Sun itself);
2) by changing the fraction of solar radiation that is reflected (called 'albedo'; e.g., by changes in cloud cover, atmospheric particles or vegetation); and
3) by altering the long wave radiation from Earth back towards space (e.g., by changing greenhouse gases (GHG) concentrations).

Climate, in turn, responds directly to such changes, as well as indirectly, through a variety of feedback mechanisms. While 1) is not related to anthropogenic activities, both 2) and 3) are subjected to human induced influences. In figure 1.1 are represented the global energy balance and fluxes.

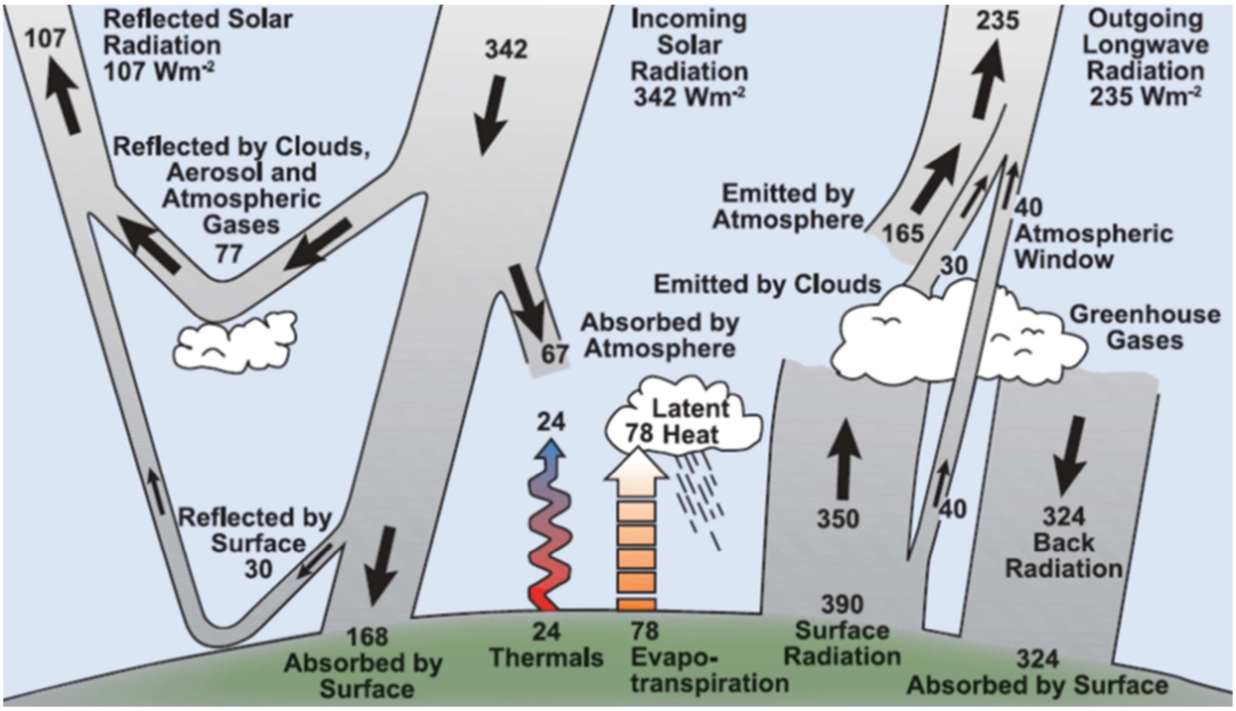


Figure 1.1 - Estimate of the Earth's annual and global mean energy balance [1].

About 30% of the sunlight that reaches the top of the atmosphere is reflected back to space. The energy that is not reflected back to space is absorbed by the Earth's surface and atmosphere. To balance the incoming energy, the Earth itself must radiate, on average, the same amount of energy back to space. The Earth does this by emitting outgoing long wave radiation. Everything on Earth continuously emits long wave radiation. That is the heat energy one feels radiating out from a fire; the warmer an object, the more heat energy it radiates.

The reason the Earth's surface is so warm is the presence of GHG, which act as a partial blanket for the long wave radiation coming from the surface. This blanketing is known as the natural greenhouse effect. The most important GHG are water vapor and carbon dioxide. The two most abundant constituents of the atmosphere – N_2 (nitrogen) and O_2 (oxygen) – have no such effect. Clouds, on the other hand, do exert a blanketing effect similar to that of the GHG; however, this effect is offset by their reflectivity, such that on average, clouds tend to have a cooling effect on climate (although locally one can feel the warming effect: cloudy nights tend to remain warmer than clear nights because the clouds radiate long wave energy back down to the surface). Human activities intensify the blanketing effect through the release of GHG. For instance, the amount of carbon dioxide in the atmosphere has increased by about 35% in the industrial era, and this increase is known to be due to human activities, primarily the combustion of fossil fuels and removal of forests [1].

Most scientists agree that the warming in recent decades has been caused primarily by human activities that have increased the amount of GHG in the atmosphere. GHG, such as carbon dioxide, have increased significantly since the Industrial Revolution, mostly from the burning of fossil fuels for energy, industrial processes, and transportation. Carbon dioxide levels are at their highest in at least 650,000 years and continue to rise.

There is no doubt that climate will continue to change throughout the 21st century and beyond, but there are still important questions regarding how large and how fast these changes will be, and what effects they will have in different regions. In some parts of the world, global warming could bring positive effects for human beings such as longer growing seasons and milder winters. Unfortunately, it is likely to bring harmful effects to a much higher percentage of the world's people. For example, people in coastal communities will likely experience increased flooding due to rising sea levels.

Human actions over the next few decades will have a major influence on the magnitude and rate of future warming. Large, disruptive changes are much more likely if GHG are allowed to continue building up in the atmosphere at their present rate. However, reducing GHG emissions will require strong national and international commitments, technological innovation, and human willpower [2].

1.1.2. The greenhouse effect

One-third of the solar energy that reaches the top of Earth's atmosphere is reflected directly back to space. The remaining two-thirds is absorbed by the surface and, to a lesser extent, by the atmosphere. To balance the absorbed incoming energy, the Earth must, on average, radiate the same amount of energy back to space. Because the Earth is much colder than the Sun, it radiates at much longer wavelengths, primarily in the infrared part of the spectrum (see figure 1.2). Much of this thermal radiation emitted by the land and ocean is absorbed by the atmosphere, including clouds, and reradiated back to Earth. This is called the greenhouse effect. The glass walls in a greenhouse reduce airflow and increase the temperature of the air inside. Analogously, but through a different physical process, the Earth's greenhouse effect warms the surface of the planet. Without the natural greenhouse effect, the average temperature at Earth's surface would be below the freezing point of water. Thus, life, as it is known, it is possible thanks to Earth's natural greenhouse effect. However, human activities, primarily the burning of fossil fuels and clearing of forests, have greatly intensified the natural greenhouse effect, causing global warming.

The two most abundant gases in the atmosphere, N_2 (approximately 78% of the dry atmosphere) and O_2 (approximately 21%), exert almost no greenhouse effect. Instead, the greenhouse effect comes from molecules that are more complex and much less common [1]. Water vapor is the most important GHG; after water vapor, in rough order of importance and size of effect, the major ones are carbon dioxide (CO_2), methane (CH_4) and ozone (O_3). These molecules are capable of absorbing passing infrared photons; the energy of the photon is converted into an excited vibrational state of the GHG molecule. Recall that just as visible light has a range of wavelengths with different energies so too the infrared spectrum spans a range of wavelengths with different energies. The various types of GHG absorb different wavelength IR (infrared) photons. In fact, the molecules often have more than one vibrational mode that allows them to absorb IR photons of more than one wavelength [3].

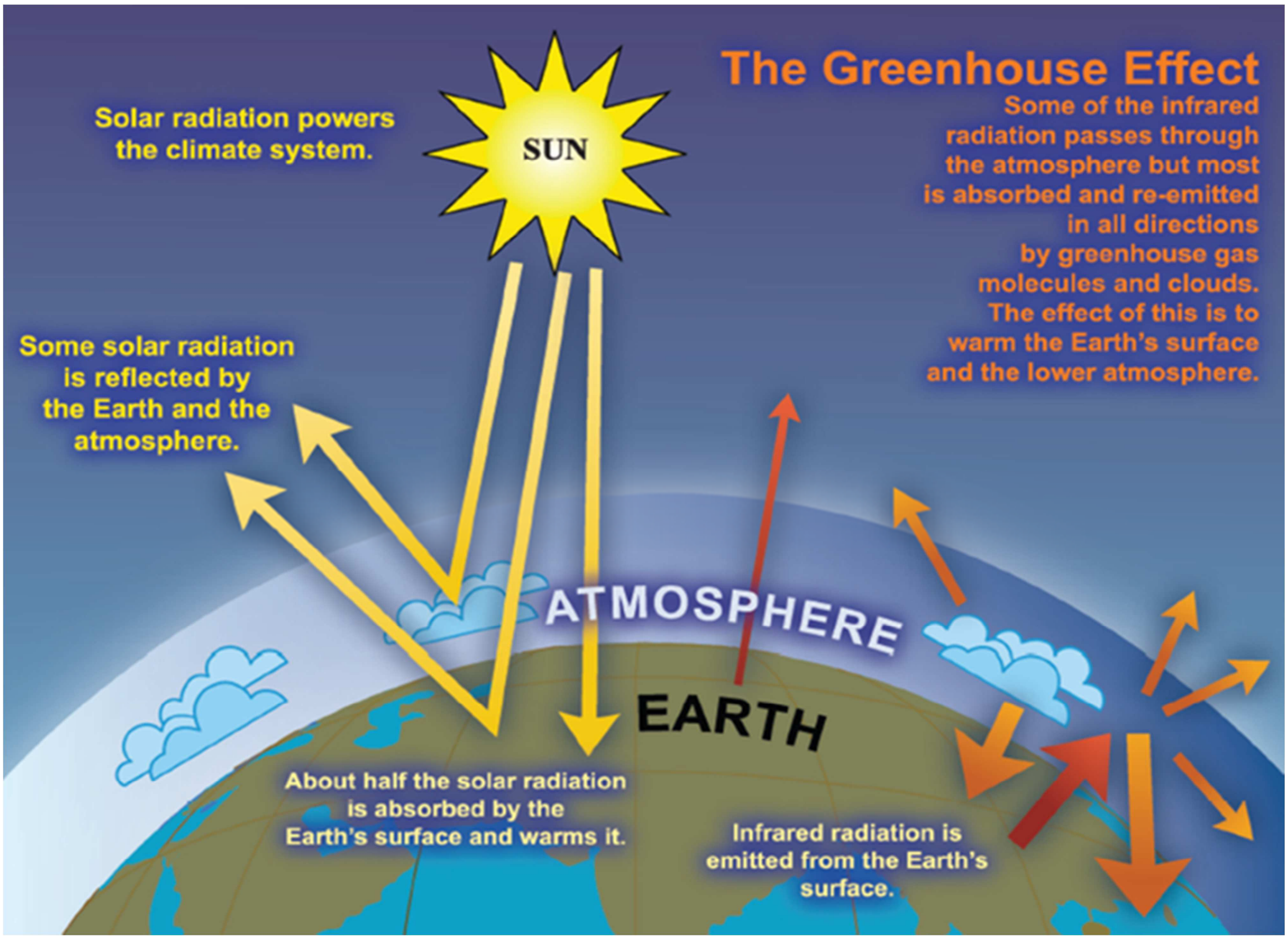


Figure 1.2 - An idealized model of the natural greenhouse effect [1].

In Table 1.1 the contributions of each of the major GHG to the overall greenhouse effect are summarized. Note that, due to the aforementioned complications, the percentages don't add up nicely to 100% [3].

Table 1.1 – Contributions of the main GHG to the greenhouse effect [3].

Greenhouse Gas	Incidence in Greenhouse Effect
Water vapor	36% - 66%
Water vapor & Cloud droplets	66% - 85%
Carbon dioxide	9% - 26%
Methane	4% - 9%
Ozone	3% - 7%

In the humid equatorial regions, where there is so much water vapor in the air that the greenhouse effect is very large. Adding a small additional amount of CO_2 or water vapor has only a small direct impact on downward infrared radiation. However, in the cold and dry polar regions, the effect of a small increase in CO_2 or water vapor is much greater. The same is true for the cold, dry upper atmosphere where a small increase in water vapor has a greater influence on the greenhouse effect than the same change in water vapor would have near the surface.

Several components of the climate system, notably the oceans and living things, affect atmospheric concentrations of GHG. A notable example is that of plants that uptake CO_2 from the atmosphere and converting it (and water) into carbohydrates via photosynthesis. The amount of warming caused by GHG depends also on various feedback mechanisms. For example, as the atmosphere warms due to rising levels of GHG, its concentration of water vapor increases, further intensifying the greenhouse effect. This in turn causes more warming, which causes an additional increase in water vapor, in a self-reinforcing cycle (positive feedback). This water vapor feedback may be strong enough to approximately double the increase in the greenhouse effect due to the added CO_2 alone [1]. Figure 1.3 shows the average atmospheric temperature anomaly on land and sea surface, as reconstructed by the Intergovernmental Panel on Climate Change (IPCC) over the last 150 years.

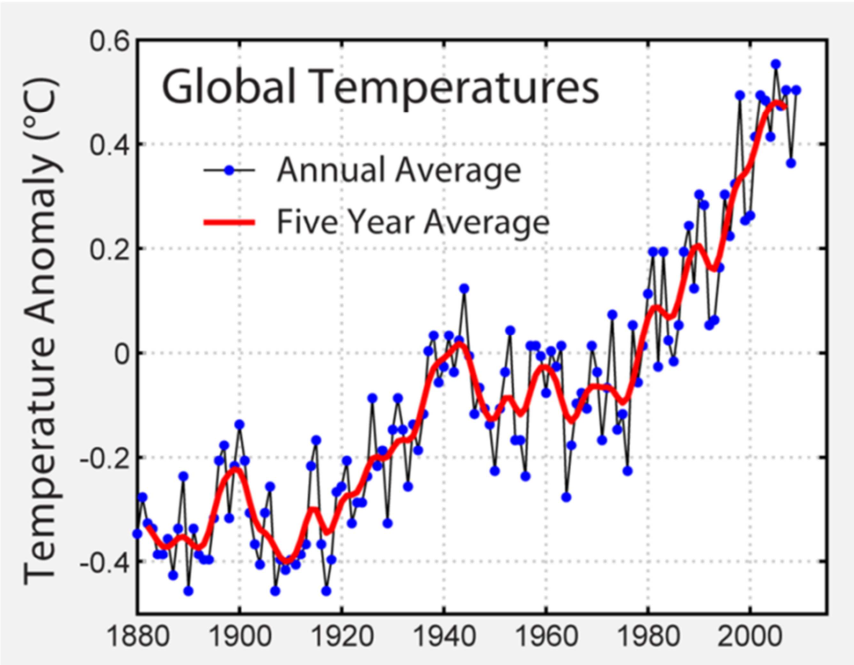


Figure 1.3 - 1880-2009 global mean surface temperature change relative to the 1961–1990 average [2].

1.1.3. Protocols and indexes, with a close up on Italy

In 1988 the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP) established a scientific IPCC in order to evaluate the available scientific information on climate variations, examine the social and economic influence on climate change and formulate suitable strategies for the prevention and the control of climate change. The first IPCC report in 1990, although considering the high uncertainties in the evaluation of climate change, emphasized the risk of a global warming due to an unbalance in the climate system originated by the increase of anthropogenic emissions of GHG (GHG) caused by industrial development and use of fossil fuels. More recently, the scientific knowledge on climate change has firmed up considerably by the IPCC Fourth Assessment Report on global warming which states that “Warming of the climate system is unequivocal (…). There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities (…). Most of the observed increase in globally averaged temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic GHG concentrations". Hence the need of reducing those emissions, particularly in the most industrialized countries.

The first initiative was taken by the European Union (EU) at the end of 1990, when the EU adopted the goal of a stabilization of carbon dioxide emissions by the year 2000 at the level of 1990 and requested Member States to plan and implement initiatives for environmental protection and energy efficiency. The contents of EU statement were the base for the negotiation of the United Nations Framework Convention on Climate Change (UNFCC) which was approved in New York on 9th May 1992 and signed during the summit of the Earth in Rio the Janeiro in June 1992. Parties to the Convention are committed to develop, publish and regularly update national emission inventories of GHG (GHG) as well as formulate and implement programs addressing anthropogenic GHG emissions. Specifically, Italy ratified the convention through law no.65 of 15/1/1994.

On 11/12/1997, Parties to the Convention adopted the Kyoto Protocol, which establishes emission reduction objectives for Annex B Parties (i.e. industrialized countries and countries with economy in transition) in the period 2008-2012. In particular, the European Union as a whole is committed to an 8% reduction within the period 2008-2012, in comparison with base year levels. For Italy, the EU burden sharing agreement, set out in Annex II to Decision 2002/358/EC and in accordance with Article 4 of the Kyoto Protocol, has established a reduction objective of 6.5% in the commitment period, in comparison with the base 1990 levels.

Italy ratified the Kyoto Protocol on 1st June 2002 through law no.120 of 01/06/2002. The ratification law prescribes also the preparation of a National Action Plan to reduce GHG emission, which was adopted by the Interministerial Committee for Economic Planning (CIPE) on 19th December 2002 (deliberation n. 123 of 19/12/2002). The Kyoto Protocol finally entered into force on 16th February 2005. As a Party to the Convention and the Kyoto Protocol, Italy is committed to develop, publish and regularly update national emission inventories as well as formulate and implement programmes to reduce these emissions. In order to establish compliance with national and international commitments air emission inventories are compiled and communicated annually to the competent institutions. Specifically, the national GHG emission inventory is communicated through compilation of the Common Reporting Format (CRF), according to the guidelines provided by the United Nations Framework Convention on Climate Change and the European Union's Greenhouse Gas Monitoring Mechanism [4].

The Kyoto Protocol uses GWP (Global Warming Potential) like function of the CO_2 remaining in the atmosphere following a pulse emission decays as a sum of exponentially decreasing terms. This response function was obtained by fitting to the response to a pulse emission in the Bern carbon cycle model at a present day background CO_2 concentration. These GWPs neglect carbon cycle feedbacks on the climate response to non-CO_2 GHG.

Various criticisms have been leveled at GWPs, in particular that equivalent emissions of short and long-lived GHG based on GWPs give rise to very different climate effects, that the values of GWPs are sensitive to the period over which they are calculated, and that GWPs are based on radiative forcing which is remote from climate impacts. In an attempt to address the latter of these criticisms, Shine proposed the Global Temperature change Potential (GTP) as an alternate metric. GTP is defined as the ratio of the temperature response to a unit mass pulse emission of a given GHG to the temperature response to a unit mass pulse emission of CO_2 at a given time horizon: since it is defined in terms of temperature change rather than radiative forcing, it is one step closer to climate impacts than GWP. Furthermore, the GTP is referenced to the temperature change per unit mass of

CO_2 emitted, which has been shown to be approximately constant and well constrained by observations. Despite being a function of temperature change rather than radiative forcing, GTP is relatively insensitive to climate sensitivity since the effects of climate sensitivity on the temperature response to each gas and to CO_2 tend to cancel. However, the GTP of a gas is in general a strongly varying function of time, of the amount of gas emitted, and of the time-profile of the emissions, and in its original formulation the GTP is defined using a very simple analytical climate model and carbon cycle model. A time-integrated version of GTP, which is defined as the mean global temperature change potential (MGTP), has some advantages over both the GTP and the more widely used GWP. This metric is related to the TEMP metric, which is chosen such that when used to convert CH_4 or N_2O emissions to CO_2-equivalent emissions over the historical period, the match to simulated global mean temperature is optimized [5].

1.2. Greenhouse gases (GHG) emissions

1.2.1. Global GHG emissions and their trends

Since pre-industrial times, increasing emissions of GHG due to human activities have led to a marked increase in atmospheric concentrations of the long-lived GHG carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs) and sulphur hexafluoride (SF_6). A variety of sources exist for determining global and regional GHG trends. However, the available databases show a similar temporal evolution of emissions.

The direct effect of all the long-lived GHG is substantial, with the total CO_2 equivalent[1]concentration of these gases being estimated in 2005 to be around 455 ppm CO_2-eq [6]. The analysis of observations from the WMO Global Atmosphere Watch Programme shows that the globally averaged mixing ratios of GHG in 2009 were the following: 386.8 ppm for carbon dioxide (CO_2), 1803 ppb for methane (CH_4) and 322.5 ppb for nitrous oxide (N_2O). These values are greater than those in pre-industrial times by 38%, 158% and 19%, respectively.

The National Oceanic and Atmospheric Administration (NOAA) Annual Greenhouse Gas Index shows that from 1990 to 2009, radiative forcing by all long-lived GHG increased by 27.5%, with CO_2 accounting for nearly 80% of this increase. The combined radiative forcing by halocarbons is nearly double that of N_2O [7].

Share by gas

Since 1970, the GWP-weighted emissions of GHG have increased by approximately 70%, with CO_2 being the largest source, having grown by approximately 80%. In 2004 CO_2 emissions represented 77% of total anthropogenic emissions in 2004 (74% in 1990), whereas CH_4 and N_2O are the other main source, accounting for more than 20 % (see Figure 1.4).

1 'CO_2 equivalence' summarises the climate effect (radiative forcing) of all human-induced GHG, tropospheric ozone and aerosols as if only the atmospheric concentrations of CO_2 change.

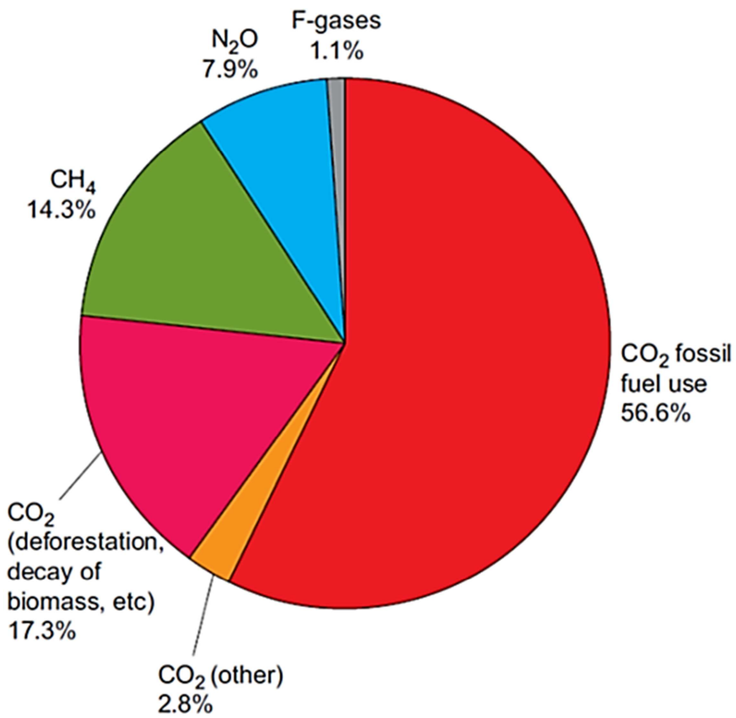


Figure 1.4 - Global anthropogenic GHG emissions in 2004 by chemicals and derivation [6].

Total CH_4 emissions have risen by about 40% from 1970, and on a sectoral basis there has been an 84% increase from combustion and the use of fossil fuels, while agricultural emissions have remained roughly stable. Agriculture, however, is the largest source of CH_4 emissions. Nitrous oxide (N_2O) emissions grew by about 50%, due mainly to increased use of fertilizer and the growth of agriculture. Emissions of the fluorinated gases (F-gases) (hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and SF_6) controlled under the Kyoto Protocol grew rapidly (primarily HFCs) during the 1990s as they replaced ozone-depleting substances (ODS) to a substantial extent and were estimated in 2004 at about 1.1% of total emissions on a 100-year GWP-basis [8].

Share by sector

In 2004, energy supply accounted for about 26% of GHG emissions, industry 19%, gases released from land-use change and forestry 17%, agriculture 14%, transport 13%, residential, commercial and service sectors 8% and waste 3%. These data should be seen as indicative, as some uncertainty remains, particularly with regards to CH_4 and N_2O emissions (error margin estimated to be in the order of 30-50% [8]. Between 1970 and 2004 GHG emissions from the industry sector's emissions have grown by close to 65%, LULUCF (land use, land-use change and forestry) by 40% while the agriculture sector (27%) and residential/commercial sector (26%) have experienced the slowest growth [6].

Figure 1.5 shows the share between the sectors for GHG emissions in 1990 and 2004, accounting also for the contribution of the various gases.

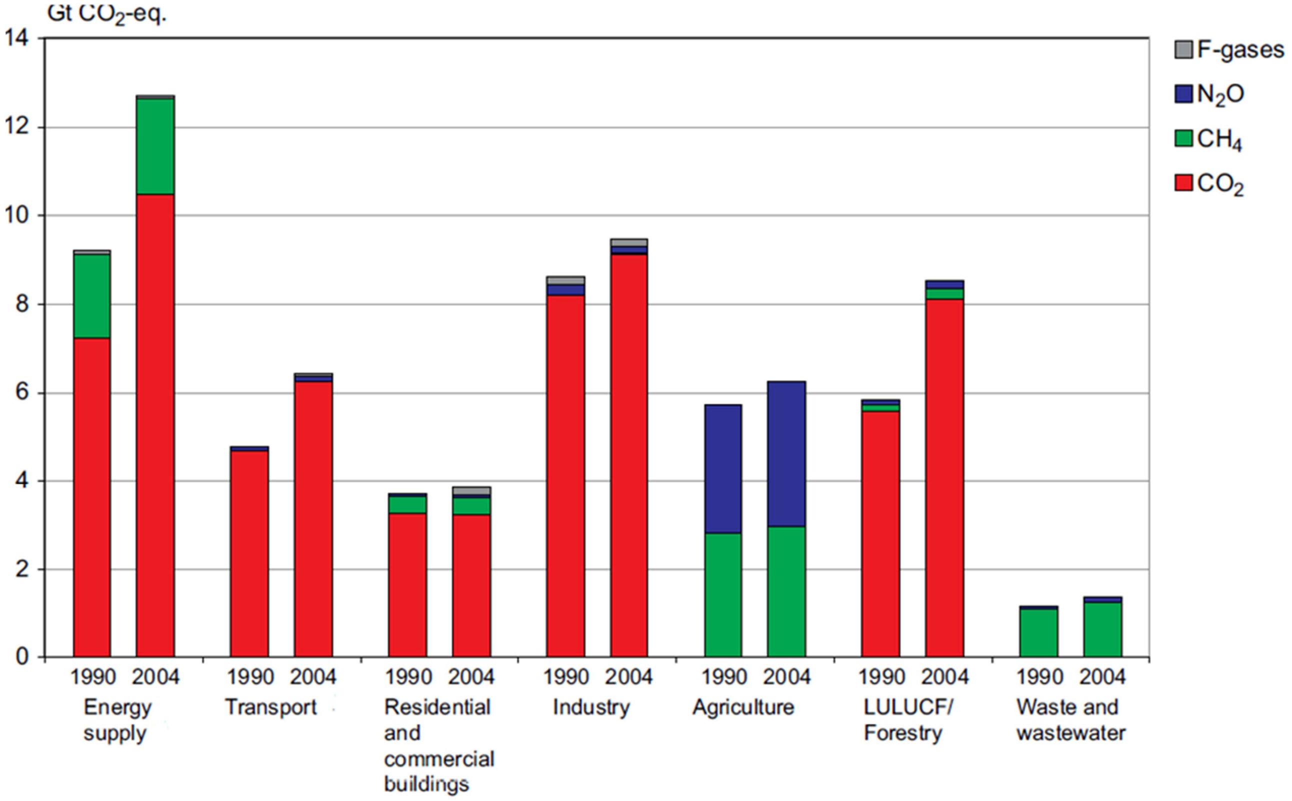


Figure 1.5 - GHG emissions by sector in 1990 and 2004.
100-year GWPs were used to convert emissions to CO_2-eq. [6].

If only CO_2 is taken into account, IEA (International Energy Agency) studies [9] report that in 2008 two sectors, electricity and heat generation and transport produced two-thirds of global CO_2 emissions. Generation of electricity and heat was by far the largest producer of CO_2 emissions and was responsible for 41% of the world CO_2 emissions in 2008. Worldwide, this sector relies heavily on coal, the most carbon-intensive of fossil fuels, amplifying its share in global emissions.

The largest growth in CO_2 emissions has come from the power generation and road transport sectors, with the industry, households and the service sector remaining at approximately the same levels between 1970 and 2004 (see Figure 1.6). By 2004, CO_2 emissions from power generation represented over 27% of the total anthropogenic CO_2 emissions and the power sector was by far its most important source. The land-use change and forestry sector plays a significant role in the overall carbon balance of the atmosphere. However, data in this area are more uncertain than those for other sectors [6].

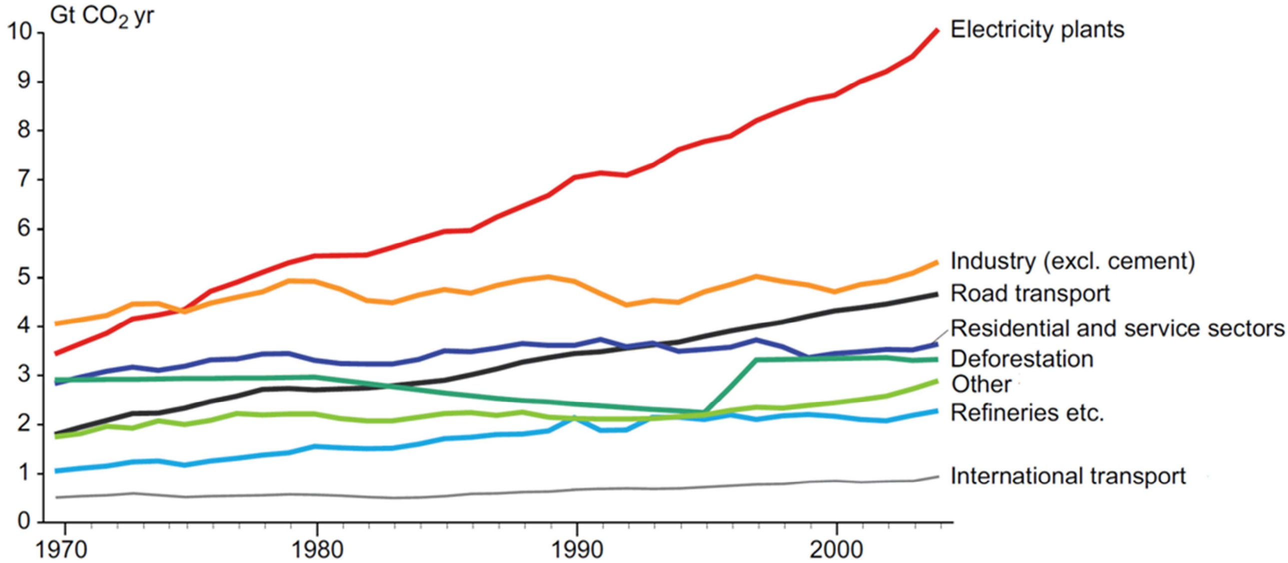


Figure 1.6 - Souces of global CO2 emissions (1970-2004) [6].

Share by region

On a geographic basis, there are important differences between regions. North America, Asia and the Middle East have driven the rise in emissions since 1972. The former countries of the Soviet Union have shown significant reductions in CO_2 emissions since 1990, reaching a level lower than that in 1972. In 2004 industrialized countries (those classified as Annex I countries by United Nations Framework Convention on Climate Change, UNFCC) held a 20% share in the world population but account for 46% of global GHG emissions, conversely the 80% of the world population living in developing countries (non-Annex I) account for 53.6% of GHG emissions [6].
The contrast between the region with the highest per capita GHG emissions and the lowest is even more pronounced: 5% of the world's population (North America, the main per capita emitter, see Figure 1.7) emits 19.4%,while 30.3% (Non-Annex I South Asia) emits 13.1% [8].

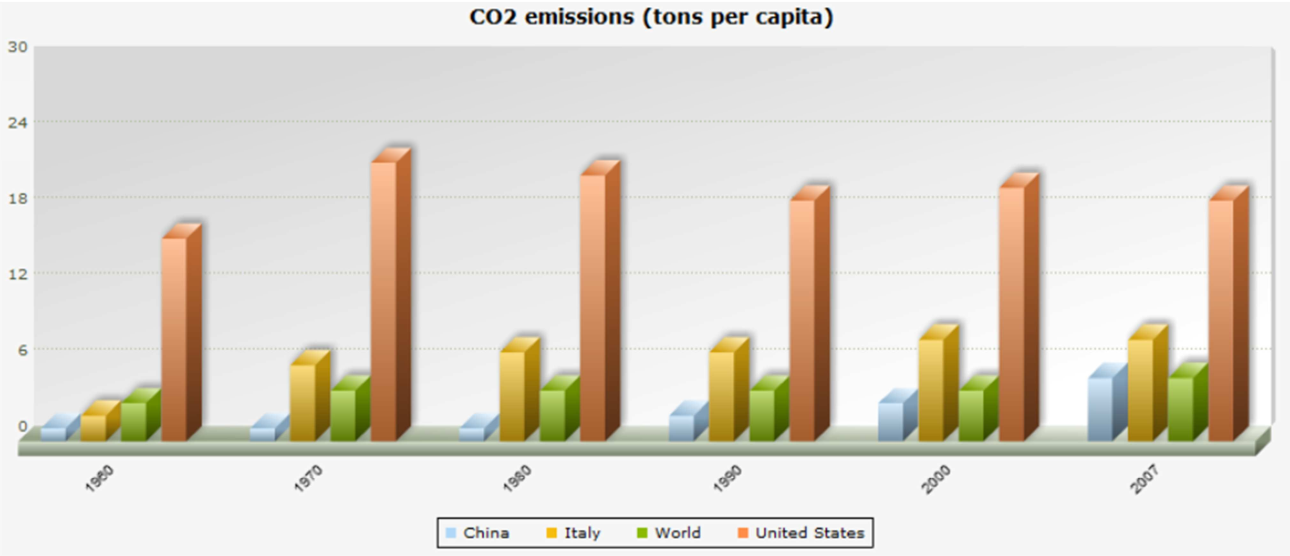


Figure 1.7 - Comparison of CO_2 emissions per capita between some representative country. Source: World Bank.

Concerning CO_2 only, two-thirds of world emissions for 2008 originated from just ten countries, with the shares of China and the United States far surpassing those of all others. Combined, these two countries alone produced 12.1 $GtCO_2$, about 41% of world CO_2 emissions [9]. See Figure 1.8 for a comparison between the share by regions in 1973 and 2008. While the overall emission almost doubled, the fraction provided by developing country significantly increased, especially that of China.

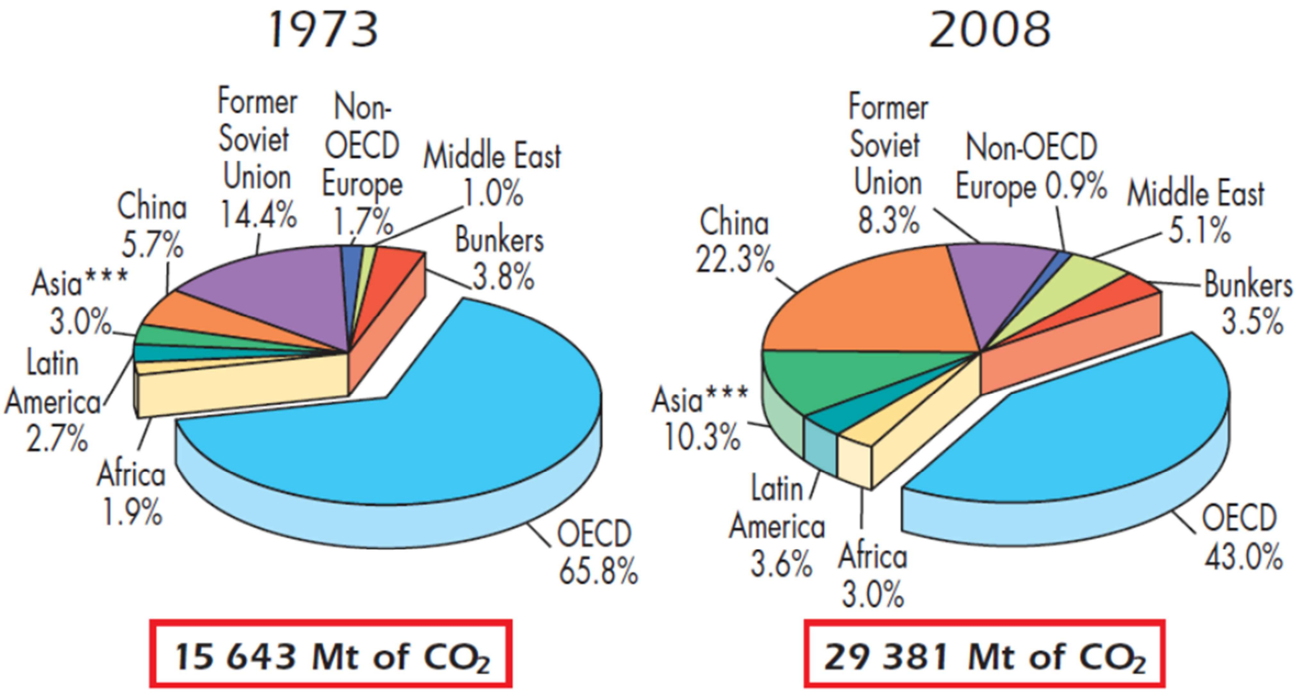


Figure 1.8 - 1973 and 2008 regional shares of CO_2 emissions [9].

Share of CO_2 emissions by fuel

Since their large predominance in global GHG emissions (more than the half of the total, see Figure 1.4) the subject of this section are only CO_2 emissions from fuel combustion. In 2008, 43% of CO_2 emissions from fuel combustion were produced from coal, 37% from oil and 20% from gas (see Figure 1.9). Growth of these fuels in 2008 was quite different, reflecting varying trends that are expected to continue in the future. It's remarkable to notice that between 2007 and 2008, CO_2 emissions from the combustion of coal increased by 3%. Currently, coal is in fact filling much of the growing energy demand of those developing countries, such as China and India, where industrial production is growing rapidly. This fact has obviously his important consequences on the overall emission trends [10].

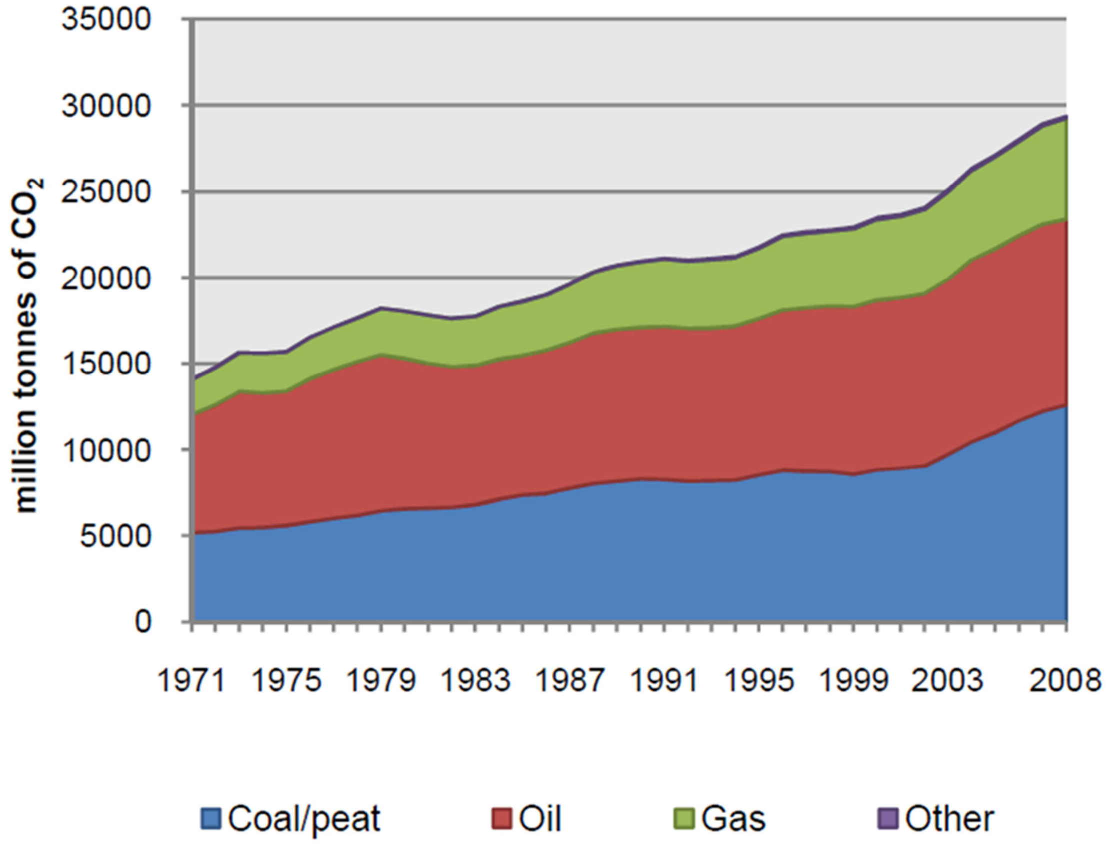


Figure 1.9 – Temporal profile of CO_2 emissions by fuel [9].

1.2.2. GHG emissions in Italy

Total Italian greenhouse gas emissions, in CO_2-eq, excluding emissions and removals from LULUCF (land use, land-use change and forestry), have increased by 4.7% between 1990 and 2008, varying from 517 to 541 MtCO_2-eq, whereas the national Kyoto target is a reduction of 6.5%, as compared the base year levels, by the period 2008-2012.

The most important GHG, CO_2, which accounts for 86.4% of total emissions in CO_2 equivalent, shows an increase by 7.4% between 1990 and 2008. CH_4 and N_2O emissions are equal, respectively, to 6.6% and 5.4% of the total CO_2 equivalent greenhouse gas emissions. CH_4 emissions have decreased by 13.4% from 1990 to 2008, while N_2O has decreased by 20.9% [4]. Figure 1.10 illustrates the national trend of GHG for 1990-2008, expressed in CO_2 equivalent terms and by substance; total emissions do not include emissions and removals from LULUCF [4].

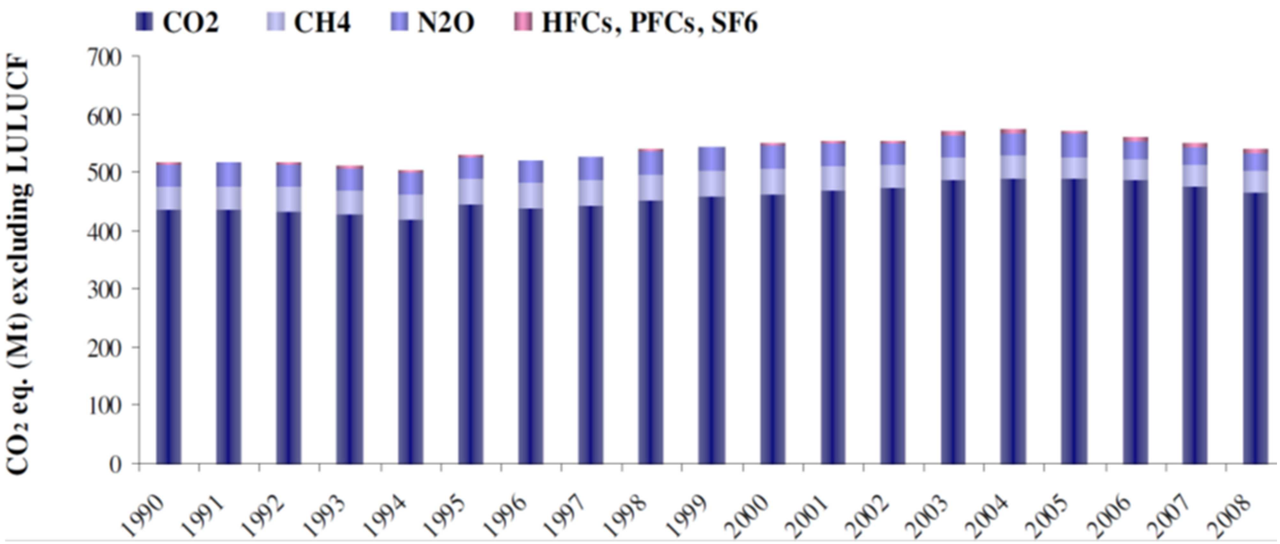


Figure 1.10 - Italian GHG emissions by chemical from 1990 to 2008 [4].

The share of the different sectors in terms of total emissions remains nearly unvaried over the period 1990-2008. For the year 2008 (see Figure 1.11), the greatest part of the total greenhouse gas emissions is to be attributed to the energy sector, with a percentage of 83.6%, followed by agriculture and industrial processes, accounting respectively for 6.6% and 6.3% of total emissions, waste contributing with 3.1% and use of solvents with 0.4%.
Considering total greenhouse gas emissions with emissions and removals from LULUCF, the energy sector accounts, in 2008, for 72.0% of total emissions and removals, as absolute weight, followed by the LULUCF sector which contributes with 13.9%.
Figure 1.11 shows total greenhouse gas emissions and removals subdivided by sector [4].

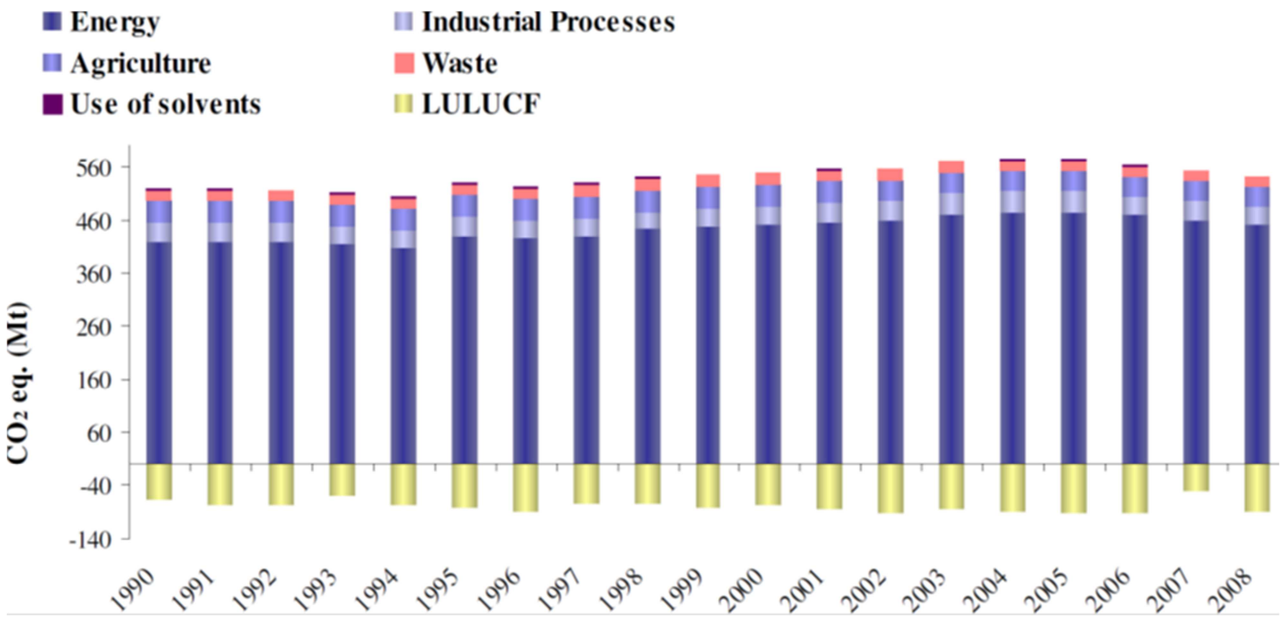


Figure 1.11 - GHG emissions and removals from 1990 to 2008 by sector (Mt CO_2 eq.) [4].

1.3. Emission scenarios

1.3.1. What are scenarios and what are they useful for?

Scenarios of future GHG emissions are the product of very complex dynamic systems, determined by driving forces such as demographic development, socio-economic development, and technological change. Their future evolution is therefore highly uncertain. They can be used in an exploratory manner or for a scientific assessment in order to understand the functioning of an investigated system, but with care for practical purposes. Scenarios are an appropriate tool with which to analyze how driving forces may influence future emission outcomes and to assess the associated uncertainties [11][12]. They assist in climate change analysis, including climate modeling and the assessment of impacts, adaptation, and mitigation. The possibility that any single emissions path will occur as described in scenarios is highly uncertain [12].
In 1994 the IPCC evaluation of emissions scenarios identified four main purposes of climate projections:

a. To provide input for evaluating climatic and environmental consequences of alternative future GHG emissions in the absence of specific measures to reduce such emissions or enhance GHG sinks.
b. To provide similar input for cases with specific alternative policy interventions to reduce GHG emissions and enhance sinks.
c. To provide input for assessing mitigation and adaptation possibilities, and their costs, in different regions and economic sectors.
d. To provide input to negotiations of possible agreements to reduce GHG emissions [13].

Some studies in the literature apply the term ‘scenario’ to ‘best-guess’ or forecast types of projections. Such studies do not aim primarily at exploring alternative futures, but rather at identifying ‘most likely’ outcomes. Probabilistic studies represent a different approach, in which the range of outcomes is based on a consistent estimate of the probability density function (PDF) for crucial input parameters. In these cases, outcomes are associated with an explicit estimate of the likelihood [12].
This first generation of proposed global scenarios included both ambitious mathematical simulation and speculative narrative. A second round of integrated global analysis began in the late 1980s and 1990s, prompted by concerns with climate change and sustainable development. These included narratives of alternative futures ranging from ‘optimistic’ and ‘pessimistic’ worlds to consideration of ‘surprising’ futures. The long-term nature of the climate change issue introduced a new dimension and has resulted in a rich new literature of global emissions scenarios. The first decades of scenario assessment paved the way by showing the power – and limits – of both deterministic modelling and descriptive future analyses. A central challenge of global scenario exercises is to unify these two aspects by blending the objectivity and clarity of quantification with the richness of narrative [13].

1.3.2. Classification of scenarios

Climate change intervention, control, or mitigation scenarios capture measures and policies for reducing GHG emissions with respect to some baseline (or reference) scenario. They contain emission profiles, as well as costs associated with the emissions reduction, but often do not quantify the benefits of reduced impacts from climate change.

A milestone work on emission scenarios was done by IPCC in the IPCC Special Report on Emission Scenarios (SRES) [12]. The SRES scenarios were representative of some 500 emissions scenarios in the literature, depending on economic and population growth as well as introduction of new technologies. They were grouped as A1, A2, B1 and B2, at the time of their publication in 2000 (see Figure 1.12).

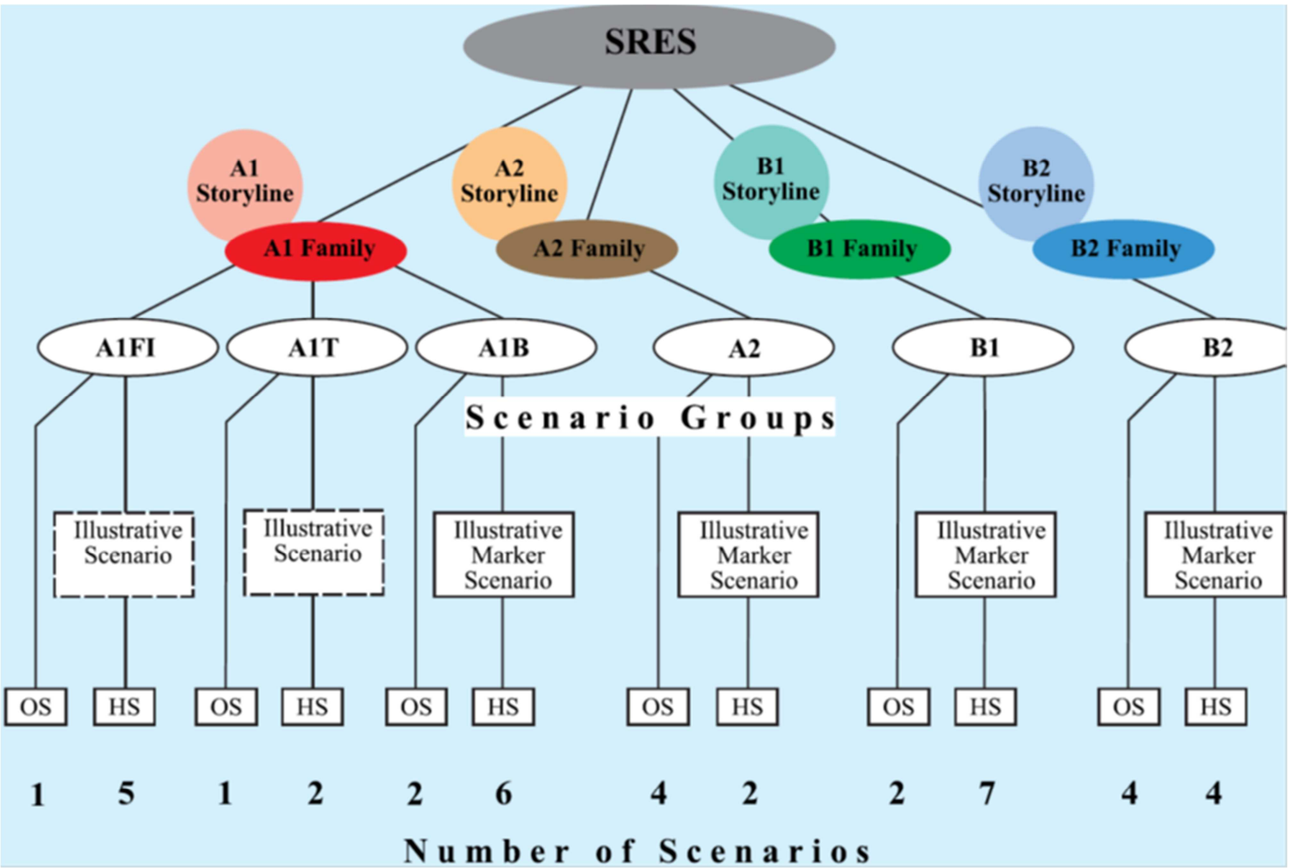


Figure 1.12 - The four SRES storylines and scenario families [12].

Stabilization scenarios are mitigation scenarios that aim at a pre-specified GHG reduction pathway, leading to stabilization of GHG concentrations in the atmosphere. A scenario can be identified as a mitigation or intervention scenario if it meets one of the following two conditions:

- It incorporates specific climate change targets, which may include absolute or relative GHG limits, GHG concentration levels (e.g. CO_2 or CO_2-equivalent (CO_2-eq) stabilization scenarios), or maximum allowable changes in temperature or sea level.

- It includes explicit or implicit policies and/or measures of which the primary goal is to reduce CO_2 or a broader range of GHG emissions (e.g. a carbon tax, carbon cap or a policy encouraging the use of renewable energy).

Some scenarios in the literature are difficult to classify as mitigation (intervention) or baseline (reference), such as those developed to assess sustainable development paths. These studies consider futures that require radical policy and behavioural changes to achieve a transition to a postulated sustainable development pathway. Another type of mitigation scenario approach sets future specified climate target (e.g. a global temperature increase of no more than 1°C by 2100), and then works backwards to develop feasible emission trajectories and emission driver combinations leading to these targets. Such scenarios, also referred to as 'safe landing' or 'tolerable window' scenarios, imply the necessary development and implementation of climate policies intended to achieve these targets in the most efficient way [13].

Baseline scenarios

The resulting span of energy-related and industrial CO_2 emissions in 2100 across baseline scenarios in the post-SRES literature is very large, ranging from 17 to around 135 $GtCO_2$-eq (4.6-36.8 GtC), about the same as the SRES range. The majority of scenarios indicate an increase in emissions during most of the century. However, there are some baseline (reference) scenarios in literature where emissions peak and then decline.

Baseline land-related GHG emissions are projected to increase with growing cropland requirements, but at a slower rate than energy-related emissions. As far as CO_2 emissions from land-use change (mostly deforestation) are concerned, post-SRES scenarios show a similar trend to SRES scenarios: a slow decline, possibly leading to zero net emissions by the end of the century. Emissions of non-CO_2 GHG as a group (mostly from agriculture) are projected to increase, but somewhat less rapidly than CO_2 emissions, because the most important sources of CH_4 and N_2O are agricultural activities, and agriculture is growing less than energy use.

In general, the comparison of SRES and new scenarios in the literature shows that the ranges of the main driving forces and emissions have not changed very much [13].

Stabilization scenarios

A commonly used target in the literature is stabilization of CO_2 concentrations in the atmosphere. If more than one GHG is studied, a useful alternative is to formulate a GHG-concentration target in terms of CO_2-equivalent concentration or radiative forcing, thereby weighting the concentrations of the different gases by their radiative properties. Alternatively, some studies look at temperature increase targets (as they are more directly related to impacts). One implication of using a temperature target, however, is the higher level of uncertainty relating to mitigation action [14]. The advantage of radiative forcing targets over temperature targets is that the calculation of radiative forcing does not depend on climate sensitivity. The disadvantage is that a wide range of temperature impacts is possible for each radiative-forcing level. Temperature targets, on the other hand, have the important advantage of being more directly linked to climate change impacts. Another approach is to calculate the risks or the probability of exceeding particular values of global annual mean temperature rise since pre-industrial times for specific stabilization or radiative forcing targets.

There is a clear and strong correlation between the CO_2-equivalent concentrations (or radiative forcing) and the CO_2-only concentrations by 2100 in the published studies, because CO_2 is the most important contributor to radiative forcing. Based on this relationship, to facilitate scenario comparison and assessment, stabilization scenarios (both multi-gas and CO_2-only studies) can be grouped into different categories that vary in the stringency of the targets.

Essentially, any specific concentration or radiative-forcing target requires emissions to fall to very low levels as the removal processes of the ocean and terrestrial systems saturate. The timing of emission reductions depends on the stringency of the stabilization target. Stringent targets require an earlier peak in CO_2 emissions. The costs of stabilization depend on the stabilization target and level, the baseline and the portfolio of technologies considered, as well as the rate of technological change. This implies that socio-economic conditions, including policies outside the field of climate policy, are just as important for stabilization costs as climate policies [14]. Global mitigation costs rise with lower stabilization levels and with higher baseline emissions. Recent stabilization studies have found that land-use mitigation options (both non-CO_2 and CO_2) provide cost effective abatement flexibility in achieving 2100 stabilization targets. In some scenarios, increased commercial biomass energy (solid and liquid fuel) is significant in stabilization, providing 5–30% of cumulative abatement and potentially 10–25% of total primary energy over the century, especially as a net negative emissions strategy that combines biomass energy with CO_2 capture and storage. The baseline choice is crucial in determining the nature and cost of stabilization. This influence is due mainly to different assumptions about technological change in the baseline scenarios [13].

1.3.3. A closer look to our possible future

Several studies, as was established with the Copenhagen Accord in 2009, indicate that a maximum temperature increase of 2°C compared to pre-industrial levels could limit the risk of a large-scale disruption of the climate system. With a somehow risky choice, the European Union and its EU Member States have adopted a 2°C target as their long-term climate objective.

In order to attain a probability greater than 50% of achieving the 2°C target, GHG concentrations need to be stabilized below 450 ppm CO_2-eq. Stabilization at 550 ppm CO_2-eq. gives only a 0–30% probability of meeting the 2°C target (depending on the probability distribution function for climate sensitivity used) [11]. At the same conclusions come IPCC, which declared that only scenarios resulting in a 50% to 80% reduction of global CO_2 emissions by 2050 compared to 200 levels can limit the long-term global mean temperature rise to 2.0 to 2.4 degrees Celsius [15]. The Stern review [16] has concluded that the benefits of limiting temperature rises to two degrees would outweigh the costs of doing so, although other analyses result in varying conclusions depending on the assumptions on which they base their calculations 15.

Table 1.2 puts into relationship CO_2 stabilized concentrations and future temperature increments. It is possible to notice that limiting within 2-2.4 °C the global mean temperature rise corresponds to stabilizing GHG emissions around 450 ppm CO_2-eq.

Table 1.2 - The relation between emissions and climate change [15].

Temperature increase (°C)	All GHGs (ppm CO_2 eq.)	CO_2 (ppm CO_2)	CO_2 emissions 2050 (% of 2000 emissions) (%)
2.0-2.4	445-490	350-400	–85 to –50
2.4-2.8	490-535	400-440	–60 to –30
2.8-3.2	535-590	440-485	–30 to +5
3.2-4.0	590-710	485-570	+10 to +60

Being impossible to make an analysis of the hundreds of scenarios present in literature, from now on a study done by IEA in 2009 [17] is analised. Its aim is to stabilize the GHG concentration in the atmosphere at 450 ppm of CO_2-eq. This 450 Scenario takes into account measures to force energy-related both CO_2 and non CO_2 emissions down to a trajectory that would be consistent with ultimately stabilizing the concentrations of all GHG in the atmosphere at 450 ppm.
Figure 1.13 shows world energy related CO_2 emissions by sector from that IEA study in the Reference and 450 Scenario.

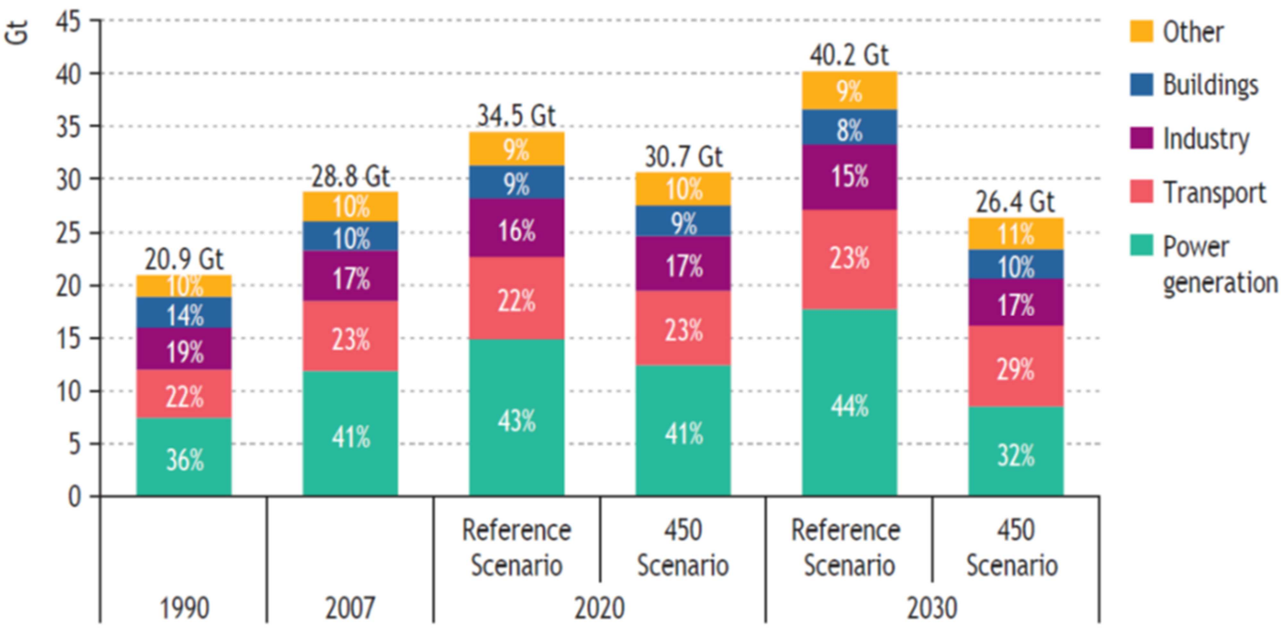


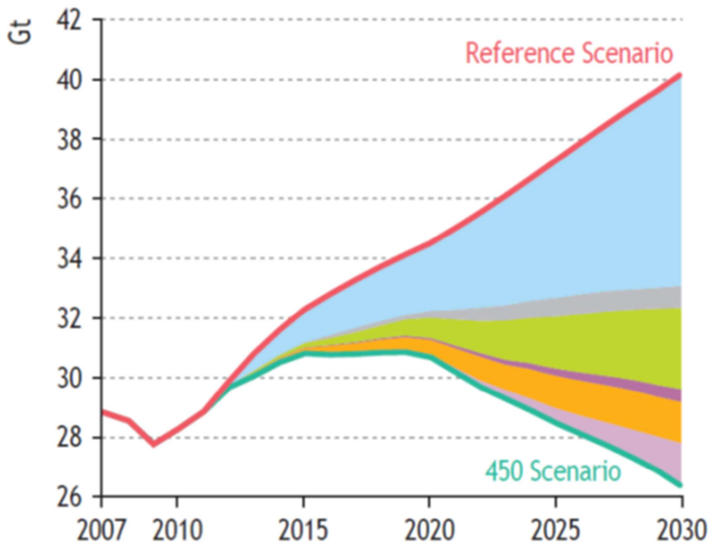
Figure 1.13 - World energy related CO_2 emissions by sector in the Reference and 450 Scenario [17].

Reference Scenario

The Reference Scenario by IEA takes into account government policies and measures adopted starting from mid 2009, although many of them were not yet been fully implemented. This includes a number of policies to limit greenhouse gas emissions, as well as various policies to enhance energy efficiency and promote renewable energy. The Reference Scenario also assumes that energy subsidies are gradually removed in all countries where they currently exist. In the absence of new initiatives to tackle climate change, rising global fossil fuel use in this scenario increases energy related CO_2 emissions from 29 Gt in 2007 to over 40 Gt in 2030 and contributes to the deterioration of ambient air quality, with serious public health and environmental effects. The rise in emissions is due to increased fossil fuel use, especially in developing countries, where per capita energy consumption still has far to go to approach that in developed countries. For developed countries emissions are projected to dip slightly over the period, due to a slower increase in energy demand, large improvements in energy efficiency and the increased use of nuclear and renewables. These effects are, in large part, due to the policies already adopted to mitigate climate change. The Reference Scenario would result in a concentration of GHG in the atmosphere of around 1000 ppm over the long term [17].

The 450 Scenario

The long term greenhouse gas concentration limit set – 450 ppm CO_2 equivalent – is less than half the concentration which occurs in the Reference Scenario. The trajectory is an overshoot trajectory, with concentrations peak at 510 ppm in 2035. The analysis focuses on energy related CO_2 emissions to 2030, which peak just before 2020 at 30.9 Gt and decline steadily thereafter, reaching 26.4 Gt in 2030 (see Figure 1.13). The 450 Scenario also takes a close look at the period through to 2020 and reflects a plausible set of commitments and policies which could emerge. All countries achieve substantial levels of abatement relative to the Reference Scenario.



	Abatement ($Mt\ CO_2$) 2020	Abatement ($Mt\ CO_2$) 2030	Investment ($2008 billion) 2010-2020	Investment ($2008 billion) 2021-2030
Efficiency	2 517	7 880	1 999	5 586
End-use	2 284	7 145	1 933	5 551
Power plants	233	735	66	35
Renewables	680	2 741	527	2 260
Biofuels	57	429	27	378
Nuclear	493	1 380	125	491
CCS	102	1 410	56	646

Figure 1.14 - World energy related CO_2 emissions abatement from 2010 to 2030. IEA's forecast [18].

The end-use contributions present in Figure 1.14 emphasize how most of the emission reductions from the Reference Scenario are achieved through energy efficiency measures. Significant reductions also come from changes to the mix of power generation technologies. The related additional investment, relative to Reference Scenario, in low carbon technologies and energy efficiency close to $430 billion in 2020 to meet 450 Scenario.

The largest increase in energy related investment is in transport, followed by the additional investment in buildings, including appliances and equipment, and by the power sector. More than three quarters of the additional investment is needed in the last decade because most of the CO_2 emission reductions occur after 2020 (global CO_2 emissions are cut by 3.8 Gt in 2020 and by 13.8 Gt in 2030, relative to the Reference Scenario) [17].

2.

WASTE MANAGEMENT

2.1. Introduction to Waste Management

A key environmental aspect in assessing waste management technologies and strategies is greenhouse gas (GHG) emissions. Waste management causes releases of GHG but may also contribute to mitigation of GHG emissions. GHG issues appear in many ways in waste management: use of energy based on fossil fuels for transport and machinery, process emissions from converting carbon rich waste for example by biological processes or incineration, production of energy that substitutes for production of energy based on other fuels, and through recycling processes that saves both energy and virgin material resources. GHG issues are hence related to activities within the waste management system as well as to the exchange between the waste management system and the energy industry, the secondary material industry, the agricultural and the forestry industries [19].

Solid waste management (SWM) is largely accepted as a complex environmental service that must be carried out using interdisciplinary methods [21]. Social acceptance, economic efficiency, organizational matters, water, soil and air pollution are among the most important issues confronted in waste management projects, either already realized or planned in the near future [20].

Integrated waste management (IWM) in its simplest sense incorporates the waste management hierarchy by considering direct impacts (transportation, collection, treatment and disposal of waste) and indirect impacts (use of waste materials and energy outside the waste management system). It is a framework that can be built on to optimize existing systems, as well as the design and implementation of new waste management systems.

Waste management is best dealt with through a soft systems approach. A concise definition of a system is a: ‘‘set of interacting units or elements that form an integrated whole intended to perform some function’’[22]. Integrated solid waste management (ISWM) is aimed at optimizing the management of solid waste and involving all the stakeholders [23]. Solid waste management is a complex and multidisciplinary problem that should be considered from technical, economic and social aspects on a sustainability basis. For a healthy environment, both municipal and industrial wastes should be managed according to the solid waste management hierarchy (prevention/minimization/recovery/incineration/landfilling). For this purpose, different techniques can be used [24].

Important tools in ISWM are:

Recycling.

It is possible to consider two options for recycling: (a) source-separated recyclables and (b) co-mingled collection of recyclables. Recyclables are either (a) delivered to a material recovery facility (MRF) where different recyclables are separated, (b) sorted according to their quality and prepared for shipping to the processor or (c) sent directly to the processor. The un-captured material is sent to landfills or incinerators or others treatments depending on the waste management scenario.

Composting.

Composting is an aerobic biological process, in which the organic fraction is stabilized. As a result of the process, CO_2 will be released to the atmosphere. However, since it originates from biotic source, it does not add to the GHG emissions inventory. Moreover, the compost is usually reduced in volume and may have a sale value as a soil amendment. Nevertheless, the process requires energy input.

Incineration.

Incineration is the controlled process of combusting municipal solid waste (MSW) in an oxygen rich environment. The heat generated from the process can be used to generate power and/or to heat water for the purpose of district heating. In order to estimate the GHG emissions from an incinerator we use the ultimate analysis method to calculate the amount of carbon available for combustion. All carbon from plastic is considered non-biotic and textiles usually contain between 5% and 25% synthetic material of hydrocarbon origin. The ‘Other’ waste stream is composed of a wide range of waste material of both organic and nonorganic origins (e.g., nappies, rubber, dirt, ash, etc.). While it is difficult to give an accurate estimate of the amount of organic carbon present in this waste stream we assume that it is in the range of 15–35% with the rest being anthropogenic.

Landfilling.

Landfilling is the most common practice of MSW management. Modern landfills are highly engineered facilities that are specifically designed to stabilize the waste and minimize its hazards to the public. Several countries around the world have issued directives to minimize the amount of waste sent to landfills. Nevertheless, it is impossible to eliminate the need for landfills because some materials are thermodynamically impossible to recycle. The starting point of the landfill module is waste characterization. This includes waste sent to landfill after collection including waste sent from transfer stations; Materials Recovery Facility (MRF) residue; composting residue; incineration ash and slag as well as residue from anaerobic digestion [25].

An integrated approach to MSW management requires a series of actions and techniques aimed firstly at minimizing the waste production at source, then at reducing the risk to public health and

the environment and finally at improving its treatability. Subsequently, separate collection of waste should maximize the quantity and the quality of recyclable materials.
Nevertheless, the objective of separate collection is not only the separation of useful materials but also the reduction of the impact of MSW by removing from waste flux items containing dangerous substances. Therefore separate collection represents a real pre-treatment of waste before subsequent treatment. Non-recyclable waste should be, if suitable, treated in Waste to Energy (WTE) plants in order to enable the production of energy in the form of electricity and heat.
Landfilling is the final and absolutely essential step of MSW management, needed to dispose of non-recyclable bottom ash and slag as well as non-combustible waste. Recycling can allow a reduction of GHG emissions while incineration and landfilling performance greatly depends on the technologies adopted (i.e. energy recovery both from landfilling and incineration, accurate control of biogas emissions from landfilling) [26].

2.2. Climate changes and benefits in implementation of waste management

Landfill disposal causes production of landfill gas (LFG) through anaerobic degradation of organic matter mediated by methanogenic bacteria. LFG is a mixture of methane (40–45 vol.% on average) and carbon dioxide (55–60 vol.% on average), nitrogen and other trace species, often toxic and malodorous. It is commonly considered that methane from landfilling represents about 23% of the total anthropogenic CH_4 discharged towards the atmosphere, thus contributing significantly to global warming. The global warming potential of GHG is a function of both instantaneous radiative forcing and residence time of gases in the atmosphere. Following IPCC (2006), the global warming potential (GWP) of methane is 23 times stronger than that of CO_2 (100-year time horizon), whereas according to Lashof and Ahuja (1990), the GWP of methane is 63 times stronger than that of CO_2 for a time horizon of 20 years. In spite of these different opinions on the GWP of CH_4, there is a general consensus on the role of the gas generated by the landfills and discharged through their soil cover into the atmosphere, which is unanimously considered to represent one of the most important contributions to global greenhouse effect.
Unfortunately, a considerable fraction of the total production of LFG escapes from the landfill surface even when collecting systems are properly installed [27]. In general, there are large uncertainties with respect to quantification of direct emissions, indirect emissions and mitigation potentials for the waste sector [28] [29].

2.3. History

In the 21st century, the sustainable management of MSW will become necessary at all phases of impact from planning to design, and to operation [30].
Generation of solid waste is a natural consequence of human life. Removal of that waste is consistent with improved quality of life. Initially, solid waste management (SWM) techniques aimed simply to eliminate waste from the vicinity of habitable areas as a means of maintaining public health. After realizing the hazards of uncontrolled disposal, measures were devised and

implemented mainly through sanitary landfilling. In recent years, a variety of material and energy recovery technologies have been devised and are now included in modern systems [31].

2.3.1. Historical developments in waste management in Italy

Basic data on waste production and landfills system are those provided by the national Waste Cadastre. The Waste Cadastre is formed by a national branch, hosted by ISPRA(Istituto Superiore per la Ricerca e la Protezione Ambientale), and by regional and provincial branches. The basic information for the Cadastre is mainly represented by the data reported through the Uniform Statement Format, complemented by that provided by regional permits, provincial communications and by registrations in the national register of companies involved in waste management activities.

These figures are elaborated and published by ISPRA yearly since 1999: the yearbooks report waste production data, as well as data concerning landfilling, incineration, composting and generally waste life-cycle data. For inventory purposes, a database of waste production, waste disposal in managed and unmanaged landfills and sludge disposal in landfills was created and it has been assumed that waste landfilling started in 1950.

The complete database from 1975 of waste production, waste disposal in managed and unmanaged landfills and sludge disposal in landfills is reconstructed on the basis of different sources, and regression models based on population. Since waste production data are not available before 1975, they have been reconstructed on the basis of proxy variables. Gross Domestic Product (GDP) data have been collected from 1950 and a correlation function between GDP and waste production has been derived from 1975; thus, the exponential equation has been applied from 1975 back to 1950.

Consequently the amount of waste disposed into landfills has been estimated, assuming that from 1975 backwards the percentage of waste landfilled is constant and equal to 80%; this percentage has been derived from the analysis of available data. As reported in the Figure 2.1, in the period 1973 – 1996 data are available for specific years (available data are reported in dark blue, whereas estimated data are reported in light blue). The trend is strictly dependent by national policies adopted for waste management and from news stories happened in those years: above all Seveso incident. From 1973 waste disposal on landfill was decreasing because of the increment of incineration practice: in 1976, Seveso incident affected the use of incineration as final waste treatment, and for some years onwards, waste disposal on land became again the most common practice. Reasonable, before 1973, the percentage of waste disposal on land has been set equal to 80% [37].

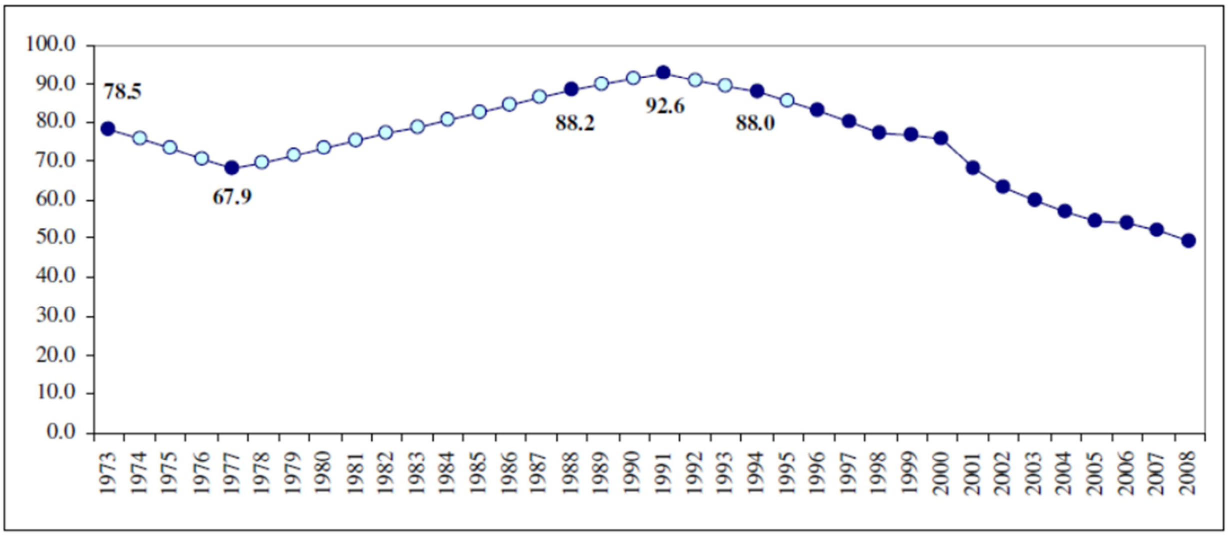


Figure 2.1- Percentage of MSW disposal on land (%) [37].

2.4. Current situation

2.4.1. European situation

The total amount of municipal waste generated has been continuously growing between 1995 and 2002 in the European Union (EU); from 2003 onwards a downward trend can be observed, though the generation of municipal waste per capita remains at high levels (EU-27, 517 kg per person in 2006). The amount of municipal waste generated per person is generally higher in the old Member States (EU-15, 563 kg per person in 2006) than in the new Member States, although Cyprus and Malta also have a relatively high production of municipal waste.

Ireland has the highest per capita generation of municipal waste in the European Union; the lowest values are reported by Poland. Germany alone generated 18.3% (46.6 million tonnes) of the total amount of municipal waste generated in EU-27 (255 million tonnes), followed by the United Kingdom (14%) and France (13%).

Municipal waste consists of waste generated by households and waste collected within the municipal waste collection scheme from businesses and institutions. The inclusion of businesses and institutions depends on individual countries' waste management procedures. Municipal waste accounts for around 9% of the total amount of waste generated in the European Union. In contrast to statistics of earlier years, the total amount of waste includes also mineral, construction and agricultural waste [32].

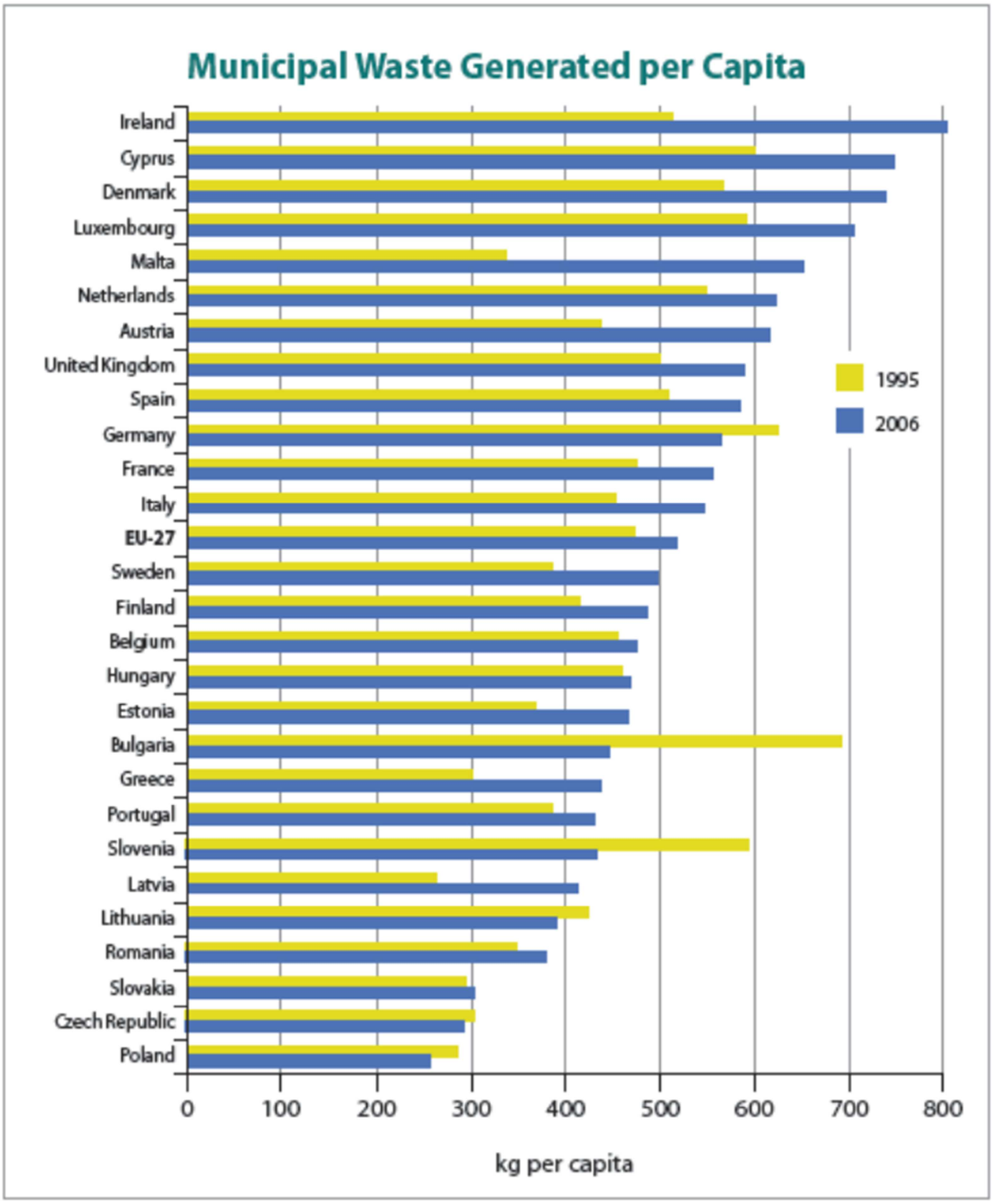


Figure 2.2 - Municipal Waste Generated per Capita [32].

The amount of waste landfilled depends on the national policy on waste management; that is, it depends on the importance given to waste avoidance, recycling and incineration. For many countries landfill remains the major treatment method, e.g. for more than 80% in Lithuania, Poland, Cyprus, Greece, Malta, Romania, Slovenia and Hungary. On the other hand, there has been a sharp decline in the amount of waste landfilled in some other Member States. In Germany there is almost no landfill of municipal waste anymore without prior treatment; the Netherlands send 2%, Denmark, Sweden and Belgium 5% of the municipal waste to landfill sites.

The result of these mixed developments among Member States is a steady decline in landfill for the EU as a total. Although landfill is still the most important way to dispose of municipal waste, nowadays less than half of the municipal waste generated is disposed of by deposit/land treatment.

The levels of municipal waste incinerated vary over Member States, depending on the number of suitable incinerators and on national waste management policies. Denmark and Luxembourg have a high level of waste incineration. Countries that drastically reduced landfilling, as Germany and

Sweden, have strongly increased their incineration capacity. The other alternative to landfill is recycling, but countries have mixed strategies. Belgium is the only country having achieved a significant reduction of waste going to landfill without increasing incineration.
Although more and more countries use incineration in their waste management, its contribution is still small in some of them. The establishment of new waste incinerators takes a lot of time and resources. For eleven Member States the use of incineration for the treatment of municipal waste is insignificant. Countries exhibit a wide variety of policies for the treatment of waste. Data from the first reporting under the Waste Statistics Regulation shows that new EU Member States still rely very much on disposal of waste by deposit/land treatment. As also reported for the sub-category municipal waste, the lowest rates with less than 20% of total waste going to landfill are reported by Denmark, the Netherlands, Belgium and Poland.
Recovery, including energy recovery from incineration, has gained a more important role in a majority of Member States and accounts for increasing shares of the treatment of total waste [32].

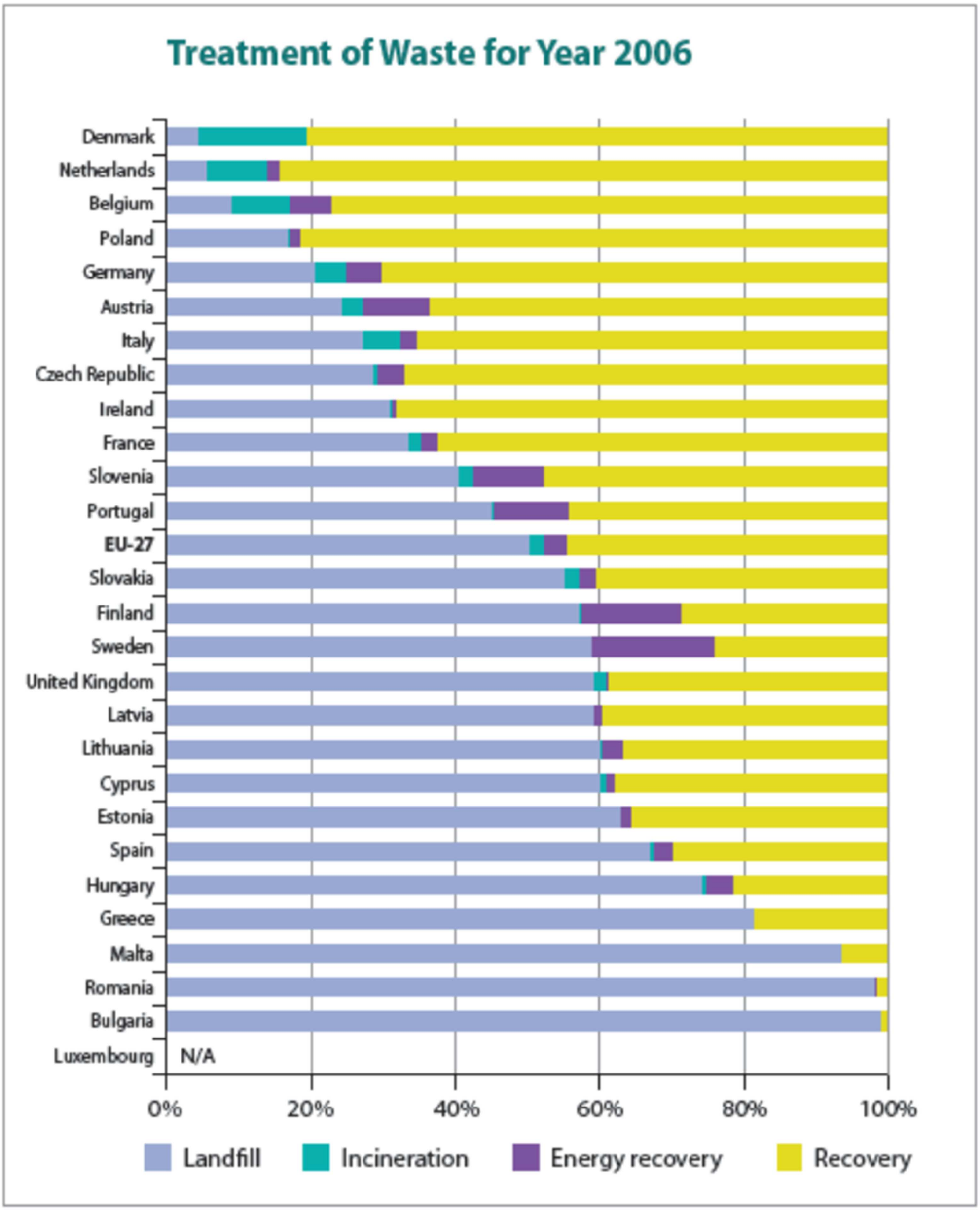


Figure 2.3 - Treatment of Waste for Year 2006 [32].

2.4.2. Italian situation

The disposal of municipal solid waste (MSW) in landfill sites is still the main disposal practice: the percentage of municipal solid waste disposed in landfills dropped from 91% in 1990 to 49% in 2008. This trend is strictly dependent from policies that have been taken in the last 20 years in waste management. In fact, at the same time, waste incineration has fairly increased, whereas composting and mechanical and biological treatment have shown a remarkable rise due to the enforcement of legislation. Also recyclable waste collection, which at the beginning of nineties was a scarce practice and waste were mainly disposed in bulk in landfills or incineration plants, has increased: in 2008, the percentage of municipal solid waste separate collection is 30.6%, but still far from legislative targets (fixed 45% in 2008).

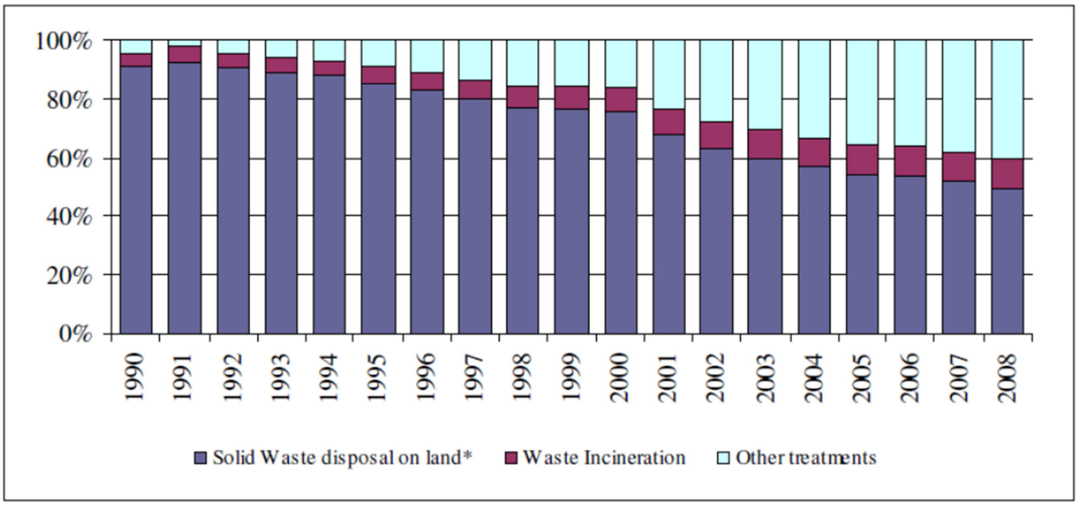


*Figure 2.4 - Percentage of municipal solid waste treatment and disposal, 1990 – 2008 (%) *except sludge [33].*

For the year 2008, the MSW landfills in Italy dispose 15,981 kt of wastes. One of the most important parameter that influences the estimation of emissions from landfills is the waste composition.

Table 2.1 - Waste composition 1991-2008 [33].

WASTE COMPONENT	Composition by weight (wet waste)
Food	**26.3%**
Garden and park	**4.5%**
Paper, paperboard	**30.1%**
Textile, leather	**5.1%**
Plastic	15.0%
Metal	3.1%
Inert	6.3%
Bulky waste	0.6%
Various	1.6%
Screened waste (< 2 cm)	7.4%

On the basis of the waste composition, waste stream have been categorized in three main types: rapidly biodegradable waste, moderately biodegradable waste and slowly biodegradable waste, as reported in Table 2.2 [33].

Table 2.2 - Waste biodegradability [33].

Waste biodegradability	Rapidly biodegradable	Moderately biodegradable	Slowly biodegradable
Food	X		
Sewage sludge	X		
Garden and park		X	
Paper, paperboard			X
Textiles, leather			X
Wood			X

2.5. Future development and potential

For 2020, business as usual (BAU) global projections indicate that landfill CH_4 will remain the largest source at 55–60% of the total. Landfill CH_4 emissions are stabilizing and decreasing in many developed countries as a result of increased landfill gas recovery combined with waste diversion from landfills through recycling, waste minimization and alternative thermal and biological waste management strategies. However, landfill CH_4 emissions are increasing in developing countries because of larger quantities of municipal solid waste from rising urban populations, increasing economic development and, to some extent, the replacement of open burning and dumping by engineered landfills. Without additional measures, a 50% increase in landfill CH_4 emissions from 2005 to 2020 is projected.

Table 2.4 - Trends for GHG emissions from waste using 1996 and 2006 UNFCCC inventory guidelines, extrapolations and BAU projections ($MtCO_2$-eq, rounded) [34].

Source	1990	1995	2000	2005	2010	2015	2020	Notes
Landfill CH_4	550	585	590	635	700	795	910	Averaged using
Incineration CO_2	40	40	50	50	50	60	60	2006 guidelines
Total	1120	1205	1250	1375	1450	1585	1740	

For the long term, if energy prices continue to increase, there will be more profound changes in waste management strategies related to energy and materials recovery in both developed and developing countries. Thermal processes, which have higher unit costs than landfilling, become more viable as energy prices increase. Because landfills continue to produce CH_4 for many decades, both thermal and biological processes are complementary to increased landfill gas recovery over shorter time frames (high agreement, limited evidence).

To minimize future GHG emissions from the waste sector, it is important to preserve local options for a wide range of integrated and sustainable management strategies. Furthermore, primary reductions in waste generation through recycling, reuse, and waste minimization can provide substantial benefits for the conservation of raw materials and energy. Over the long term, because landfills continue to produce CH_4 for decades, landfill gas recovery will be required at existing landfills even as many countries change to non-landfilling technologies such as incineration, industrial co-combustion, mechanical-biological treatment, large-scale composting and anaerobic digestion. In addition, the ‘back-up’ landfill will continue to be a critical component of municipal solid waste planning. In developing countries, investment in improved waste management confers significant co-benefits for public health and safety, environmental protection and infrastructure development [37].

2.6. Waste management as a wedge of PolyGame

The "National Observatory on Waste Report 2008" announced that the production of municipal waste to Italy in 2007 was 32.547.543 t [35]. Considering that more or less 50% of the waste are landfilled, about 16,3 Mt of waste are managed through landfill.

Reducing 5 Mt/year CO_2 emissions in waste management means to send waste to incinerator, to do composting, improve the recycling systems, improve management systems like described in the previous parts. To evaluate the sufficient quantity to be treated in an alternative way to the landfill is necessary to know the emission factors associated with the treatment of waste. From literature we can consider that for every tonne of waste sent to landfill we have 829 kg of CO_2 eq. while a ton of MSW, using solid waste integrated management, emits 102 kg CO_2 eq. [26] [34] [36]. Using these data one obtains that about 6,8 Mt MSW have to be geared to the integrated management of waste.

Finally, in order to reduce CO_2 emissions by 5 Mt/year, it will be necessary to reduce by 42% the use of landfills.

3.

DEFORESTATION CONTROL

3.1. Forest is a Carbon sink

With the rise in importance of potential global climate change, decision makers are actively exploring the possibility of using forests as a carbon sink [38]. Sinks are systems that absorb and store greenhouse gases, mainly carbon dioxide (CO_2) [39]. Forest sinks hold enormous potential as one of the most efficient, low-cost ways to capture or sequester carbon [40].
Forests and trees are important components of the global C cycle as they store large quantities of carbon in vegetation and soils. However, forests are both sources and sinks of atmospheric CO_2. They release carbon to the atmosphere when disturbed by natural or human causes, and they absorb atmospheric CO_2 when vegetation and soil carbon accumulate after afforestation or natural revegetation [41].

3.2. History

Urbanization, industrialization and intensive agriculture often result in rapid landscape changes, losses of ecological capacity, diversity, and scenic beauty, as well as damage to historically valuable cultural landscape [42]. Worldwide, historical demand for land, timber products and energy has removed a large part of the Earth's original forest cover, most of it during the 20th century [43]. On the global scale, during the last decade of the 20th century, deforestation in the tropics and forest regrowth in the temperate zone and parts of the boreal zone remained the major factors responsible for CO_2 emissions and removals, respectively. Emissions from deforestation in the 1990s are estimated at 5.8 $GtCO_2$/yr [44].

3.3. Impacts of climate change on forests

Forests have the capacity to both emit and sequester carbon dioxide (CO_2), a leading greenhouse gas that contributes to climate change. Trees, through the process of photosynthesis, naturally absorb CO_2 from the atmosphere and store the gas as carbon in their biomass, i.e. trunk (bole), leaves, branches, and roots. Carbon is also stored in the soils that support the forest, as well as the understory plants and litter on the forest floor. Wood products that are harvested from forests can also provide long term storage of carbon.

When trees are disturbed, through events like fire, disease, pests or harvest, some of their stored carbon may oxidize or decay over time releasing CO_2 into the atmosphere. The quantity and rate of CO_2 that is emitted may vary, depending on the particular circumstances of the disturbance. Forests function as reservoirs in storing CO_2. Depending on how forests are managed or impacted by natural events, they can be a net source of emissions, resulting in a decrease to the reservoir, or a net sink, resulting in an increase of CO_2 to the reservoir [45].

Net CO_2 Benefit = (CO_2 Sequestered + CO_2 Emissions Avoided) - CO_2 Released [46].

In other words, forests may have a net negative or net positive impact on the climate [45].

The rate of carbon absorption depends on the amount of dry biomass in the forest. Trees typically grow slowly at first, then at an increasing rate until growth begins to level off as they approach maturity The growth pattern depends on species, climatic conditions, soil fertility, and other factors. In some parts of the world, certain species grow quickly and can accumulate substantial biomass in less than a decade [47].

3.3.1. Global Forest and their Carbon storage capacity

Estimates made for FRA (Forest Resources Assessment) 2010 show that the world's forests store more than 650 billion tonnes of carbon, 44% in the biomass, 11% in dead wood and litter; and 45% in the soil. The estimated total carbon stock in forests in 2010 is 652 billion tonnes, which equates to 161.8 tonnes per hectare. The total carbon stock has decreased during the period 1990-2010, mainly as a result of the loss of forest area during the period. Carbon stocks per hectare show a slight increase, but it is unlikely to be significant in statistical terms [48].

Tropical forests (mainly restricted to the land area between the latitudes 22:50 North and 22:50 South of the Equator) play a vital role in C forest sinks because they account for slightly less than half of the total area forest of the World, divided between three main continents: South and Central America (32% of land area), Africa (52%) and South and South East Asia (17%). A huge amount of C is held in their vegetation and soils, which is as much as the sum of temperate zone and boreal forests combined. Trees in tropical forests store about 50% more Carbon per hectare than trees outside the tropics. The average biomass of tropical forests is estimated at 129 t C/ha while average biomass of non-tropical forests is estimated at 45 t C/ha [49].

Tropical deforestation is considered the second largest source of greenhouse gas emissions and is expected to remain a major emission source for the foreseeable future. Tropical deforestation released over 1.6 billion metric tons of carbon (GtC) to the atmosphere annually throughout the period 1990-2010, accounting for almost 20% of anthropogenic greenhouse gas emissions.

According to Yadvinder Malhi (2010) tropical biome conversion is estimated to be a source of around 1.3±0.2 Pg C year^{-}1 to the atmosphere in the period 1990-2005, whereas intact tropical biomes were estimated to be a net carbon sink of 1.1±0.3 Pg C year^{-}1, and it was 23% lower their former estimate of Van der Werf et al., 2009.

Deforestation is caused by exploitation of natural resources including expanding populations, logging, agriculture, biofuel production, and wild res. Clearing forests for the production of biofuels is causing major concern, as experts contend that it has a significant negative impact on forests without doing much to reduce greenhouse gas emissions [50]. In most cases, drivers of deforestation are a combination of direct and indirect economic, institutional, political, natural or social factors.

Direct causes: Land-use changes.

Agricultural expansion is a leading cause worldwide due to population pressure, with more land being needed to grow food and non-food crops and to expand pasture for livestock production. This is driven mainly by the sharp increase in demand for livestock products especially in Asia, where land scarcity has led producers to rely increasingly on imported feed. The emerging market for agrifuels could also exert further pressure on forest resources.
Mining for the extraction of natural resources is frequently a destructive activity that damages forest ecosystems, causing problems for people living near to and downstream of mining operations.

Infrastructure development.

Development of new, or expansion of existing, infrastructures such as roads, urban and industrial settlement, energy plants and lines contribute to the deforestation process. New forest roads can also provide farmers with easier access to previously inaccessible land, thus extending the agricultural frontier.

Unsustainable and illegal logging.

Unsustainable and illegal logging, mainly targeting high commercial value trees, can contribute to deforestation and forest degradation.

Indirect causes: Institutional issues.

In some countries, governments have put in place policies which indirectly en- courage deforestation through agriculture incentives, transportation and infrastructure development, urban expansion, and timber subsidies. Policies that are outside the forest sector, such as land planning, infrastructure development, mining/quarrying, agriculture, land tenure, etc. can have a large impact on deforestation.

Equivalent rates of deforestation will generally cause more carbon to be released from the tropical forests than from forests outside the tropics. Thus, avoiding deforestation specially in tropical forest plays a significant role in carbon dioxide mitigation since only deforestation accounts for around 20% of global carbon dioxide (CO_2) emissions [50].
Trends in the rates of tropical deforestation are difficult to predict, but at todays rates, without implementation of effective policies and measures to slow deforestation, clearing of tropical forests will likely release an additional 87 to 130 GtC by 2100, corresponding to the carbon release of more than a decade of global fossil fuel combustion at current rates.

3.4. Current situation

3.4.1. World situation

Deforestation, mainly due to conversion of forests to agricultural land, shows signs of decreasing in several countries but continues at an alarmingly high rate in others. Globally around 13 million hectares of forest were converted to other uses or lost through natural causes each year in the last decade. This compares with a revised figure of 16 million hectares per year in the 1990s. Both Brazil and Indonesia (which had the highest net loss of forest in the 1990s) have significantly reduced their rates of loss, while in Australia, severe drought and forest fires have exacerbated the loss of forest since 2000. At the same time, afforestation and natural expansion of forests in some countries and regions have significantly reduced the net loss of forest area at the global level. The total net change in forest area in the period 1990–2000 is estimated at -8.3 million hectares per year, which is equivalent to a loss of 0.20 percent of the remaining forest area each year during this period. The total net change in forest area in the period 2000–2010 is estimated at -5.2 million hectares per year, an area slightly bigger than the size of Costa Rica, or equivalent to a loss of more than 140 km^2 of forest per day. The current annual net loss is 37 percent lower than that in the 1990s, and equals a loss of 0.13 percent of the remaining forest area each year during this period. This substantial reduction in the rate of forest loss is a result of both a decrease in the deforestation rate and an increase in the area of new forest established through planting or seeding and natural expansion of existing forests.

The ten countries with the largest net loss per year in the period 1990–2000 had a combined net loss of forest area of 7.9 million hectares per year. In the period 2000–2010, this was reduced to 6.0 million hectares per year as a result of reductions in Indonesia, Sudan and Brazil and despite increased net losses in Australia.

Table 3.1 - The ten countries with the largest annual net loss of forest area, 1990–2010 [51].

Country	Annual change 1990–2000		Country	Annual change 2000–2010	
	1 000 ha/yr	%		1 000 ha/yr	%
Brazil	-2 890	-0.51	Brazil	-2 642	-0.49
Indonesia	-1 914	-1.75	Australia	-562	-0.37
Sudan	-589	-0.80	Indonesia	-498	-0.51
Myanmar	-435	-1.17	Nigeria	-410	-3.67
Nigeria	-410	-2.68	United Republic of Tanzania	-403	-1.13
United Republic of Tanzania	-403	-1.02	Zimbabwe	-327	-1.88
Mexico	-354	-0.52	Democratic Republic of the Congo	-311	-0.20
Zimbabwe	-327	-1.58	Myanmar	-310	-0.93
Democratic Republic of the Congo	-311	-0.20	Bolivia (Plurinational State of)	-290	-0.49
Argentina	-293	-0.88	Venezuela (Bolivarian Republic of)	-288	-0.60
Total	**-7 926**	**-0.71**	**Total**	**-6 040**	**-0.53**

The ten countries with the largest net gain per year in the period 1990–2000 had a combined net gain of forest area of 3.4 million hectares per year due to afforestation efforts and natural expansion of forests. In the period 2000–2010, this increased to 4.4 million hectares per year due to the implementation of ambitious afforestation programs in China.

Table 3.2 - The ten countries with the largest annual net gain in forest area, 1990–2010 [51].

Country	Annual change 1990–2000		Country	Annual change 2000–2010	
	1 000 ha/yr	%		1 000 ha/yr	%
China	1 986	1.20	China	2 986	1.57
United States of America	386	0.13	United States of America	383	0.13
Spain	317	2.09	India	304	0.46
Viet Nam	236	2.28	Viet Nam	207	1.64
India	145	0.22	Turkey	119	1.11
France	82	0.55	Spain	119	0.68
Italy	78	0.98	Sweden	81	0.29
Chile	57	0.37	Italy	78	0.90
Finland	57	0.26	Norway	76	0.79
Philippines	55	0.80	France	60	0.38
Total	3 399	0.55	Total	4 414	0.67

At the global level, the area of other wooded land decreased by about 3.1 million hectares per year during the decade 1990 to 2000 and by about 1.9 million hectares per year during the decade 2000 to 2010.

In Europe it decreased in the period 1990–2000, but remained almost constant in the period 2000–2010. The area of other wooded land decreased in both periods in Africa, Asia and South America.

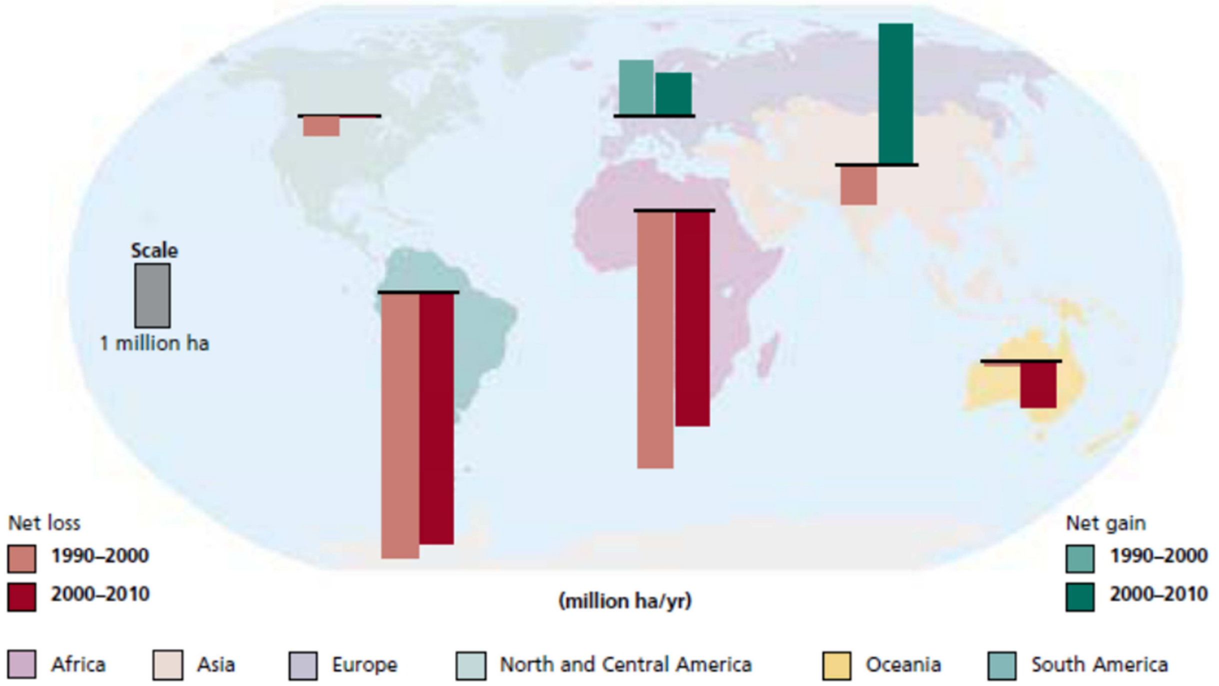


Figure 3.1 - Annual change in forest area by region, 1990-2010 [51].

From these data is it possible estimates that the world's forests store 289 gigatonnes (Gt) of carbon in their biomass alone. While sustainable management, planting and rehabilitation of forests can conserve or increase forest carbon stocks, deforestation, degradation and poor forest management reduce them. For the world as a whole, carbon stocks in forest biomass decreased by an estimated 0.5 Gt annually during the period 2005–2010, mainly because of a reduction in the global forest area [51].

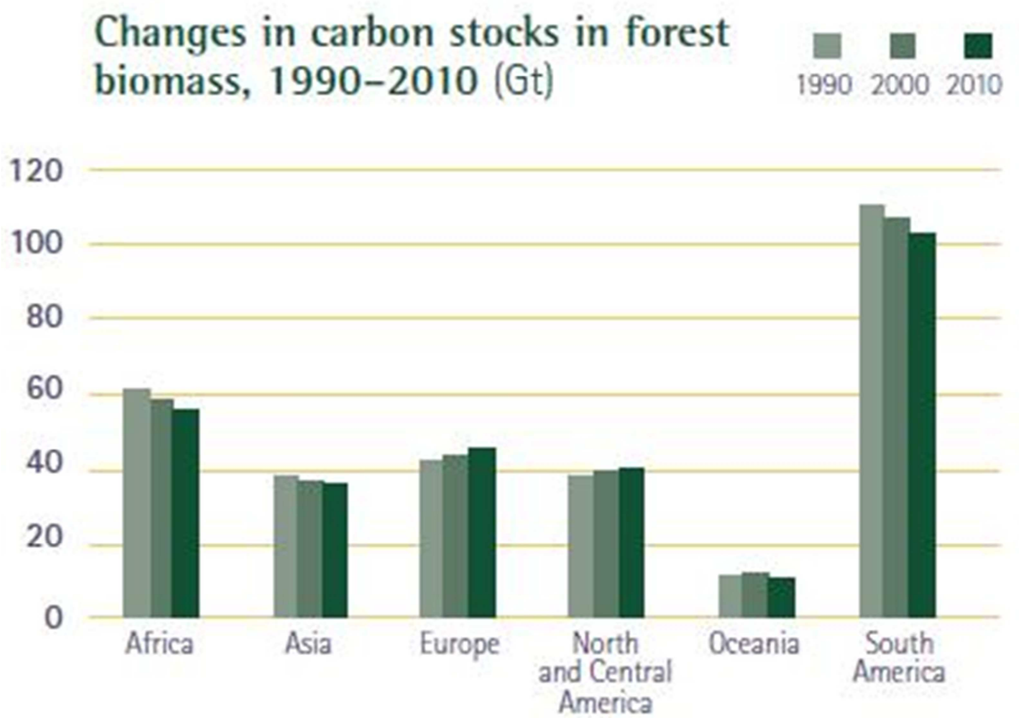


Figure 3.2 - Changes in carbon stocks in forest biomass, 1990-2010 (Gt) [52].

3.4.2. Characteristics of the world's forests.

Primary forests account for 36% of forest area, but have decreased by more than 40 million hectares since 2000. On a global average, more than one third of all forest is primary forest, i.e. forest of native species where there are no clearly visible indications of human activities and the ecological processes have not been significantly disturbed. Primary forests, in particular tropical moist forests, include the most species-rich, diverse terrestrial ecosystems. The decrease of primary forest area, 0.4 percent over a ten-year period, is largely due to reclassification of primary forest to "other naturally regenerated forest" because of selective logging and other human interventions. The area of planted forest is increasing – it now accounts for 7% of total forest area Forests and trees are planted for many purposes and make up an estimated 7 percent of the total forest area, or 264 million hectares. During 2005–2010, the area of planted forest increased by about 5 million hectares per year. Most of this was established through afforestation, i.e. planting of areas not forested in recent times, particularly in China. Three-quarters of all planted forests consist of native species while one-quarter comprises introduced species [52].

3.4.3. Italian situation

Extent of forest and other wooded land 2010 in Italy.

Table 3.3 - Extent of forest and other wooded land 2010 [53].

Forest		Other wooded land		Other land (1 000 ha)	
1 000 ha	% of land area	1 000 ha	% of land area	Total	of which with tree cover
9149	31	1767	6	18495	-

In Italy, roadleaved species make up two thirds of the volume of growing stock, the principal species being beech, deciduous and evergreen oaks, poplars and chestnut. The main coniferous species are pines, Norway spruce and European larch. Three fifths of the forest is available for wood supply and two fifths not available, partly for conservation, partly for economic reasons. Virtually all forest is semi-natural, with some areas of plantations, including introduced species such as some poplar species, Douglas fir, radiata pine and eucalyptus; the area of forest and other wooded land undisturbed by man is small. Two thirds of Italian forests are privately owned, mostly by individuals in small holdings; one third is publicly owned, mainly by communes and municipalities. Non-wood forest products are of importance for the rural economy [53].

Table 3.4 - Trends in extent of forest 1990-2010 [53].

Forest area (1 000 ha)				Annual change rate					
1990	2000	2005	2010	1990-2000		2000-2005		2005-2010	
				1 000 ha/yr	%	1 000 ha/yr	%	1 000 ha/yr	%
7590	8369	8759	9149	78	0,98	78	0,92	78	0,88

3.5. Future development and potential

3.5.1. Forest Mitigation Activities

Forest mitigation options include reducing emissions from deforestation and forest degradation, enhancing the sequestration rate in existing and new forests, providing wood fuels as a substitute for fossil fuels, and providing wood products for more energy intensive materials. The important strategy is the design of a forest sector mitigation portfolio should consider the trade-off is between increasing forest ecosystem carbon stocks and increasing the sustainable rate of harvest and transfer of carbon to meet human needs. The selection of forest sector mitigation strategies should minimize net GHG emissions throughout the forest sector and other sectors affected by these mitigation activities [53].

3.5.2. Reducing deforestation and degradation

Globally, reduced deforestation and degradation is the forest mitigation option with the largest and most immediate carbon stock impact in the short term per ha and per year, because those activities could prevent the emissions of about 350-900 tCO_2/ha [50]. In addition, Sathaye et al.(2008) [54] applied the three models which are Dynamic Integrated Model of Forestry and Alternative Land Use (DIMA), the Generalized Comprehensive Mitigation Assessment Process Model (GCOMAP) [54], and the Global Timber Model (GTM) [55], to estimate the global carbon dioxide mitigation and the costs of reduced emissions by avoiding deforestations. According to the research, the results generally indicate that substantial emission reductions can be accomplished over the entire 25 year period examined. For \$20/tCO_2, the models project that the average global emission reduction from AD activities between 2005 and 2030 would be in the range of 1.6 to 4.3 $GtCO_2$/yr. For higher prices at \$100/CO_2, the models project emission reductions of 3.1-4.7 $GtCO_2$/yr. The time path of marginal costs suggests that the low cost emission reductions occur earlier on. At \$100/tCO_2, the emission reduction averaged for all three models in 2010 is 4.0 $GtCO_2$/yr, but this falls to 3.1 $GtCO_2$/yr by 2030. Marginal costs tend to rise over time because the lowest-cost opportunities are adopted first and rates of deforestation decline, while later the opportunity costs of land rise because of rising productivity in agriculture. The Table 3.5 describes the results of the prediction of Sathaye (2008) [54].

Table 3.5 - Emission reduction and cost by avoiding deforestation, 2005-2030 [54].

Reduction rate of deforestation (% of Area)	Cost (\$/tCO_2)	Annual reduction (Gt CO_2)	Total Annual Cost (billion \$)
10	2 – 5	0.3 – 0.6	0.4 – 1.7
50	10 – 21	1.5 – 2.7	17.2 – 28

3.5.3. Afforestation and Reforestation

One more forest mitigation option is increasing forest area by afforestation and reforestation which are the direct human-induced conversion of non-forest to forest land through planting, seeding, and/or the human-induced promotion of natural seed sources. The two terms are distinguished by how long the non-forest condition has prevailed [50]. The former is related to the activity of planting seed or trees to make a forest on a land which has not been a forest recently, or which has never been a forest. Reforestation, on the contrary, is the re-establishment of a forest after removal. To date, carbon sequestration has rarely been the primary driver of afforestation, but future changes in carbon valuation could result in large increases in the rates of afforestation (US EPA, 2005) [56]. Afforestation typically leads to increases in biomass and dead organic matter car-bon pools, and to a lesser extent, in soil carbon pools, whose small, slow increases are often hard to detect within the uncertainty ranges. Accumulation of carbon in biomass after afforestation varies greatly by tree species and site, and ranges globally between 1 and 35 tCO_2/ha yr (Richards and Stokes, 2004) [57]. Cost estimates for carbon sequestration projects for different regions compiled by Cacho et al., (2003) [58] and by Richards and Stokes (2004) [57] show a wide range. The cost is in the range of 0.5 US\$ to 7 US\$/tCO_2 for forestry projects in developing countries, compared to 1.4 US\$ to 22 US\$/tCO_2 for forestry projects in industrialized countries. However, old-growth natural forests act as large long-term carbon sinks, accumulating carbon in soils and woody biomass, and preventing its release. By contrast, young forests frequently produce far more CO_2 than their re-growth will absorb, and even mature plantations are almost always net emitters of carbon. That means reducing deforestation is better than afforestation with the respect of environment.

3.6. Deforestation control as a wedge of PolyGame

In Italy, the forest cover an area of about 9.149 billion hectares, corresponding to approximately 31% of the available land. Reduce by an additional 5 Mt / year of CO_2 emissions through forest management, it means to increase the forests extensions [59]. To achieve this, it was calculated that the average yield of CO_2 absorption by forests and soils in temperate zones, such as Italy, is 5.5 tCO_2/ha/anno [60]. Through the average yield of CO_2 is possible to compute that, for obtaining a reduction of 5 Mt / year, is needed to increase 909,256 ha (9093 km^2) forest. In percentage this means to increment the forest surface by about 10%.

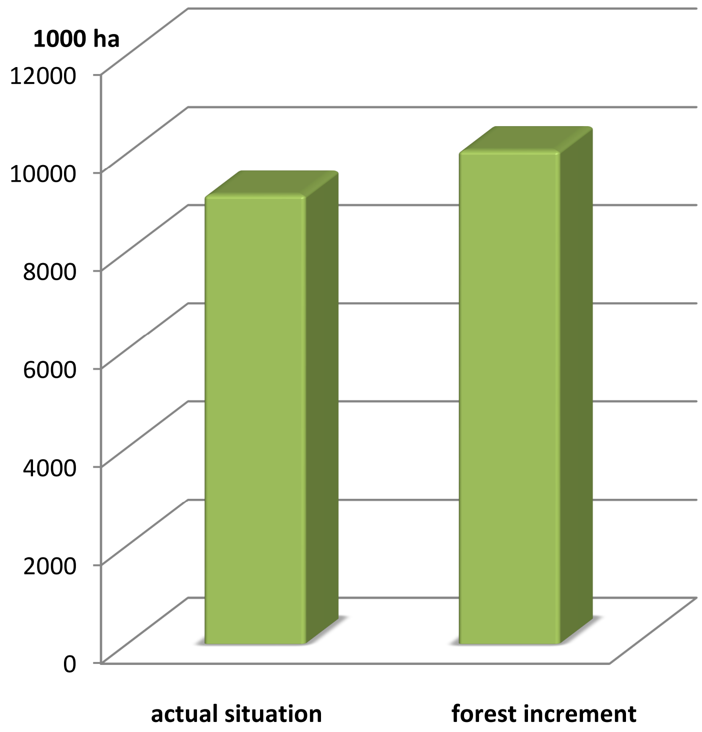


Figure 3.3 – Deforestation control as a wedge of PolyGame.

4.

GEOTHERMAL ENERGY

4.1. Introduction to geothermal energy

Geothermal energy is heat stored in the Earth's crust within the rocks and fluids. This heat can be recovered as steam or hot water and used for several applications (e.g. for heating buildings or generating electricity). The origin of this heat, which is unevenly distributed and often at too large depths to be used, is linked with the internal structure of our planet and the physical processes occurring there [61]. Heat transfer within the Earth's crust takes place by three processes:

1) advection of magma;
2) advection of geothermal fluids and
3) thermal conduction.

Heat transfer associated with the advection of magma and geothermal fluids is a relatively fast process; thermal conduction on the other hand, is a relatively slow process. Heat is transferred from the earth's interior towards the surface mostly by the conduction process; this heat flow makes temperatures rise with increasing depth in the crust by 25 to 30 degrees centigrade on average per kilometer depth. This is called the geothermal gradient [62][61].

A geothermal system (see Figure 4.1) is made up of three main elements: a heat source, a reservoir and a fluid, which is the carrier that transfers the heat. The reservoir is a volume of hot permeable rocks from which the circulating fluids extract heat. The geothermal fluid is water in the liquid or vapor phase, depending on its temperature and pressure [63].

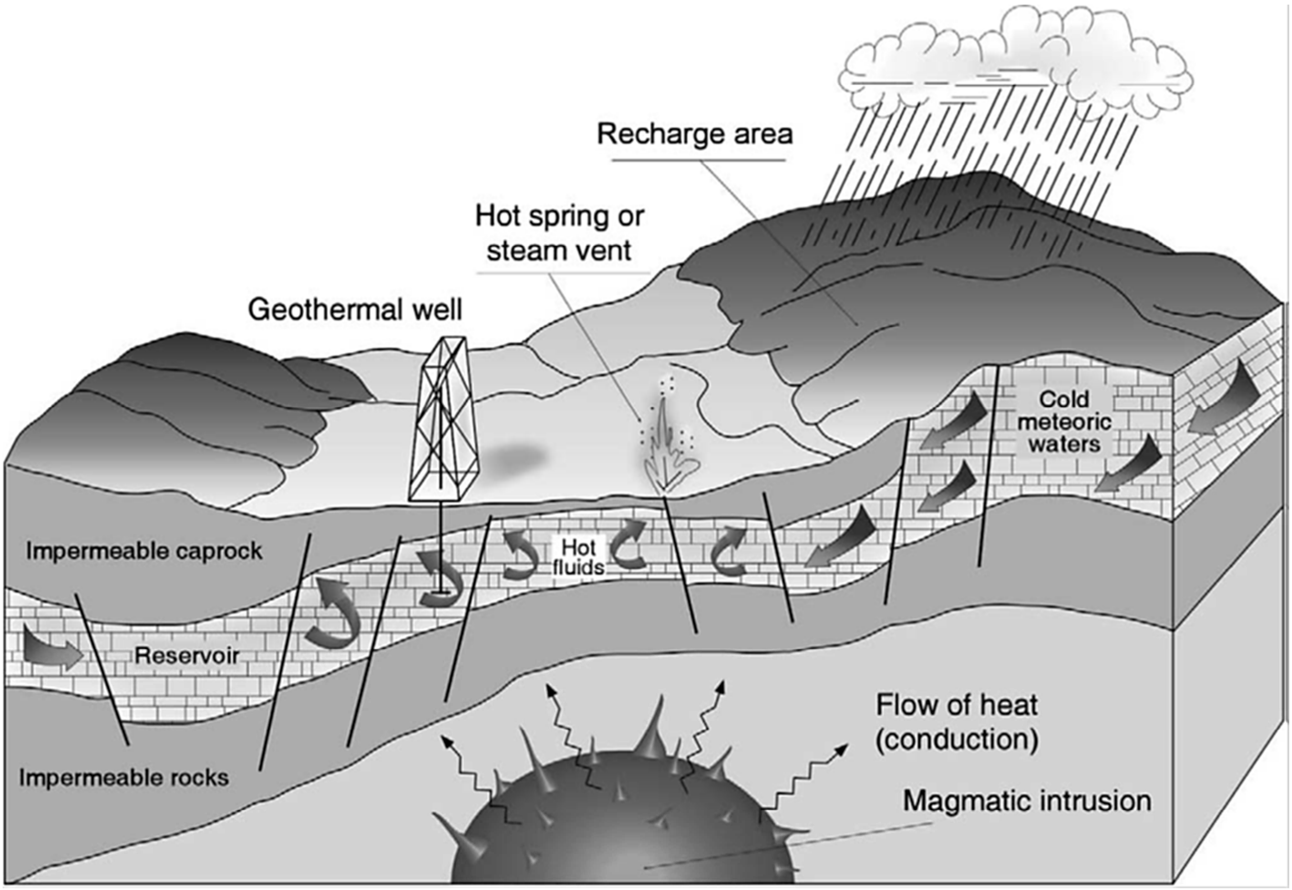


Figure 4.1 - A typical geothermal system with its elements [122].

Geothermal systems can be found in regions with a normal or slightly above normal geothermal gradient, and especially in regions around plate margins where the geothermal gradients may be significantly higher than the average value. In the first case the systems will be characterised by low temperatures, usually no higher than 100 °C [64]; in the second case the temperatures could cover a wide range from low to very high, and even above 400 °C [63].

Geothermal energy is being strongly considered as a potentially inexhaustible energy source [65], but not always can be treated as such. The few studies that examined the sustainability of production from geothermal resources agree that the most critical factor for the classification of geothermal energy as a renewable energy source is considered to be the rate of energy recharge. If energy recharge takes place by advection of thermal water, which is a “fast” process, geothermal energy is certainly a renewable energy resource. On the contrary, if geothermal energy is recharged only by thermal conduction (i.e. via hot and dry rocks), it cannot be classified as renewable anymore, because the rate of the process is too slow [63][61].

Furthermore, it must be considered that geothermal energy has several potential environmental impacts that are usually mitigated. These are emission of harmful gases, noise pollution, water use and quality, land use, and impact on natural phenomena, wildlife and vegetation [65][66][67].

Geothermal utilization is commonly divided into two categories: electricity production at large scale (for high-temperature geothermal resources, with temperature >150 °C) and direct application to the end user (for medium-to-low temperature resources) [68][69].

Electricity production

As for electricity production, three main conversion technologies are available at present (see Figure 4.2):

- Dry steam plants, where steam from production wells is gathered and transmitted via pipelines directly to a steam turbine [66].
- Flash plants, taking hot water out of the ground and allow it to boil as it rises to surface [68].
- Binary plants, where a secondary working fluid is used. The geothermal fluid yields heat to the secondary fluid (characterised by a low boiling point) through heat exchangers, in which this fluid is heated and vaporizes [63].

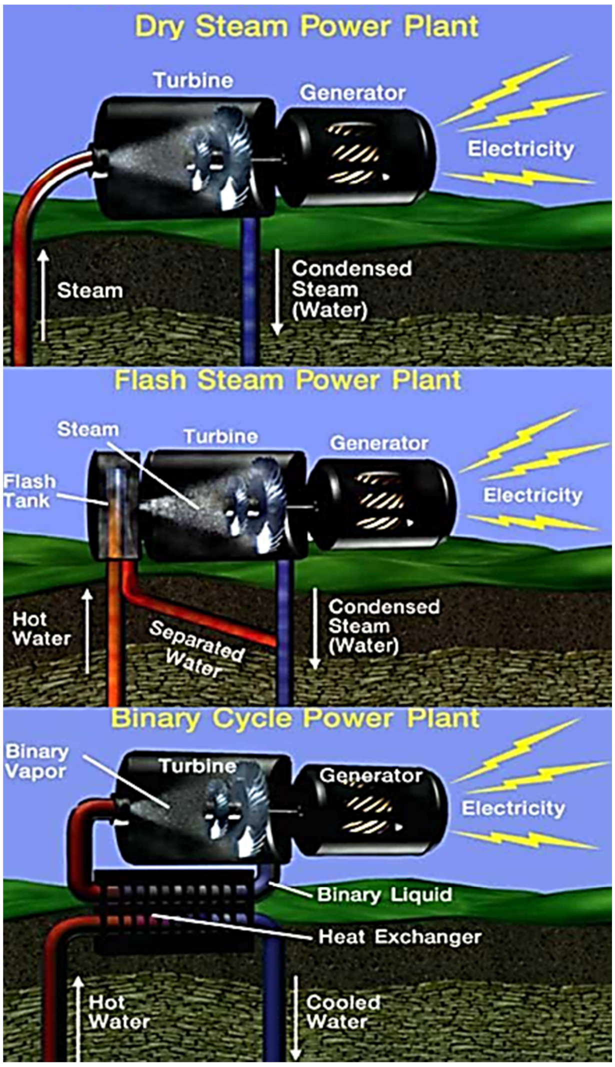


Figure 4.2 - Diagrams of the three main types of geothermal power plants [128].

To take advantage of both technologies, oftentimes a combination of flash and binary technologies, known as the flash/binary combined cycle, is implemented.
Resource characteristics, temperature, pressure, volumes of fluid produced, and chemical properties of the geothermal reservoir are the primary determinants of the size and type of power conversion equipment. If sufficient volumes of fluid are produced, the temperature determines the most efficient conversion design [70]. Dry steam plants enable generation of electricity directly from

high temperature steam, flash technology from steam-water mixtures at intermediate temperatures and binary plants from geothermal water with either intermediate and low temperature (70-170°C) [71]. Hence, while binary plants can utilize various temperature resources, low temperature resources impose the use of a binary plant [70].
In addition to the conversion technologies presented so far, several “non-traditional” technology applications have also been considered. Some are emerging and could further expand geothermal potential [72]. Among them, hybrid systems and above all enhanced geothermal systems (EGS) are the most promising. Hybrid plants combine in various ways the plants described above, in order to achieve higher efficiencies. Direct-steam/binary units; and flash-steam/binary units are two common combinations [66]. EGS aims at extracting geothermal energy from hot rocks where fracture permeability and fluid circulation lack, by creating permeability through fracturing, and maintaining fluid circulation in the fractures by means of a system of injection, so that the thermal energy can be transmitted to the land surface [73].

Direct use

Direct use applications exploit directly underground hot water. Direct application of geothermal energy can be both at small and large scale, involving a wide variety of end uses. The main utilization categories are: (1) bathing and swimming; (2) space heating and cooling including district energy systems; (3) agribusiness applications such as greenhouse heating, aquaculture, irrigation and soil heating; (4) snow melting; (5) industrial applications such as mineral extraction, food and grain drying; and, (6) geothermal (ground-source) heat pumps (GHP), used for both heating and cooling [74][75].
Space heating, including heat pumps, is the most common type of direct use of geothermal fluids [71]. Direct applications can use low-to-moderate temperature geothermal resources. Since these resources are more abundant and easier to be exploited, direct use is more widespread in the world than electricity production and exists in at least 80 countries [76][75]. The technology, reliability, economics, and environmental acceptability of direct use of geothermal energy has been demonstrated throughout the world [76].

4.2. History

Practical uses of geothermal energy, for bathing, washing and cooking, date back to prehistory. Early humans probably used geothermal water that occurred in natural pools and hot springs. There is archeological evidence that the Indians of the Americas occupied sites around these geothermal resources for over 10000 years to recuperate from battle and take refuge [75]. Moreover, there are written records of geothermal usage in China which are over two thousand years old [76]. Also the Etruscans, Romans, Greeks, Indians, Mexicans and Japanese have all left evidence that they used hot waters in ancient times, where these waters were commonly thought to have healing properties [61].
Space heating with hot air was known during Roman times, but radiators for space heating first became common a century ago [76]. Even in Iceland, where hot springs are abundant and Reykjavik is at present the only capital city of the world heated entirely by geothermal energy,

geothermal space heating was first installed in a house in 1909 [61]. Between 1910 and 1940 the low pressure steam from Larderello site in Tuscany was brought into use to heat the industrial and residential buildings and greenhouses [63].
The first use of geothermal energy for electric power production was in Italy with experimental work by Prince Gionori Conti between 1904 and 1905 and the first commercial power plant was commissioned in 1913 at Larderello [75][61]. Since 1950 other countries have followed the Italian example. In 1958 a small geothermal power plant began operating in New Zealand, in 1959 another began in Mexico, in 1960 in the USA, followed by many other countries in the years to come [63].

4.3. Geothermal energy and GHG mitigation

In a comparison with the amount of greenhouse gases (GHG) emitted from different types of power plant, the environmental benefits using a geothermal plant are evident and documented in Figure 4.3). Geothermal power plants do not practically emit CO_2 nor other important GHG, such as nitrous oxides and methane [77].

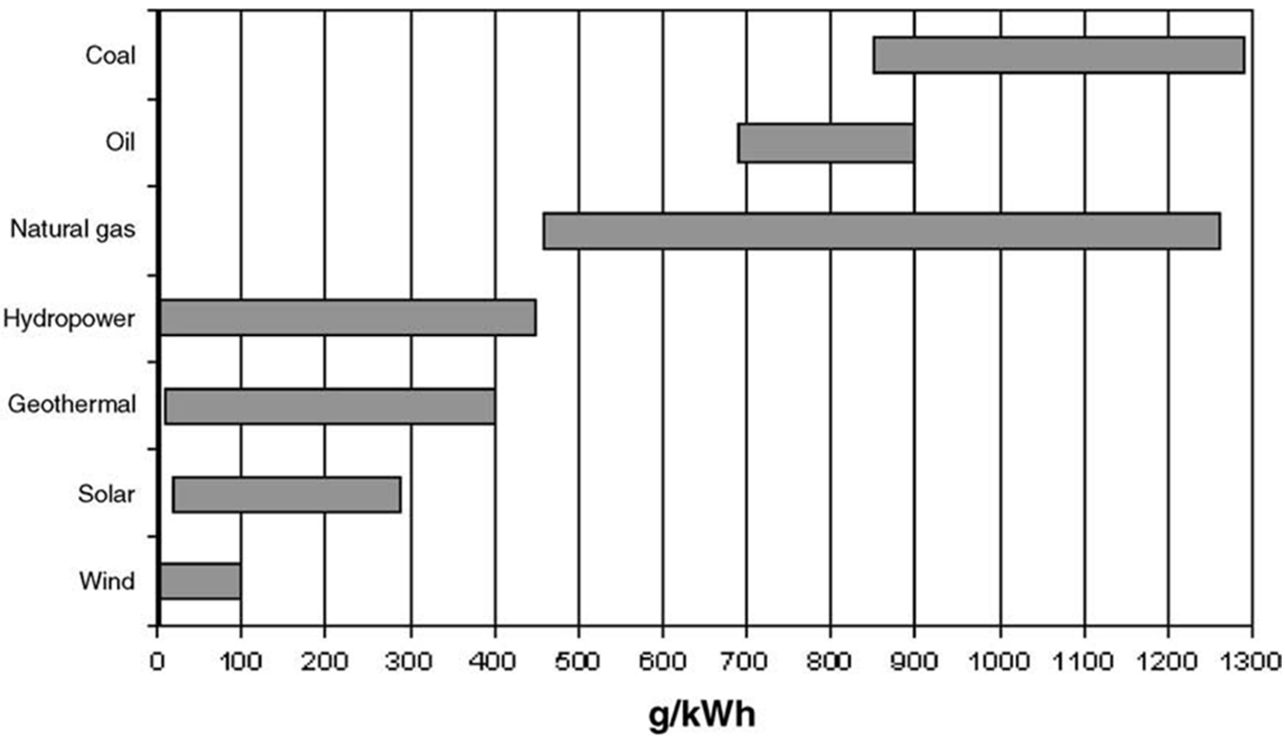


Figure 4.3 – GHG emissions from various types of energetic resources used to generate electricity (CO_2-eq.) [78].

Bertani and Thain (2002) described the results of a survey of CO_2 emissions from geothermal power plants and they found for the emissions from geothermal plants a weighted average of 122 g kWh^{-1} [79]. However, the amount of carbon dioxide found in geothermal fluid, and hence the amount of carbon dioxide actually released into the atmosphere, can vary depending on location. This makes it difficult to estimate the average amount of carbon dioxide emitted by a generic geothermal power plant. For example, binary plants with air cooling are in a closed loop system and

emit no carbon dioxide because in this system the geothermal fluids are never exposed to the atmosphere [67][63]. Furthermore, the gas emissions from low-temperature geothermal resources are normally only a fraction of the emissions from the high-temperature fields used for electricity production [76]. Hence, a range of emission is preferable to a single value: the range is found to be 13-380 g for every kWh of electricity produced [63].
It has also been pointed out that the CO_2 emitted from geothermal plants is not created by power generation but is CO_2 that would have been vented out gradually through the earth anyway [78]. In fact, geothermal systems are often located in volcanic terrains or other areas characterized by high CO_2 fluxes of magmatic origin or derived from metamorphism of carbonate rocks at depth [79]. A research made by Bertani and Thain from volcanic terrains of Larderello site suggests that the development of geothermal fields makes no difference to the total CO_2 emanated from those terrains [78]. They concluded that all gas discharge resulting from power production is balanced by a reduction in natural emissions, and that the resultant net change is insignificant. On the basis of these results, Italy decided not to consider CO_2 emission from geothermal plants as anthropogenic [79].

4.4. Current situation

4.4.1. World situation

Both the number of countries producing geothermal power and the total worldwide geothermal power capacity appear to be significantly increasing [80]. Global installed electrical capacity at the end of 2010 was 10715 MW, with a 20% increase in geothermal power on line between 2005 and 2010 [71][80]. The growth of geothermal utilization for power generation has averaged roughly 5.5% per year over the last 30 years, and the geothermal installed capacity in the world has been increased by about 1 GW every 5 years (see Figure 4.4) [71].

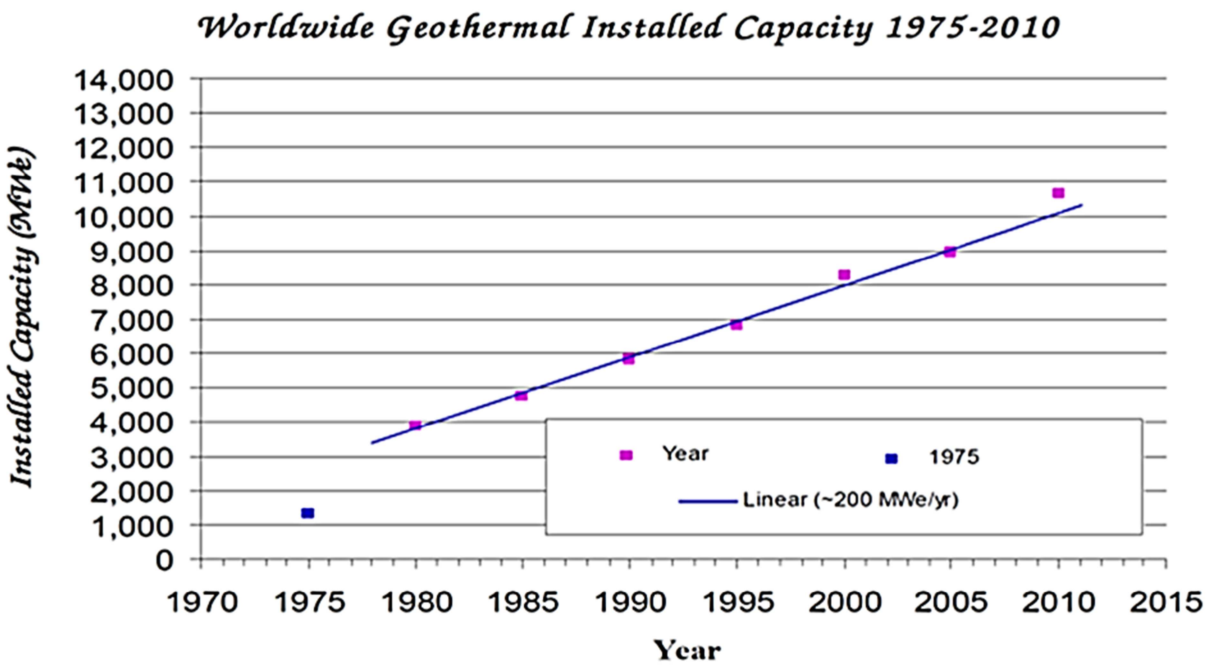


Figure 4.4 - Worldwide geothermal installed capacity for the period 1975-2010 [81].

In 2010 the top-five countries generating geothermal power were (see Figure 4.5), in descending order: US (3086 MW) Philippines (1900 MW), Indonesia (1200 MW), Mexico and Italy (below 1 GW). The highest growth between 2005 and 2010 took place in US, Indonesia and Iceland [80]. More than 97 % of the 2010 geothermal production was from reservoirs heated by volcanic magma bodies. [82].

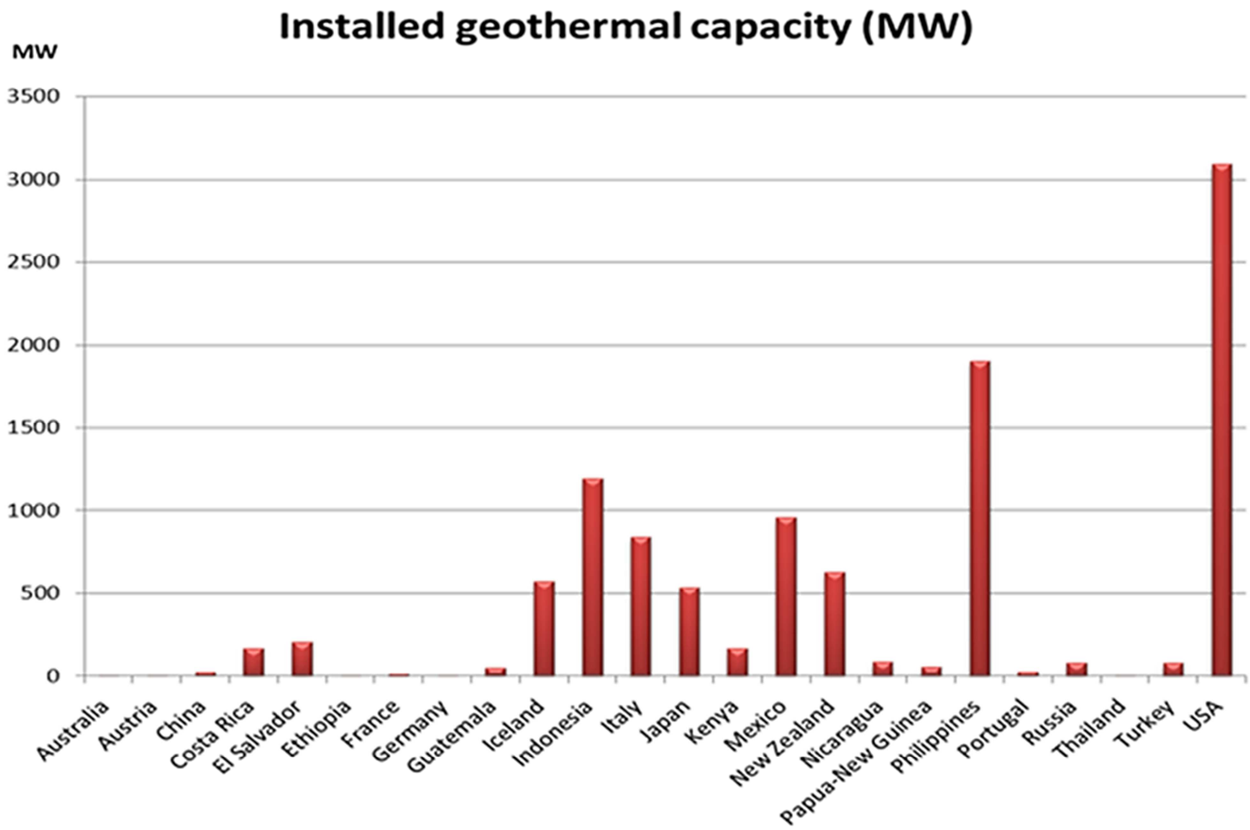


Figure 4.5 - Installed geothermal electrical capacity by country in 2010 (MW) [71].

As for direct applications, the total installed capacity, reported through the end of 2009 for geothermal direct utilization worldwide was 50583 MW_{th}, a 78.9% increase from 2005, growing at an annual compound rate of 12.33%. The total annual energy use was 121696 GWh, indicating a 60.2% increase over 2005. Therefore, the worldwide capacity factor is slowly declining, being 0.28 in 2009 down from 0.31 in 2005 and 0.40 in 2000. In 1985, only 14 countries reported an installed capacity of more than 100 MW_{th}. At the end of 2009, there were 36 countries reporting over 100 MW_{th}, an increase of 3 countries over 2005. The five countries with the largest installed capacity are: USA, China, Sweden, Norway and Germany accounting for 60% of the world capacity. However, an examination of the data in terms of land area or population shows that the smaller countries dominate, especially the Nordic ones [74].

The growing awareness and popularity of geothermal heat pumps have had the most significant impact on direct-use of geothermal energy. The other two most common applications in direct use of geothermal power are for balneology and space heating (see Table 4.1) [81].

Table 4.1 - Worldwide geothermal direct use categories and their development 1995-2005 [81].

Category	Capacity (MWth)					Utilization (TJ/yr)				
	1995	2000	2005	2007	2008	1995	2000	2005	2007	2008
Geothermal heat pumps	1,854	5,275	15,384	19,010	-	14,617	23,275	87,503	105,000	-
Space heating	2,579	3,263	4,366	-	-	38,230	42,926	55,256	-	-
Greenhouse heating	1,085	1,246	1,404	-	-	15,742	17,864	20,661	-	-
Aquaculture pond heating	1,097	605	616	-	-	13,493	11,733	10,976	-	-
Agricultural drying	67	74	157	-	-	1,124	1,038	2,013	-	-
Industrial uses	544	474	484	-	-	10,120	10,220	10,868	-	-
Bathing and swimming	1,085	3,957	5,401	-	-	15,742	79,546	83,018	-	-
Cooling/snow melting	115	114	371	-	-	1,124	1,063	2,032	-	-
Others	238	137	86	-	-	2,249	3,034	1,045	-	-
Total	**8,664**	**15,145**	**28,269**	**35,570**	**36,023**	**112,441**	**190,699**	**273,372**	**329,270**	**329,880**

4.4.2. Italian situation

In Italy the most interesting geothermal opportunity is the exploitation of high-temperature steam reservoirs to generate electricity [84][81]. Italy's major geothermal areas of Larderello-Travale/Radicondoli and Mount Amiata (see Figure 4.6) have seen sustained development over the past century [83]. Tuscany is the Italian region where all the geothermal power plants are located. With the addition of two new geothermal power units in 2009, the total installed geothermal power capacity in Italy reached 843 MW [80]. In 2008, the net electricity generation reached 5200 GWh; though this represents only 1.8% of Italy's total domestic generation, it meets about 25% of the electricity demand in Tuscany [81]. If the decision makers would be inclined to stimulate geothermal energy, the fraction of the country's electricity generated from this source could rise five-fold so reaching as much as 10% within the next 10 years [80]. However, some obstacle to new plants has to be overcome. The main one is local opposition for environmental reasons [84].

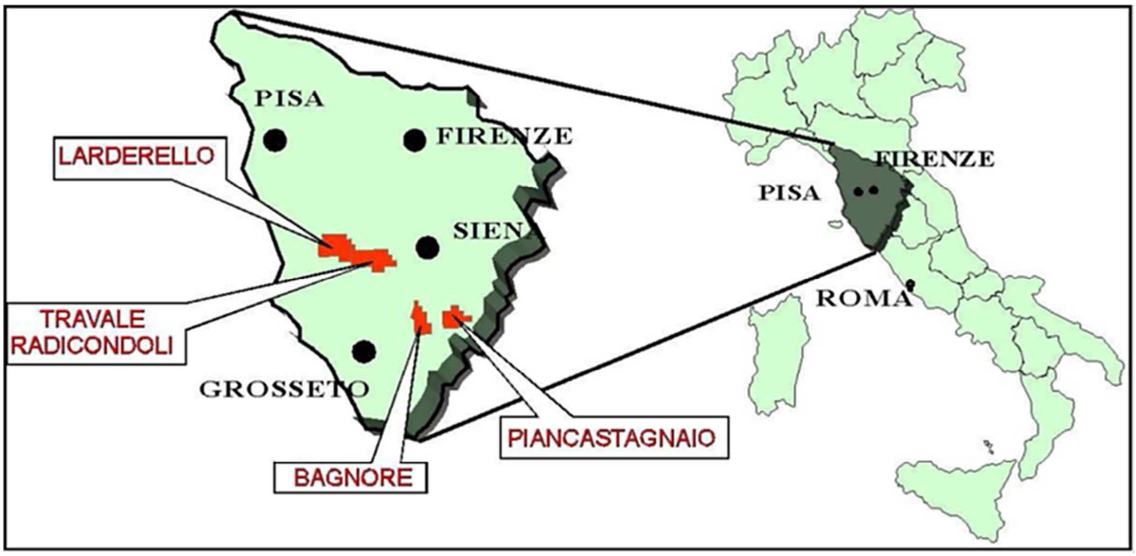


Figure 4.6 - Location of geothermal plants in Italy [85].

Geothermal direct-use has increased by a factor of 1.2 from 2004 to 2009, reaching 867 MW_{th} and 2761 GWh/yr. Installations of geothermal heat pumps has increased 15% in 2010 with about 12000 units installed. However, this larger contribution, in terms of installed power, is mainly due to the wide development, mainly in the northern areas of Italy, of geothermal district heating and in the number of single household installation [86].
At present, most of the direct applications (60% of the supply) are devoted to bathing (temperatures less than 40°C), which has a long tradition in Italy, dating back to Etruscan and Roman times. There are also several other uses including space and district heating, fish farming, greenhouses and industrial process heat [81].

4.5. Potential and future development

Only a small fraction of the world´s geothermal potential has been developed so far, and there are ample resources available for a greatly expanded use of geothermal energy both for electricity generation and for direct applications [71]. The greatest potential for development of conventional resources at the planetary scale is in the volcanic chains of the Pacific Rim [82]. In 2005, Stefansson (2005) estimated the most likely worldwide total technical potential for geothermal resources located along tectonic plate boundaries and near volcanic hot spots to be about 6.5 TW_{th}/yr, about 40% of the 2007 worldwide total annual supply [81].
The most pessimistic projection for future growth rate can be considered the twenty five-year trend of 202 MW per year seen between 1980 and 2005; with this trend, the installed capacity would reach about 20000 MW by 2050. A more reasonable assumption for future growth rate may be 413 MW per year seen over the last 5 years. This assumption indicates the prospect of an installed capacity of 28000 MW by 2050. However, it is likely that there would be continuous acceleration in the rate of growth of geothermal power capacity over the next few decades. If this exponential growth rate seen between 2005 and 2010 were to continue over the next few decades, an installed power capacity of 58000 MW would be reached by 2050 (see the optimistic trend in Figure 4.7) [87].

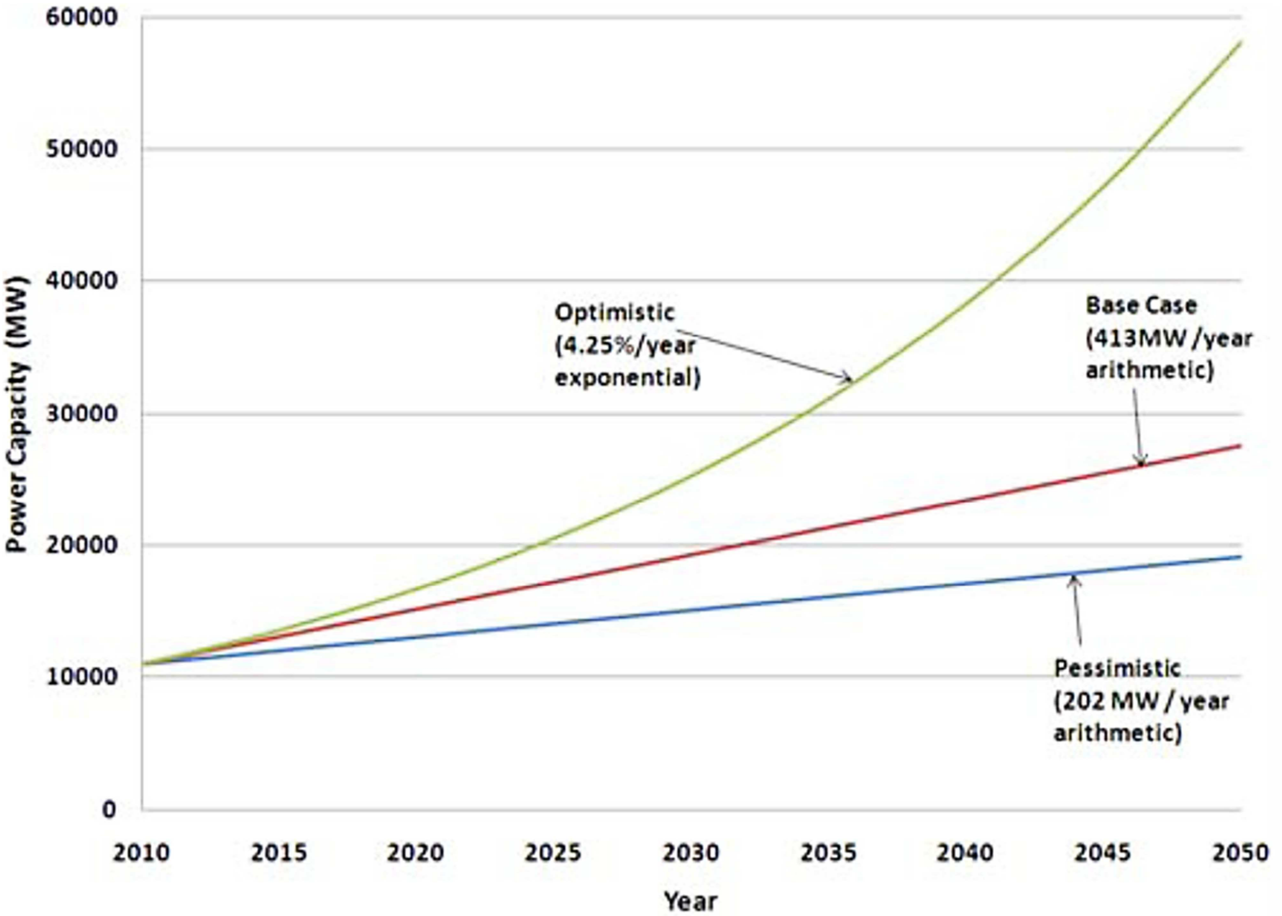


Figure 4.7 - Possible Growth Trends in Worldwide Geothermal Power Capacity [87].

In 2008, Demirbas [88] assessed the global geothermal prospects by 2040. Results showed that the share of global geothermal energy in global renewable energy will be 4.73, 6.90 and 7.76% in 2010, 2020, 2030, and 2040, respectively. As for electricity production, according to this scenario, the share of global geothermal electricity in global total electricity will be 0.67, 1.25, 2.03, and 2.81% in 2010, 2020, 2030, and 2040, respectively.

Finally, forecasts made by International Energy Agency (IEA) in 2008 [15] foresee that geothermal power production will increases twenty-fold to 200 GW in 2050 in the BLUE Map scenario (see Figure 4.8). A significant share of the growth will be based on enhanced geothermal systems (EGS) currently under development. The extent to which the EGS technology will be commercialized is absolutely vital for making prosper geothermal power in the next decades, since the other types of geothermal energy resources offer a much smaller resource base over the long term [87].

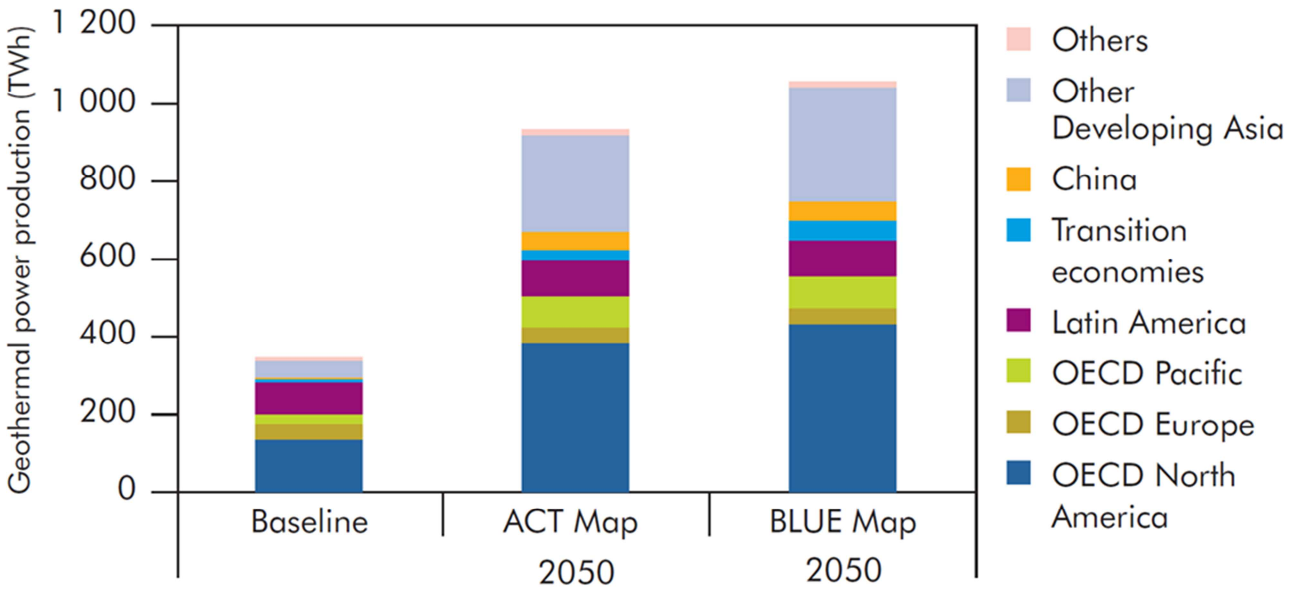


Figure 4.8 - Geothermal forecasted power production for 2050 in IEA's scenarios [15].

4.6. Geothermal power as a wedge of PolyGame

As discussed above, 122 g CO_2/kWh [79] are the average estimated emission in electricity generation from geothermal power plants. Since the average CO_2 intensity in electricity production in Italy was of 380 g CO_2/kWh in 2007, 258 g CO_2 are saved per each KWh produced in a new geothermal power plant. Hence, in order to catch the emission reduction target set above, additional 19385 GWh/year of electricity are required to be generated by geothermal power. This amount corresponds to a total capacity of 2.77 GW, assuming an average capacity factor of 80% for the new plants [62].

In 2008, 5197 GWh were generated from geothermal power plants with an average capacity factor of 89% and the total installed capacity was of 670 MW at the end of the year [89]. As such, the installed capacity and the power generated in Italy should be enhanced by factors of 5.2 and 4.7, respectively. The mismatch between the two incremental factors is due to different capacity factors for the electricity already generated (89%) and the electricity to be generated (80%).

5.

REDUCTION OF CAR USE

5.1. Introduction to car use

Car use is important for many households' activity patterns in western societies. Households use their car to travel to various activities, for instance work, shopping, public services, and leisure activities. However, personal car use has obvious negative effects, such as the use of non-renewable fuel, pollution, noise, and congestion [90].

In several aspects private car use is a future threat to the human environment. This has led to the development and implementation of transport policy measures aiming at reducing or changing car use [91].

The environmental problems associated with private car use, for example air pollution, noise, land use fragmentation, health impacts, and climate change, need to be taken seriously. One way of dealing with these issues is to attempt to reduce travel demand by means of implementing various policies, so called travel demand management (TDM) measures. Structural TDM measures change the context through laws and regulations, economic instruments, or changes of the physical environment in order to influence travel demand. A useful distinction has been made between push measures attempting to make car use less beneficial (e.g., raising the cost for using the car) and pull measures aiming to improve alternative travel options (e.g., improving the public transport). Before implementing TDM measures, the effectiveness of the measures need to be determined. According to Vieira, Moura, and Viegas (2007), the effectiveness of transport policies concerns the improvement of the environmental performance of the transportation system. Hence, there is a need to understand the behavioral responses to TDM measures; for example, changes in travel distance, in the number of car trips, and in the use of alternative travel modes as well as what strategies car users employ to make behavioral changes, such as, changing travel mode, carpooling, and trip chaining. In addition, it is essential to understand factors that are important for making these adjustments, for example, contextual and individual factors.

The processes by which TDM measures influence travel behavior are important to be understood. One general assumption is that the measures are expected to influence one or several of the factors important for travel behavior. More specifically, a conceptual analysis presented by Gärling et al. (2002), stipulates that TDM measures influence the trip chain attributes (e.g., increasing the cost for using the car) which in turn influence the individual car users' setting of adjustment goals as well as travel choices. Moreover, the goal to change travel behavior is also influenced by individual factors, such as, background factors and psychological factors. In general, studies have demonstrated that background factors, for example, gender, age, income, and car access are important for travel behavior, although, psychological factors may be even more important. To understand how psychological factors motivate changes in travel behavior, different psychological models are valuable.

The theory of planned behavior (TPB) has been used to clarify factors important for limiting car use or using alternative travel modes. In the TPB, the intention to act reflects different motivational aspects and is a result of three factors; attitude toward the behavior (i.e. a favorable or unfavorable evaluation of the behavior), subjective norm (i.e. the perceived social pressure to perform or not to perform the behavior), and perceived behavioral control (i.e. the perceived possibilities to perform the behavior). In turn, behavior is determined by perceived behavioral control and intention. Background factors are perceived to have indirect effects on behavior, mediated by the presented psychological factors.

In studies of pro-environmental travel behavior, many studies have instead drawn on personal norm as an important motivating factor for traveling pro-environmentally. According to the value-belief-norm (VBN) theory of environmentalism, personal norm experienced as a perceived moral obligation to act pro-environmentally may be activated as a result of certain values and environmental beliefs.

More specifically, an altruistic value orientation, awareness of the environmental problems, and ascribing responsibility to oneself activate a personal norm to save the environment. In turn, personal norm is a predictor of pro-environmental behavior. In addition to using either the TPB or the VBN-theory, several researchers advocate a combination of the factors stipulated by the TPB and personal norm in order to explain travel behavior. Overall, both the TPB and the VBN-theory highlight internal motivational factors important for reducing car use. However, in the VBN-theory, environmental motives for changing travel behavior are salient, while the intention to act in the TPB is a broader concept since environmental reasons for acting are not specifically stated. In studies of pro-environmental behavior, environmental motives as well as other motives, for example economical and health reasons, have been found to be important for acting pro-environmentally [92] [93].

5.2. Car use and GHG mitigation

The increase in transport CO_2 emissions is largely a result of increasing demand for individual mobility, in particular private car transport, already a key component of transport energy demand in developed countries. Private cars are a significant focus of energy efficiency and climate change policy, with a range of policy measures seeking to encourage modal shifts, technological improvements and behavioral change [94].

Given the positive effects of higher population densities on public transport use, walking, cycling and CO_2 emissions, better integrated spatial planning is an important policy element in the transportation sector. There are some good examples for large cities in several countries. Transportation Demand Management (TDM) can be effective in reducing private vehicle travel if rigorously implemented and supported. Soft measures, such as the provision of information and the use of communication strategies and educational techniques have encouraged a change in personal behaviour leading to a reduction in the use of the car by 14% in an Australian city, 12% in a German city and 13% in a Swedish city (medium agreement, medium evidence).

Fuel-economy standards or CO_2 standards have been effective in reducing GHG emissions, but so far, transport growth has overwhelmed their impact. Most industrialized and some developing countries have set fuel-economy standards for new light-duty vehicles. The forms and stringency of standards vary widely, from uniform, mandatory corporate average standards, through graduated standards by vehicle weight class or size, to voluntary industry-wide standards. Fuel economy standards have been universally effective, depending on their stringency, in improving vehicle fuel economy, increasing on-road fleet average fuel economy and reducing fuel use and carbon emissions. In some countries, fuel-economy standards have been strongly opposed by segments of the automotive industry on a variety of grounds, ranging from economic efficiency to safety. The overall effectiveness of standards can be significantly enhanced if combined with fiscal incentives and consumer information (high agreement, much evidence).

Taxes on vehicle purchase, registration, use and motor fuels, as well as road and parking pricing policies are important determinants of vehicle-energy use and GHG emissions. They are employed by different countries to raise general revenue, to partially internalize the external costs of vehicle use or to control congestion of public roads. An important reason for fuel or CO_2 tax having limited effects is that price elasticity tend to be substantially smaller than the income elasticity of demand.

In the long run, the income elasticity of demand is a factor 1.5–3 higher than the price elasticity of total transport demand, meaning that price signals become less effective with increasing incomes. Rebates on vehicle purchase and registration taxes for fuel-efficient vehicles have been shown to be effective. Road and parking pricing policies are applied in several cities, with marked effects on passenger car traffic (high agreement, much evidence).

Many governments have introduced or are intending to implement policies to promote biofuels in national emission abatement strategies. Since the benefit of biofuels for CO_2 mitigation comes mainly from the well-to-tank part, incentives for biofuels are more effective climate policies if they are tied to entire well-to-wheels CO_2 efficiencies. Thus preferential tax rates, subsidies and quotas for fuel blending should be calibrated to the benefits in terms of net CO_2 savings over the entire well-to-wheel cycle associated with each fuel. In order to avoid the negative effects of biofuel production on sustainable development (e.g., biodiversity impacts), additional conditions could be tied to incentives for biofuels [37].

5.3. Current situation

5.3.1. World situation

Transport activity is increasing around the world as economies grow. This is especially true in many areas of the developing world where globalization is expanding trade flows, and rising personal incomes are amplifying demand for motorized mobility. Current transportation activity is mainly driven by internal combustion engines powered by petroleum fuels (95% of the 83 EJ of world transport energy use in 2004).

As a consequence, petroleum use closely follows the growth in transportation activity. In 2004, transport energy amounted to 26% of total world energy use. In the developed world, transport energy use continues to increase at slightly more than 1% per year; passenger transport currently consumes 60–75% of total transport energy there. In developing countries, transport energy use is rising faster (3 to 5% per year) and is projected to grow from 31% in 2002 to 43% of world transport energy use by 2025.

Transport activity is expected to grow robustly over the next several decades. Unless there is a major shift away from current patterns of energy use, projections foresee a continued growth in world transportation energy use of 2% per year, with energy use and carbon emissions about 80% above 2002 levels by 2030.

In developed economies, motor vehicle ownership approaches five to eight cars for every ten inhabitants. In the developing world, levels of vehicle ownership are much lower; non-motorized transport plays a significant role, and there is a greater reliance on two and three wheeled motorized vehicles and public transport. The motorization of transport in the developing world is, however, expected to grow rapidly in the coming decades. As incomes grow and the value of travellers' time increases, travellers are expected to choose faster modes of transport, shifting from non-motorized to automotive, to air and high-speed rail. Increasing speed has generally led to greater energy intensity and higher GHG emissions [37].

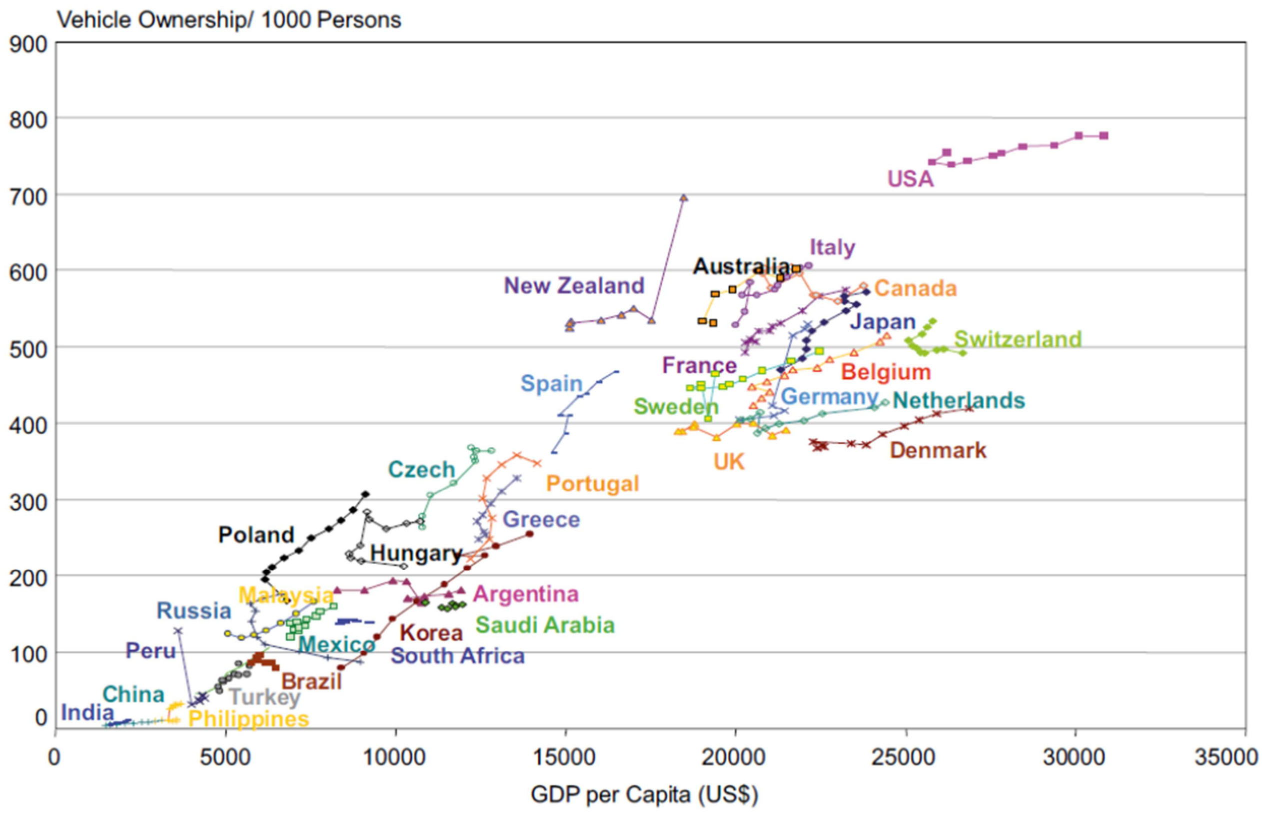


Figure 5.1 - Vehicle ownership and income per capita as a time line per country (data are for 1900–2002, but the years plotted vary by country, depending on data availability) [37].

5.3.2. Italian situation

In 2008, total GHG emissions from road transportation were about 93.0% of the total national emissions from transport, 25.1% of the energy sector and about 21.3% of the GHG national total.

From 1990 to 2008, GHG emissions from the sector increased by 21.5% due to the increase of vehicle fleet, total mileage and consequently fuel consumptions.
In the last years, from 2004, fuel consumption and emissions stabilized. In 2008, GHG emissions from road transport started to decrease and were about 4.1% lower than those of 2007.
Emissions from road transport are calculated either from a combination of total fuel consumption data and fuel properties or from a combination of drive related emission factors and road traffic data [95].

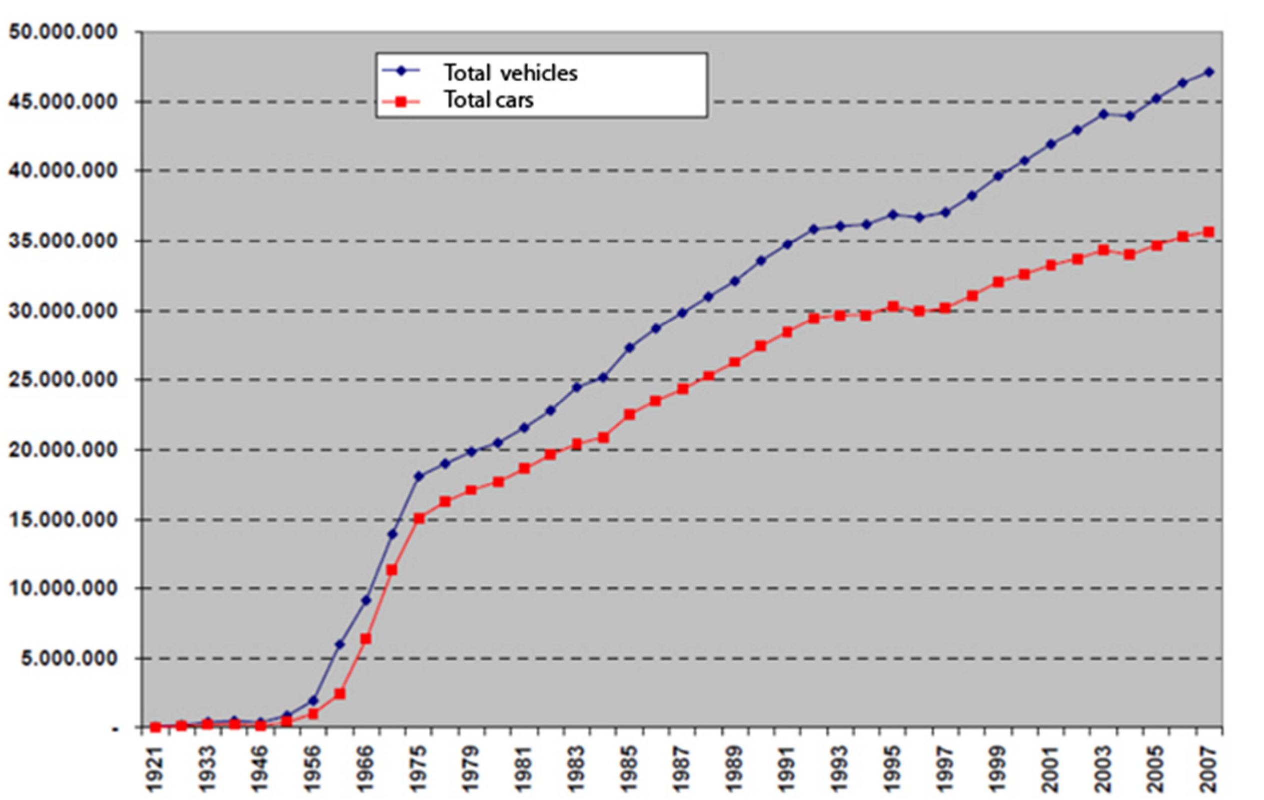


Figure 5.2 - Cars in Italy (1921-2007) [96].

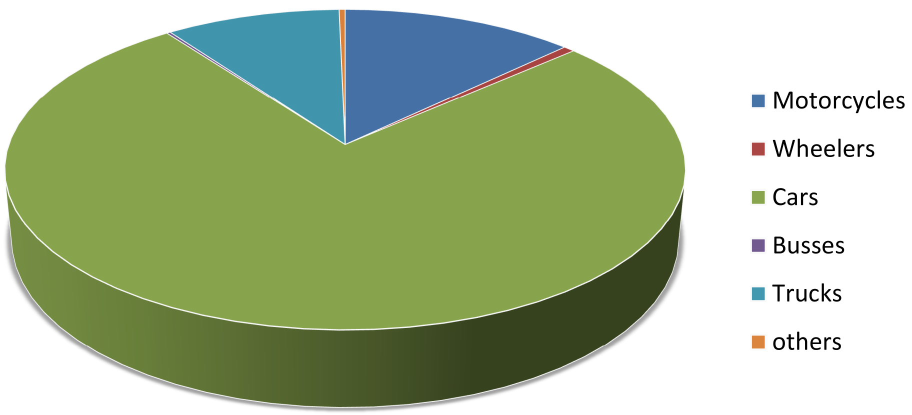


Figure 5.3 - Shape of transport in Italy (2009) [97].

5.4. Potential and future development

The International Energy Agency's (IEA's) World Energy Outlook Reference Case projects that between 2000 and 2030, transport energy use and CO_2 emissions in OECD countries will each increase by 50%, despite recent and on-going policy initiatives intended to dampen this growth.1 The oil share of transport energy use is expected to remain at about 97%, and the increase in transport oil use will account for virtually all the increase in OECD oil use over this period. In all three OECD regions oil import dependence is increasing and by 2030 is projected to reach 85% in OECD Europe (from about 50% today), 50% in OECD North America (from about 35% today), and 95% in OECD Pacific (from about 90% today). To make matters even more urgent, transport energy use and carbon emissions in non-OECD countries is expected to increase even more rapidly over the next 30 years.

A long-term focus is important in order to bring about an evolution toward a more sustainable transport system, including near-zero carbon emissions and non-petroleum fuels. However, this should not overshadow potential nearer-term actions that could provide substantial benefits over the next few years, particularly in light of renewed concerns for energy security and diversity of energy supply. Recent IEA studies have highlighted promising opportunities for cutting oil use and emissions by 20-30% over the next 10 years, both within OECD countries and beyond, that should not be ignored. Should an oil emergency occur, very short-term actions will be needed to ameliorate the impact of reduced gasoline and diesel fuel supplies.

An important message is that many technologies are already available to provide near-term oil savings, energy security benefits, and CO_2 reductions. Government leadership and action is needed that focus on rapid, relatively low-cost changes.

These include:

Reductions in Vehicle In-use Fuel Intensity.

Vehicles on the roads in OECD countries typically use 10-20% more fuel per kilometre than indicated by their rated efficiency. While many of the reasons for this gap are inevitable due to traffic congestion and other factors, there are also a number of potential measures to significantly reduce this gap.

The IEA estimates that a 5%-10% reduction in average fuel consumption per kilometre could be achieved through a combination of the following measures: stronger inspection and maintenance programmes to target fuel efficiency, adoption of on-board technologies that improve in-use fuel efficiency and improve driver awareness of efficiency; better and more widespread driver training programmes, and better enforcement and control of vehicle speeds. External control of vehicle speeds, though controversial, is being looked at closely in some countries (like the UK) for its potential safety benefits.

Reductions in demand for vehicle travel.

Policies to dampen the growth in vehicle travel are often undertaken for purposes other than saving energy or reducing CO_2, but they can of course also have important impacts in these areas. From a technology point of view there are a number of measures that can reduce the demand for vehicle travel while improving the general efficiency of the transport system. These include infrastructure improvements, “intelligent transport” technologies and systems such as better routing systems and congestion reduction, information systems that can help to substitute for travel systems, better transit systems and road-pricing programmes.

An aggressive combination of such measures could realistically cut travel (or travel growth) by 10-15% over a ten year period.

Though many such measures are normally undertaken at the local or regional government level, national governments can put in place incentive programmes to encourage adoption of strong approaches. And though national governments' departments of transport often spearhead transport sector efficiency policies, greater consideration to energy use impacts can be championed by energy agencies [98].

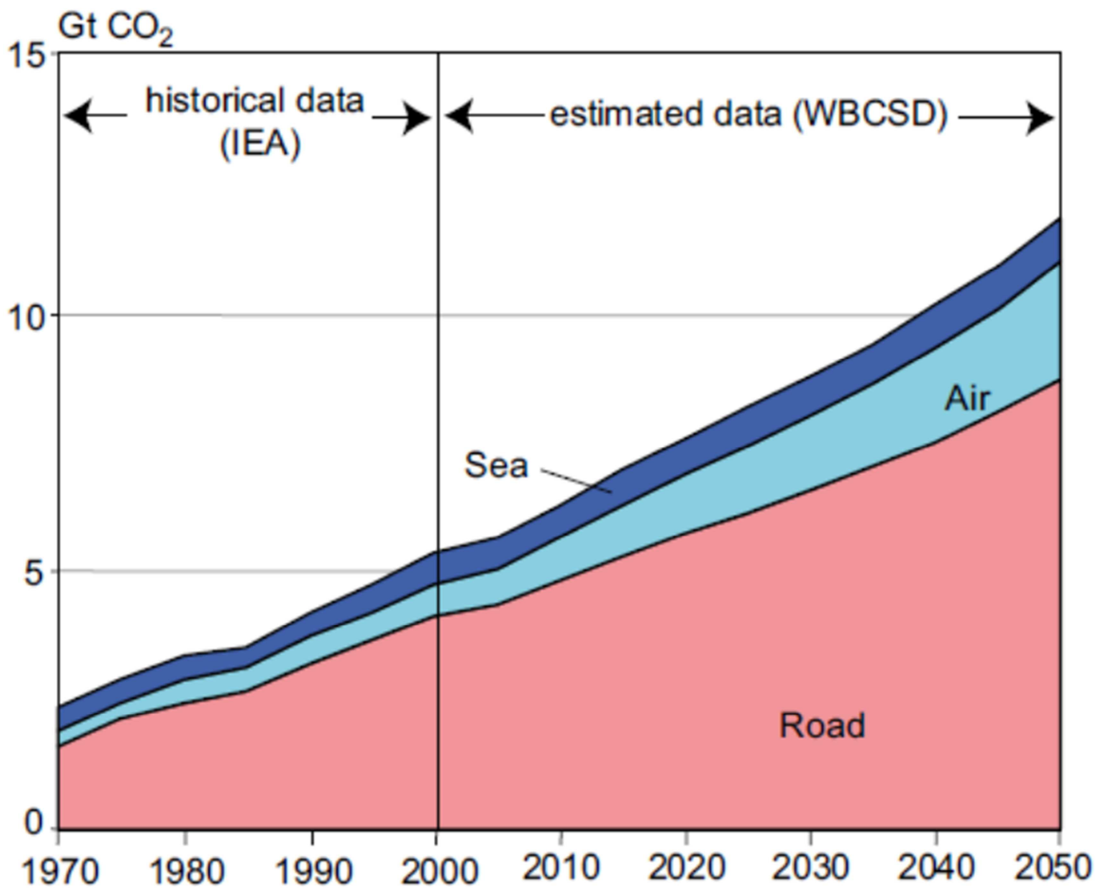


Figure 5.4 - Historical and projected CO_2 emissions from transport [37].

5.5. Car use as a wedge of PolyGame

There are available in literature different emission factors for different models of cars. We consider that an average cars emission factor is about 170 gCO_2/km, the number of cars in Italy is 36.371.790 and the average path for each car is 11.100 km / year [99] [100]. We obtain that to have a reduction about 5 Mt CO_2/ year, we need to reduce the average path about 7% (-809 km/year) [101].

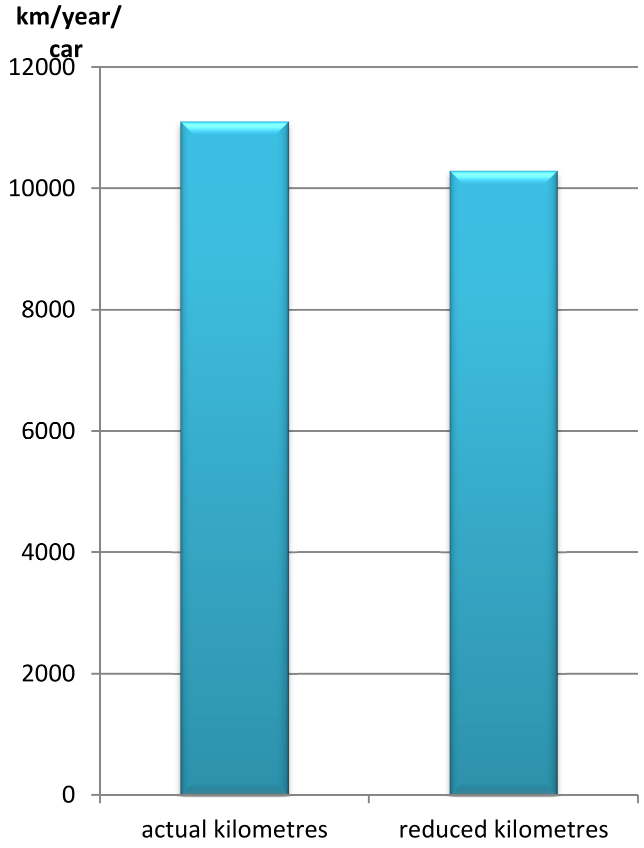


Figure 5.5 - Car use as a wedge of PolyGame.

6.

BIOFUELS

6.1. Introduction to biofuels

Biofuels can be an important option for energy supply, notably as renewable substitutes for fossil fuels. Some considered them as a renewable and endless resource, since they are produced from biomass, usually from an agricultural crop, that is a renewable resource. Besides, it is a current belief that, by replacing oil products, their use could reduce greenhouse gases (GHG) emissions. Yet, there are some discordant voices that point out that any biomass production and industrial transformation require the use of fossil fuel energy in the form of fertilizers, agrochemicals, machinery, and for inputs and raw material transportation. Moreover, monoculture might result in soil degradation, natural ecosystem destruction and, in this case, there is a competition for the use of arable land between the production of energy and food crops [102].

Methanol and ethanol are good candidates as alternative fuels since they are liquids and have several physical and chemical properties similar to those of gasoline and diesel fuels. Ethanol can be produced from biomass such as sugar cane, sugar beet, wood, corn, and other grain. The production of ethanol from biomass sources involves fermentation and distillation of crop. Ethanol is biodegradable and will evaporate quickly if spilled on land. Methanol can be produced from natural gas, gasification of coal or biomass. However, coal is not preferred as a feedstock because conversion process is complex and more costly than using other feedstock in commercial methanol production. Both methanol and ethanol have much higher octane number than gasoline. This allows to alcohol engines to have much higher compression ratios, and so increasing thermal efficiency. Nevertheless, a significant disadvantage of methanol and ethanol relative to gasoline is that they have lower energy content [103].

The production of transport fuel from biomass, in either liquid or gas form, holds the promise of a low net fossil-energy requirement and low life-cycle GHG emissions. The successful development of advanced biofuels technologies, using non-food biomass feed stocks, could help overcome most barriers and achieve sustainable, very low CO_2, cost-effective biofuels.

Table 6.1- Typologies of liquid biofuels with respective characteristics [15].

Fuel	Feedstock	Regions where currently mainly produced	GHG reduction impacts vs. petroleum fuel use	Costs	Biofuel yield per hectare of land	Land types
1st generation ethanol	Grains (wheat, maize)	US, Europe, China	Low-moderate	Moderate-high	Moderate	Croplands
	Sugar cane	Brazil, India, Thailand	High	Low-moderate	High	Croplands
2nd generation ethanol	Biomass (cellulose)	None used but widely available	High	High	Medium-high	Croplands, Pasture lands, Forests
1st generation biodiesel (FAME)	Oil seeds (oilseed rape, soybean,)	US, Europe, Brazil	Moderate	Moderate-high	Low	Croplands
	Palm oil	Southeast Asia	Moderate	Low-moderate	Moderate-high	Coastal lands, Forests
2nd generation biodiesel	Any biomass	None used commercially	High	High	Medium-high	Croplands, Pasture lands, Forests

The conversion process is classified according to whether it uses "first-generation" biofuels (i.e. those already under commercial production, based on food-crop feed stocks) or advanced-technology "second-generation" biofuels (mainly lignocellulosic feed stocks such as straw, bagasse, vegetative grasses and wood). There are also "third-generation" biofuels under development, including oils from algae and other alcohols such as bio-butanol, but due to the lack of production experience to date, it has been assumed that these will make little contribution before 2050. For energy produced by algae, see chapter 6. The characteristics of the different types of biofuels vary substantially. Second generation technologies hold the promise of high-yielding, low GHG emitting and sustainably produced liquid fuels derived from forest and agricultural residues and purpose-grown energy crops. It is likely that commercial production of second generation biofuels to produce gasoline or diesel substitutes from a range of ligno-cellulosic feed stocks will eventually complement and perhaps supersede current first-generation biofuels from grains and oil-seed crops [15].

6.2. History

The first prototypes of internal combustion engines built in the nineteenth century by Samuel Morey in 1826 and Nicholas Otto in 1876 were able to use ethanol as fuel. The first car produced by Henry Ford in 1896 could use pure ethanol as fuel. The Ford Model-T, the first car manufactured in series by 1908, was a flexible vehicle able to use ethanol as a fuel, as well as gasoline or any mixture of both. The use of bio-ethanol as fuel was widespread used in Europe and the United States until the early 1900s. After the First World War there was a decrease in demand for ethanol, because it became more expensive to be produced than petroleum-based fuel, however there was an interest in ethanol as both an antiknock agent (i.e., octane enhancer) and a possible replacement for petroleum fuels.

Brazil had a pioneering program to produce alcohol for automobile since 1927, when it has installed the first pump alcohol that continued until the early years of the next decade. However, the fuel ethanol market was revived in the 1970s when, for economic reasons as the global oil crisis and problems in the international sugar market due to overproduction, the National Alcohol Program (ProAlcool) was created in Brazil in 1975. This program was based on the sugarcane use as raw material, and was intended to target the large-scale use of ethanol as a substitute for gasoline. With substantial government intervention to increase the supply and demand for ethanol, Brazil has developed institutional capacities and technologies for the use of renewable energy in large scale. In 1984, most new cars sold in Brazil required hydrated bio-ethanol (96% bio-ethanol+4% water) as fuel. As the sugar-ethanol industry matured, policies evolved, and the Pro Álcool program was phased out in 1999, permitting more incentives for private investment and reducing government intervention in allocations and pricing. Although Brazilians have driven some cars that run exclusively on ethanol since 1979, the introduction of new engines that let drivers switch between ethanol and gasoline has transformed what was once an economic niche into the planet's leading example of renewable fuels. Widespread availability of flex-fuel vehicles (promoted through tax incentives) combined with rising oil prices have led to rapid growth in bio-ethanol and sugarcane production since 2000. Today, more than 80% of Brazil's current automobile production has flex-fuel capability.

In the United States, the combination of raising taxes, a concerted campaign by major oil producers and availability of cheap petrol effectively extinguished ethanol as a transport fuel in the early part of the 20th century. The desire to promote the production and use of bio-ethanol restarted in the early of 1980, largely to revitalize the farming sector at a time of oversupply of agricultural production. The United States rebuilt its fuel ethanol industry more gradually than Brazil, and is nowadays the world leader in its production and usage. A blended fuel E85 (85% bio-ethanol and 15% gasoline) is used in vehicles specially designed for it. Government has been promoting the development of this blend and several motor vehicle manufacturers including Ford, Chrysler, and GM, have increased the production of flexible-fuel vehicles that can use gasoline and ethanol blends ranging from pure gasoline all the way up to E85. Currently ethanol is the main bio-fuel used in the world and its use is increasingly widespread, the worldwide prospects are the expansion of the production and consumption of ethanol [104].

6.3. Biofuels and GHG mitigation

The impact of replacing conventional transportation fuels (petroleum-based) by biofuels on GHG emissions is subject of fierce debate [105][127][106][107].

Biofuels are theoretically carbon neutral, releasing CO_2 recently absorbed from the atmosphere by the crops used to produce them, while fossil fuels add to the CO_2 supply in the atmosphere by giving off CO_2 absorbed and trapped in plant material millions of years ago. In fact, most LCAs (Life Cycle Assessments) have found a significant net reduction in GHG emissions and fossil energy consumption when bioethanol and biodiesel are used to replace, respectively, conventional diesel and gasoline [127]

Overall, anyway, calculating the performance of biofuels on GHG emissions and fossil energy use is difficult, due to the large number of uncertain parameters and impacts, as well as methodological issues [108]. The crucial factors are the amount of CO_2 produced when using fossil fuels for transport and processing of biofuels and the emissions of N_2O produced during manufacture and after application of nitrogenous fertilizers [109]. In addition, results may depend on assumptions on system boundaries, reference land, location of crop cultivation and related yields, co-product allocation, energy sources used in the production of agricultural inputs and feedstock conversion to biofuels [108][110]. Therefore, even for a particular feedstock, standard life-cycle analyses of biofuels in the literature exhibit a wide range in terms of the overall reduction in GHG emissions. As such, the GHG savings of biofuels should not be assumed but need to be examined on an individual basis [108].

Nonetheless, in most of the several LCAs carried out in recent years, biodiesel achieves 40–65% of the GHG emissions of conventional diesel, while for bioethanol technologies the range of GHG reduction is wider: for some bioethanol production chains (e.g. for corn to ethanol in coal-fired process plants) the GHG emissions may be as high as 80–90% of their fossil fuel competitors, whereas they may be as low as 20–35% for bioethanol from sugar cane [127]. See Table 6.2 for some comparison.

Table 6.2– Comparison of GHG emissions from biofuels and fossil fuels [127].

Energy product	GHG emissions ($g\ CO_2$-eq./km)
Transportation fuel	
Bioethanol from sugar cane	50–75
Bioethanol from other crops (corn, sugar beet, wheat)	100–195
Biodiesel (rapeseed, soy, sunflower)	80–140
Bioethanol from lignocellulose	25–50
Gasoline	210–220
Diesel	185–220

However, it must be emphasized that data shown in the above table are valid only for systems that do not give rise to direct or indirect land use changes. The results from the life cycle GHG emissions of biofuels, when the ILUC (Indirect Land Use Change) factor is included suggest that these savings are diminished considerably when, for instance, grassland is converted to the cultivation of feedstock rather than using existing cropland. Indirect land use change resulting from biofuel production is found to have a great impact on GHG emissions from biofuels, showing biofuels to increase GHG emissions relative to their fossil fuel counterparts in most of the cases [110]. If bioenergy crops are cultivated on fallow, marginal or degraded land where previously no conventional crops were grown, and wise management strategies are implemented, no indirect GHG emissions occur and the GHG balance can be favourable [127]. In a sense, this can be viewed as a sort of ecological restoration. In addition, the GHG and energy balance may also depend on the

scale at which biomass is used. For instance, large-scale use may lead to significant land use changes, which can lead to increases or decreases in terrestrial carbon stocks [127][108].
In conclusion, biofuels can contribute to GHG mitigation strategies in transport sector only if significant emissions from land use change are avoided and appropriate production technologies are used [127]. As a final remark, obviously the above considerations refer to the use of pure biofuel, which allows maximum energy and GHG savings, while the use mixtures of fossil fuels and biofuels, in any case, may save energy and GHG, but only to a very small degree [111].

6.4. Current utilization of biofuels

6.4.1. World situation

Bio-fuels are attracting growing interest around the world, with some governments announcing commitments to bio-fuel programs as a way to both reduce greenhouse gas emissions and dependence on petroleum-based fuels [112]. In the last decade biofuels production has been driven by governmental policies. The key instruments widely adopted to foster production and increase consumption have been mandatory blending targets, tax exemptions and subsidies [126]. The United States, Brazil, and several EU member states have the largest programs promoting bio-fuels in the world [112]. Over the last ten years biofuels production has increased dramatically. Despite that, biofuels today represent only about 1.5% of the total road transport fuel consumption [126][109] and they only account for about 2% in the final bioenergy mix (in energy terms) [126].
Between 2000 and 2008 biodiesel grew from 0.8 to 14.7 billion liters (see Figure 6.1) [110][113]. Most of global biodiesel production is based in Europe, which accounts for 87% of the global biodiesel supply[126].

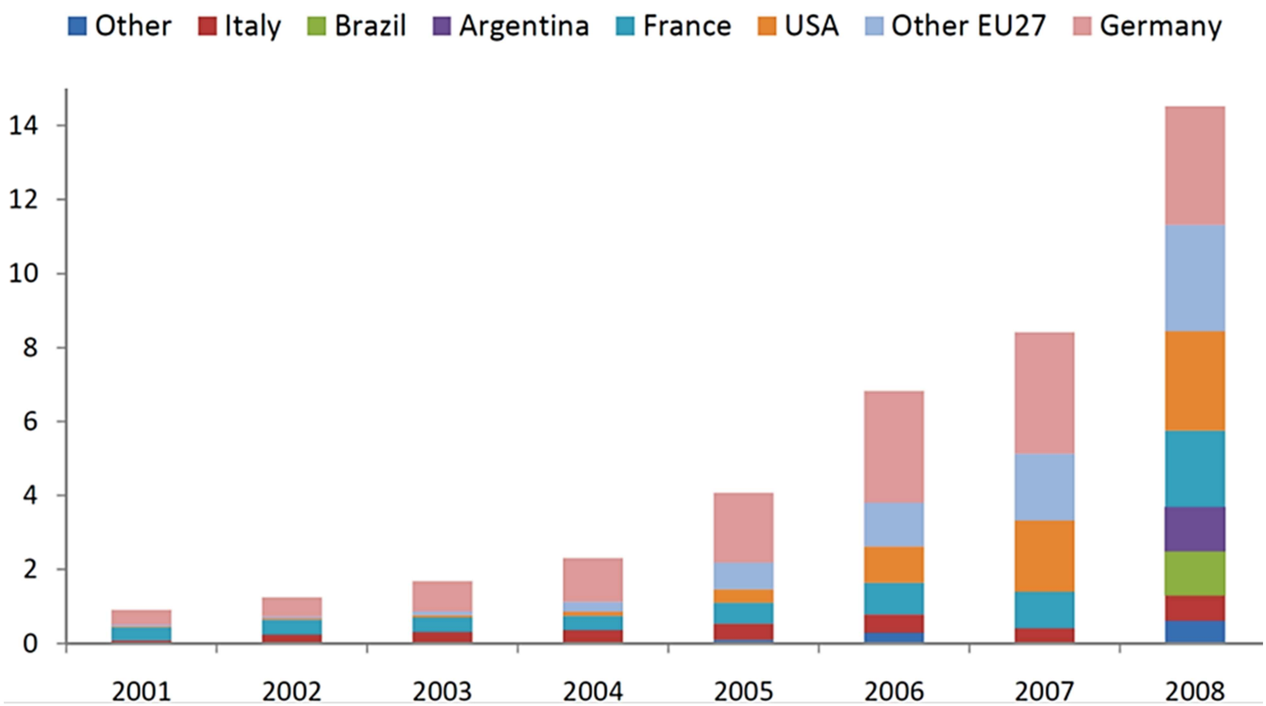


Figure 6.1 – Global biodiesel production in billion liters [110].

The total global production of biodiesel remains small compared with that of ethanol. In fact, between 2000 and 2009 fuel ethanol output experienced an increase from 16.9 to 72.0 billion liters [113]. By far the largest volume of bioethanol is produced in Brazil and the USA (see Figure 6.2), where plants with capacities up to more than 500 million litres per year are located. Also China and India produce significant quantities of ethanol [126].

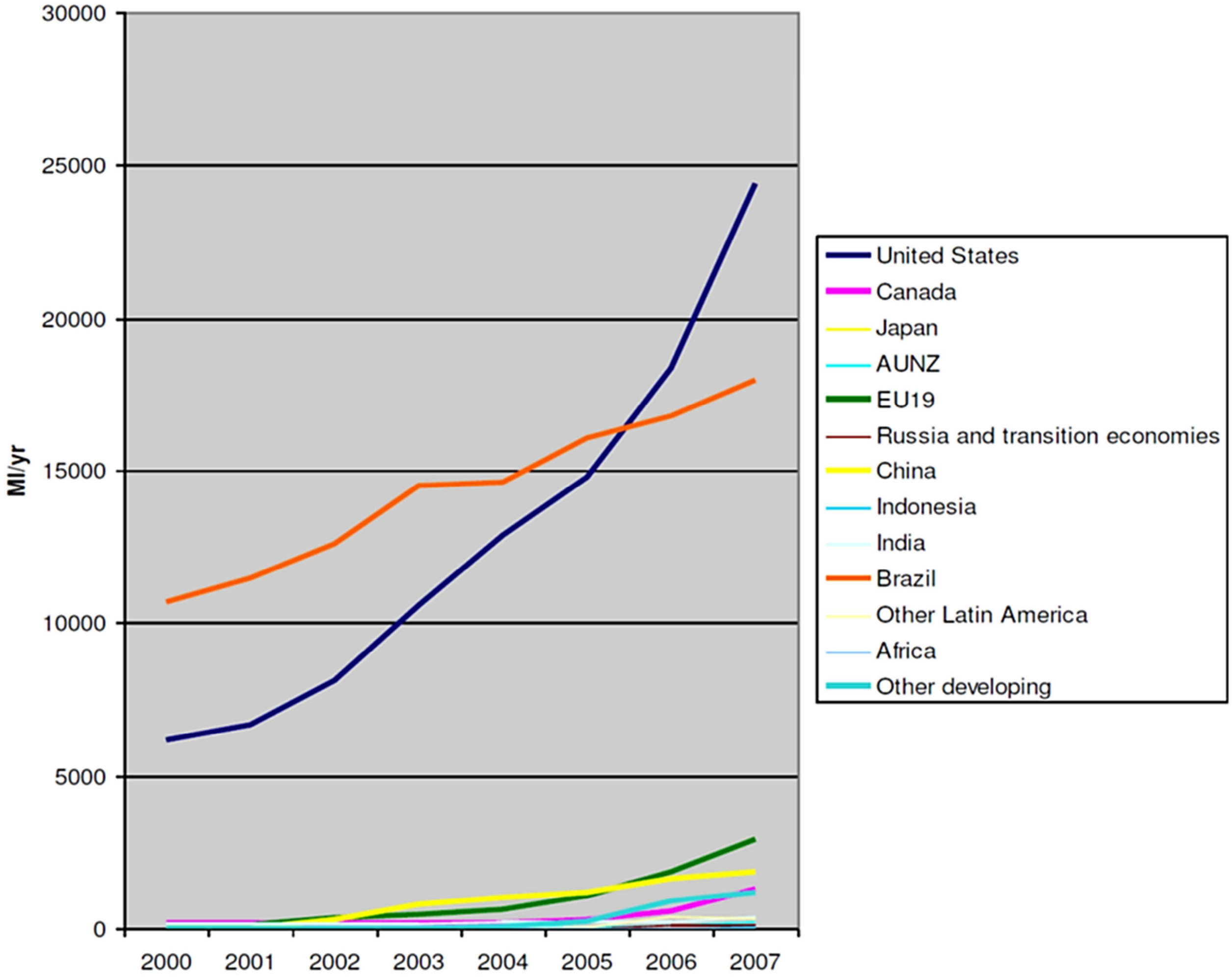


Figure 6.2 - Global ethanol production trends in the major producing countries and regions [109].

Even if ethanol is produced from a wide range of feedstocks the 80% of its production comes from corn (maize) and sugarcane. Corn ethanol is mainly produced in the US and sugarcane ethanol in Brazil [109]. Nowadays, almost all the Brazilian vehicles use ethanol, in the pure form or in mixture with the gasoline, where ethanol corresponds up to 25% of the mixture. The flex-fuel cars, that can be fueled with ethanol and/or gasoline in any proportion, represent 90% of the light vehicle sales. The flexibility of using both fuels in a vehicle favored the ethanol consumption in Brazil, which corresponds to 40% of the total fuels used in vehicles [104]. In the United States, ethanol is actually used in two forms: mixed with gasoline in the maximum proportion of 10%, or in mixtures containing 85% ethanol and 15% gasoline, as an alternative fuel [104].
Finally, as for second-generation biofuels, there are yet no large scale production facilities [126].

6.4.2. European situation

The European biofuels market is mainly determined by the European Union's policy and legislation on biofuels [114]. The European fuel specifications currently allow blending of up to 5 percent ethanol and 15 percent ethers (oxygen-containing organic compounds for which ethanol is one possible feedstock) in gasoline, and up to 5 percent biodiesel in petroleum diesel. Raising these limits is currently under consideration to expand the use of biofuels [107].

It is interesting to provide a brief summary about European legislation concerning biofuels. In 2003, the EU bio-fuels directive (2003/30/EC) set a target, which was not reached, of an indicative 5.75% total bio-fuel share of all consumed gasoline and diesel fuel for transport placed on the market by 2010, as a goal. This indicative target has been adopted by most Member States in their national bio-fuel objectives [112]. In 2006 was published the Commission´s communication *"An EU Strategy for Biofuels"*. In this EU Strategy a range of market-based, legislative and research measures are presented to boost the production of biofuels. Basing on the responses gathered through a public consultation in 2006, the EC (European Commission) reviewed the Biofuels Directive and thereupon published the *"Biofuels Progress Report"* in January 2007. According to this report the Commission reduced the incorporation rates of biofuels in the EU, showing that the European biofuel production needed further support [114]. In January 2008, the European Commission proposed a binding minimum target of 10% for the share of bio-fuels in transport in the context of the ''EU directive on the promotion of the use of energy from renewable sources" that envisages a 20% share of all renewable energy sources in total energy consumption by 2020 [109]. In April 2009 the parliament of the European Union endorsed a minimum binding target of 10% for biofuels in transport by 2020 as part of the EU Directive 2009/28/EC on renewable energy. The directive also specified a minimum 35% reduction in GHG emissions savings compared to fossil fuels to be achieved by biofuels during their life cycle, including direct land use change effects [115][116]. Sustainability criteria for indirect land-use changes are also provided. No bio-feedstocks shall originate from primary forests, highly bio-diverse grassland, protected territories and carbon-rich areas [113].

In 2009, total biofuel use in Europe amounted to 12 Mtoe (million tonnes of oil equivalent), which represents a 4% incorporation rate across all road transport fuels estimated at 300 Mtoe in 2009 [116]. In Figure 6.3 the shares by country and by biofuel type can be appreciated. In 2005, of the 7.0 million hectares of set-aside land, 836000 were planted with feedstocks for biofuels. Farmers are compensated for setting aside land [107].

The European Union is the world's largest biodiesel producer; its annual production surged from 1.9 million liters in 2004 [107] to 8.8 million tonnes in 2008 [113]. The top three biodiesel producers in the European Union in 2006 were Germany, France, and Italy [107]. In Europe, biodiesel is produced from rapeseed, sunflower, and soybean oil; and ethanol from sugar beets, wheat, and barley.

EU ethanol production is smaller, although increasing from 0.5 billion liters in 2004 [107] to 3.7 billion liters in 2009 [117]. The top three EU ethanol producers were Germany, Spain, and France [107].

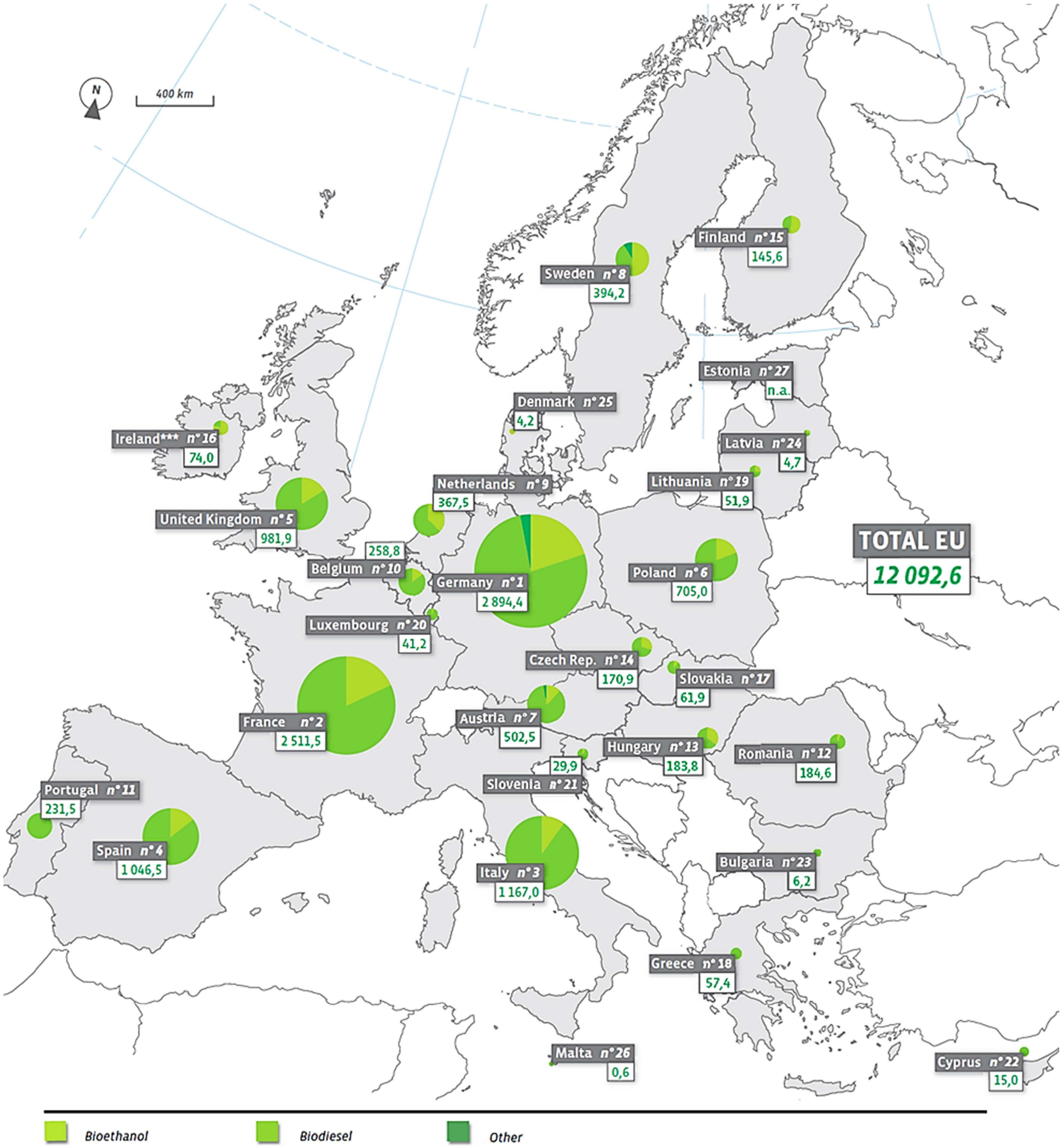


Figure 6.3 - Biofuels consumption for transport in EU-27 in 2009 (ktoe) with respective shares [116].

6.4.3. Italian situation

Having trailed behind the other major European Union countries, Italy took a giant stride and increased its biofuel consumption for transport in 2009. According to the Economic Development Ministry's Department of Energy, the country's consumption rose by 62.9% over 2008 to 1167002 toe, raising the biofuel incorporation rate to 3% (2.4% in 2008). To do so, it doubled its bioethanol fuel consumption (up by 103.3%) to 118014 toe and significantly increased its biodiesel consumption (by 59.3%) to 1048988 toe [116].

Looking at the production, Italy was the fourth largest biodiesel producer in the European Union in 2009, with 737 tonnes [118]. The capacity is far higher, 2375 tonnes/year being estimated for 2010 [118]. The main feedstock for biodiesel production is oil seed [110].
For what concerns ethanol, the production increased by 20% in 2009, reaching 72 Ml [117] and the main feedstock are cereals [110].

6.5. Future development and potential

Various scenarios have resulted in high estimates of biofuel in the future energy system. The availability of the resources is an important factor if high shares of biofuel penetrate the electricity, heat or liquid fuel market. The rationale is to facilitate the transition from the hydrocarbon economy to the carbohydrate economy by using biomass to produce bioethanol and bio methanol as replacements for traditional oil-based fuels and feed stocks. The biofuel scenario produced equivalent rates of growth in gross domestic product (GDP) and per capita affluence, reduced fossil energy intensities of GDP, reduced oil imports and gave an energy ratio. Each scenario has advantages whether it is rates of growth in GDP, reductions in carbon dioxide emissions, the energy ratio of the production process, the direct generation of jobs, or the area of plantation biomass required to make the production system feasible.
Renewable resources are more evenly distributed than fossil and nuclear resources, and energy flows from renewable resources are more than three orders of magnitude higher than current global energy use. Today’s energy system is unsustainable because of equity issues as well as environmental, economic, and geopolitical concerns that have implications far into the future [119].

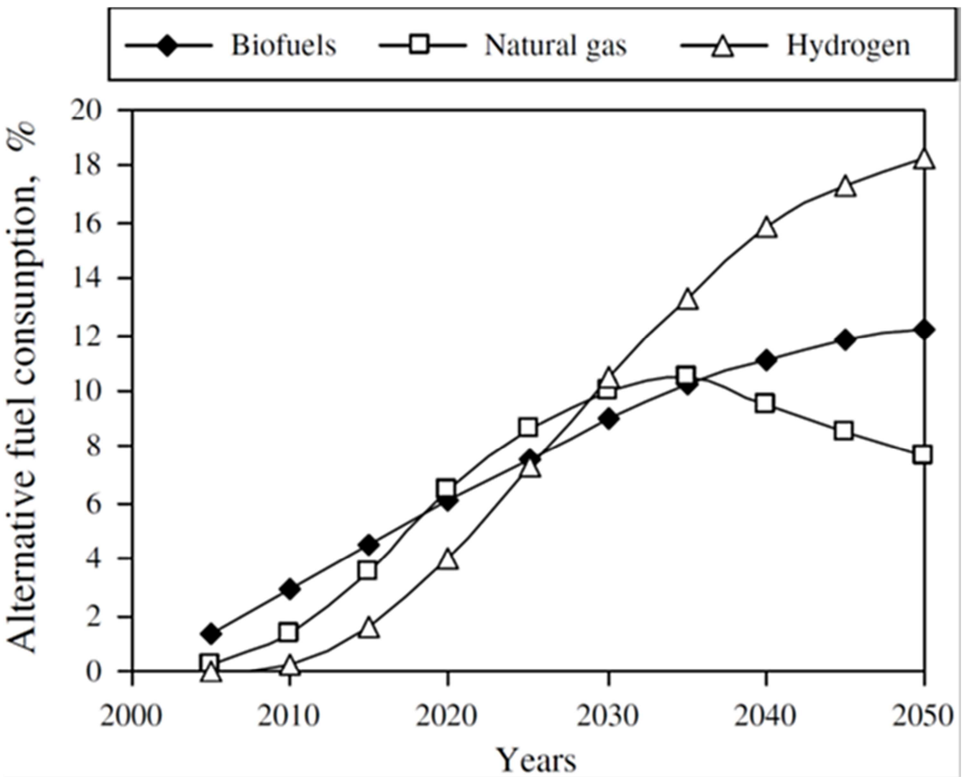


Figure 6.4 - Shares of alternative fuels compared to the total

automotive fuel consumption in the world (2000.2050) [119].

The IEA publication Energy Technology Perspectives (ETP) contains a number of scenarios, but the one most relevant for the road mapping process is “BLUE Map”, the main scenario where energy-related CO_2 emissions are reduced by 50% in 2050 relative to their 2005 level. For transport, a variety of strong measures are undertaken, including a rapid ramp-up of second-generation biofuels production after 2010.
Figure 6.6 shows the projected production of biofuel out to 2050 in the BLUE Map scenario. The production levels by 2030 is several orders of magnitude above the starting point in 2010, requiring a challenging pace of investment and construction of biofuels facilities, and increases in feedstock production. The cumulative production over this period also allows for a great deal of experience to be gained over time. Given this assumption, transport fuel demand by 2050 is projected to be over 760 Mtoe. On this basis, biofuels would provide around 27% of transport fuel in that year [120].

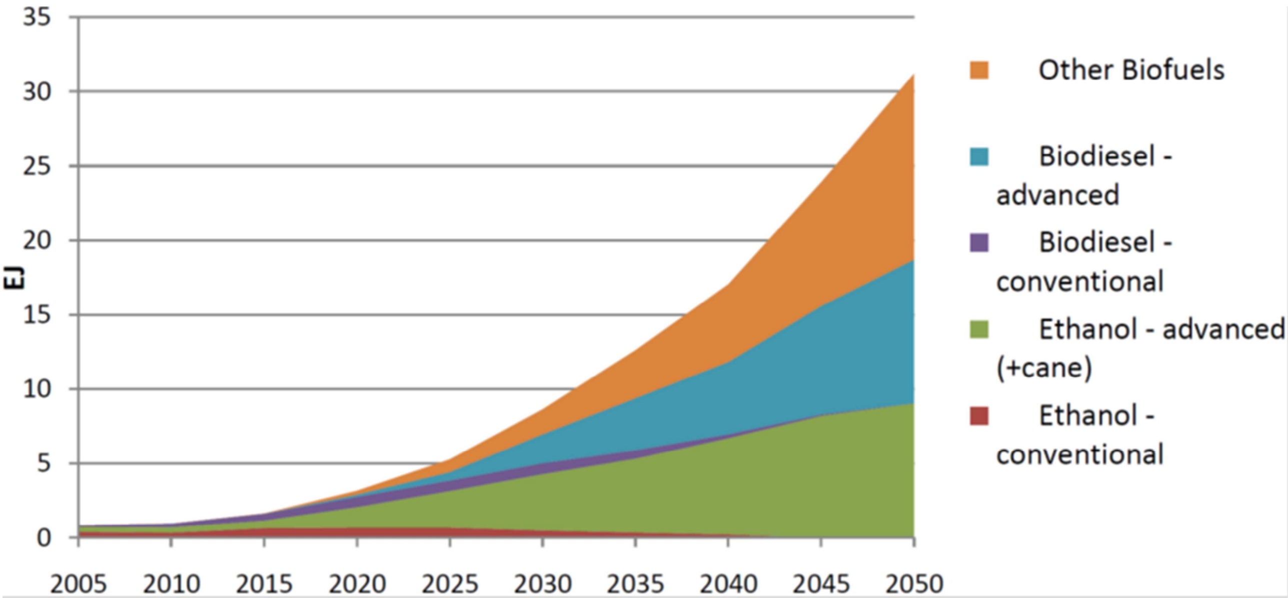


Figure 6.5 - Biofuels production projections in the BLUE Map scenario [120].

Another point of view it’s that of Richard Doornbosch from the Organization for Economic Co-operation and Development (OECD). He presented an economist’s perspective, arguing that biofuels have somewhat limited potential and that current policies were in fact leading to the deployment of solutions that were not likely to be helpful to the climate change issue. His analysis took into account other land-uses (including the land for forestry, arable use, and pasture needed to support the world’s growing population).
The potential of ‘2nd generation’ technologies was calculated based on the estimated availability of feedstocks which do not require dedicated land, i.e., crop and forest residues, and organic wastes. Crops grown on marginal and degraded land have been mentioned as possible additional sources but these were not included in the calculation. Doornbosch also found a geographical mismatch between areas with high resource availability and transport fuel demand. Referring to recent science articles, Doornbosch stressed that emissions from direct or indirect land-use change might significantly reduce the climate change benefits of increasing levels of biofuels production [121].

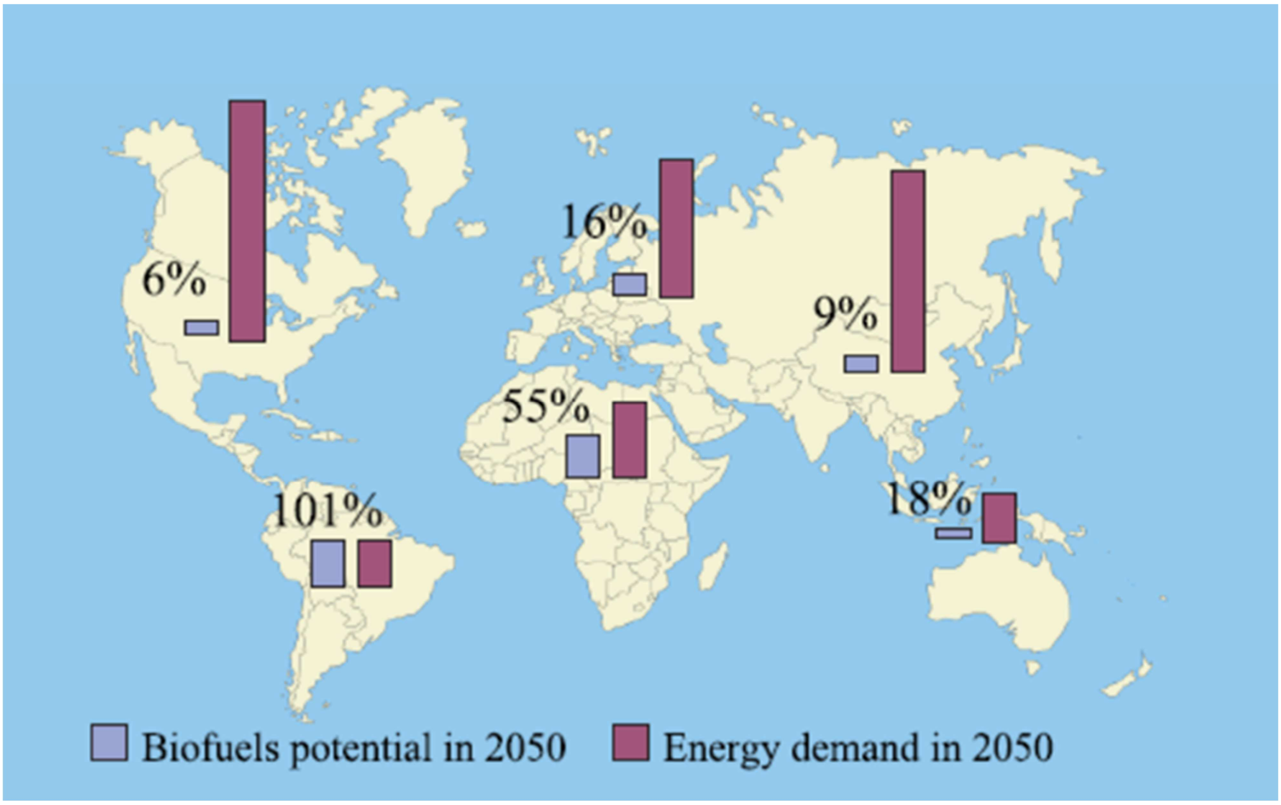


Figure 6.6 - Technical global biofuel potential for 2050 [121].

6.6. Biofuels as a wedge of PolyGame

At the end of 2009 in Italy there were 41555643 motor vehicles [122], so that a reduction in CO_2 emissions of 0.12 t/year/vehicle is required. Knowing that the annual average mileage in Italy is 13000 km/year [123], a total mileage per year of 540223 Mkm and a required emission reduction per motor vehicle and km of 9.2 g CO_2 are obtained. Given a total emission from road traffic in 2008 of 114 Mt [124], an average emission factor of 211 g CO_2/km is calculated, so that to reach our goal with mixed fuels using traditional fossil fuels and biofuels, an average emission factor of 202 g CO_2/km is required.
For the calculation of the biofuels emission factor, under the hypothesis of the substitution of gasoline with a mixture gasoline/bioethanol and of diesel with a mixture diesel/biodiesel, a weighted average between bioethanol and biodiesel was carried out. Average emission factors of 110 g CO_2/km for biodiesel and of 82.5 g CO_2/km for bioethanol are assumed [127]. To biodiesel was given a weight of 0.35 and to bioethanol of 0.65, values corresponding the the relative share of diesel and gasoline in the Italian motor vehicle fleet in 2007 [125]. Therefore, the average biofuels emission factor used in the calculations was equal to 92 g CO_2/km. As such, for the entire Italian motor vehicle fleet, the traditional fossil fuels should be blended with biofuels in mixtures in which biofuels account for 7.8%.

7.

Electric cars

7.1. Introduction to electric cars

Road transport today is responsible for a significant and growing share of global anthropogenic emissions of CO_2, moreover it is almost entirely dependent on oil-derived fuels and Therefore highly vulnerable to possible oil price shocks and supply disruptions. Finally, using oil-derived fuels in internal combustion engines generates tail pipe emissions of pollutants such as PM_{10} (particulate matter), NO_x and VOCs (Volatile Organic Compounds) which are harmful to human health. Improving road transport requires all these issues to be addressed. Managing demand and promoting co-modality can provide a partial solution, however introducing alternative transport fuels and vehicles will also be necessary in order to achieve the objectives of decarbonisation, energy security and urban air quality [128].
So, with the increasing demand for environmentally friendlier and higher fuel economy vehicles, automotive companies are focusing on electric vehicles [129].
Electric vehicles (EV) are expected to reduce CO_2 emissions and oil dependence. EV can reduce total energy consumption because of its high efficiency and can run with both oil and electricity. Introduction of EV reduces oil consumption, but it also increases electricity demands. Therefore, we must evaluate EV's CO_2 reduction potential, not only in the transport section but also in the power grid section [130].

7.1.1. General characteristics

An electric vehicle consists of a battery that provides energy, an electric motor that drives the wheels, and a controller that regulates the energy flow to the motor [131].
The electrification of vehicle propulsion systems comprises a wide range of technology options. Different vehicle concepts show variant degree of electrification. Besides fully electrified vehicles solely driven by an electric powertrain, hybrid electric vehicles combine a conventional internal combustion engine with an additional electric propulsion system to improve the overall efficiency of the vehicle's drive train.

Mild hybrid electric vehicle

On the electrification path towards an increasing electric driven powertrain, mild hybrid electric vehicles represent the first real step away from a purely combustion engine driven vehicle. In addition to the conventional internal combustion engine, mild hybrid systems include an engine start-stop system, regenerate braking energy by recharging the battery and utilize a small electric motor which provides acceleration assistance.

Mild hybrid vehicles do not allow driving only on electric propulsion, due to the small size of the electric motor and the limited capacity of the battery. However, due to regenerative braking and the automatic engine start-stop system, mild hybrid vehicles achieve fuel efficiency gains in the range of 10 to 15 % compared to conventional internal combustion engine vehicles.

Full hybrid electric vehicle

Compared to the mild hybrid system, full hybrid electric vehicles are characterized by a stronger emphasis on the electrification of the power train and an increase in fuel economy.

The internal combustion engine remains the main propulsion system, but it is further complemented by a larger battery and a more powerful electric motor. This configuration allows a more efficient electric launching of the vehicle, electric acceleration assistance, and even pure-electric driving at low speeds and for a limited driving range is possible. The battery takes up energy from regenerative braking and is further recharged by the internal combustion engine; recharging from the power grid is not possible.

Full hybrid vehicles show fuel consumption benefits of about 25 to 30 % in standard test driving cycles, compared to conventional combustion engine vehicles.

Plug-in hybrid electric vehicle

The plug-in hybrid electric vehicle (PHEV) is an upgrade of the full hybrid allowing an increased proportion of electric driving. Besides a more powerful electric motor, a high capacity battery and a correspondingly smaller combustion engine, the battery of the plug-in hybrid is not only charged by the on-board generator, but can also be charged with electricity from the power grid. Plug-in hybrid vehicles can be driven in electric mode over much longer distances. While its energy efficiency in conventional driving mode, where the combustion engine mainly drives the vehicle, corresponds approximately to that of a full hybrid, in the electric driving mode much higher energy efficiency gains can be acquired which are close to the energy consumption of battery electric vehicles.

Battery electric vehicle

The battery electric vehicle is entirely propelled by electricity stored in an on-board traction battery that is charged from the power grid. It is situated at the top of the electrification path. The conventional mechanical drive train and the combustion engine are replaced by an electric drive train with a powerful electric motor. Battery electric vehicles show the highest tank-to-wheel energy efficiency of all vehicle propulsion systems due to the particularly efficient operation of the electric motor and further efficiency gains through regenerative braking. In contrast to the favourable characteristics of electric propulsion it is limited with regard to performance and driving range by the battery technology's potentials [132].

7.2. History

First electric vehicles have been on the road already in 1838, 52 years before combustion engine vehicles entered the market. In 1913, the production of electric vehicles started to decline and the starting mass-commercialization of combustion engine vehicles has led quickly to road transport dominated by combustion engine technology.

Until the 1960s, electric vehicle remained at an insignificant level. In the 1970, in the context of a rising environmental awareness and the oil crises, several prototypes of electric vehicles have been developed in Europe, Japan and the US and experts at that time have estimated a steeply rising deployment of electric vehicles. Finally, the production of electric vehicles remained at a negligible level during the 1980s.

A new boost of electric propulsion technology occurred in the mid-1990s, where several OEMs in Europe and the United States relaunched the development of electric vehicles.

In the U.S., eight different electric vehicles were produced by six major OEMs. They were primarily developed in response to the September 1990 California ZEV (zero emission vehicle) mandate, initially requiring by 2003 10 % of new cars sales to be ZEV. In 1996, the California ZEV mandate has been postponed and the targets for zero-emission vehicles by 1998 and 2002 have been finally cancelled.

In Europe, electric vehicles with driving ranges of about 80 to 100 kilometres and maximum speeds of about 100 km/h, intended for urban use, were produced in the same period by several companies.

Plug-in hybrid electric vehicles have been developed and tested since the 1980s. The first commercially produced PHEV is the Renault Kangoo Elect'road that has been in limited production since 2003. However, the developed vehicle concepts were commercially not successful at that time and have been only produced in low numbers. In particular the immature battery technology and the low driving range inhibited the market introduction of these vehicles. However, the research and development of electric propulsion systems in the 80s and 90s is considered the main technological groundwork for today's technological developments and the re-emergence of electric vehicles [133] [134].

7.3. Electric cars and GHG mitigation

Electric vehicles have the potential to contribute to significant reductions in both carbon emissions and the world‘s dependence on oil as its prime transport fuel. Even when the electricity itself is far from low carbon, such as when the generation mix contains a large proportion of unabated coal-fired power stations, the greater energy conversion efficiency of the electric motors mean overall life cycle emissions (known as ―well-to-wheel‖) are often lower than conventional petrol and diesel alternatives. Decarbonisation of the electricity sector is possible by various measures, many well-established and others under development [135].

Energy use per kilometer

The first parameter, energy use/km is currently quite difficult to estimate, as there are few EVs in use and there is a lack of reliable and comparable energy use data. Energy use/km depends on parameters such as the efficiency of the engine and drive train, the vehicle weight and size, tyres, aerodynamics, etc.

Looking at recent literature, energy use estimates for EVs are found to vary between 0.11 and 0.20 kWh/km, another study assumed a value of 0.16 kWh/km in their calculations for 2010, 0.13 kWh/km for 2020 and 0.11 kWh/km for 2030.

CO_2 emissions per kWh electricity

CO_2 emissions of power production can vary significantly between countries, depending on the fuel mix that is used. For example, CO_2 emissions per kWh are highest if lignite or coal is used (due to their high carbon content), lower for gas-fired power plants and close to zero for most types of renewable energy.

CO_2 emissions of EVs per kilometer

The average EU passenger car currently emits about 184 g CO_2/km from well-to-wheel (160 g/km direct emissions and about 15% indirect emissions due to oil production and refining). Direct car emissions will have to be reduced to 130 g/km by 2015 and to 95 g/km by 2020. The emissions from EVs charged from lignite-fired power production are more than or equal to the emissions from the current average ICE (depending on the energy efficiency of the EV). The data on coal power production are somewhat inconclusive. Gas-fired power production seems to score better, as will, of course, renewable energy [136].

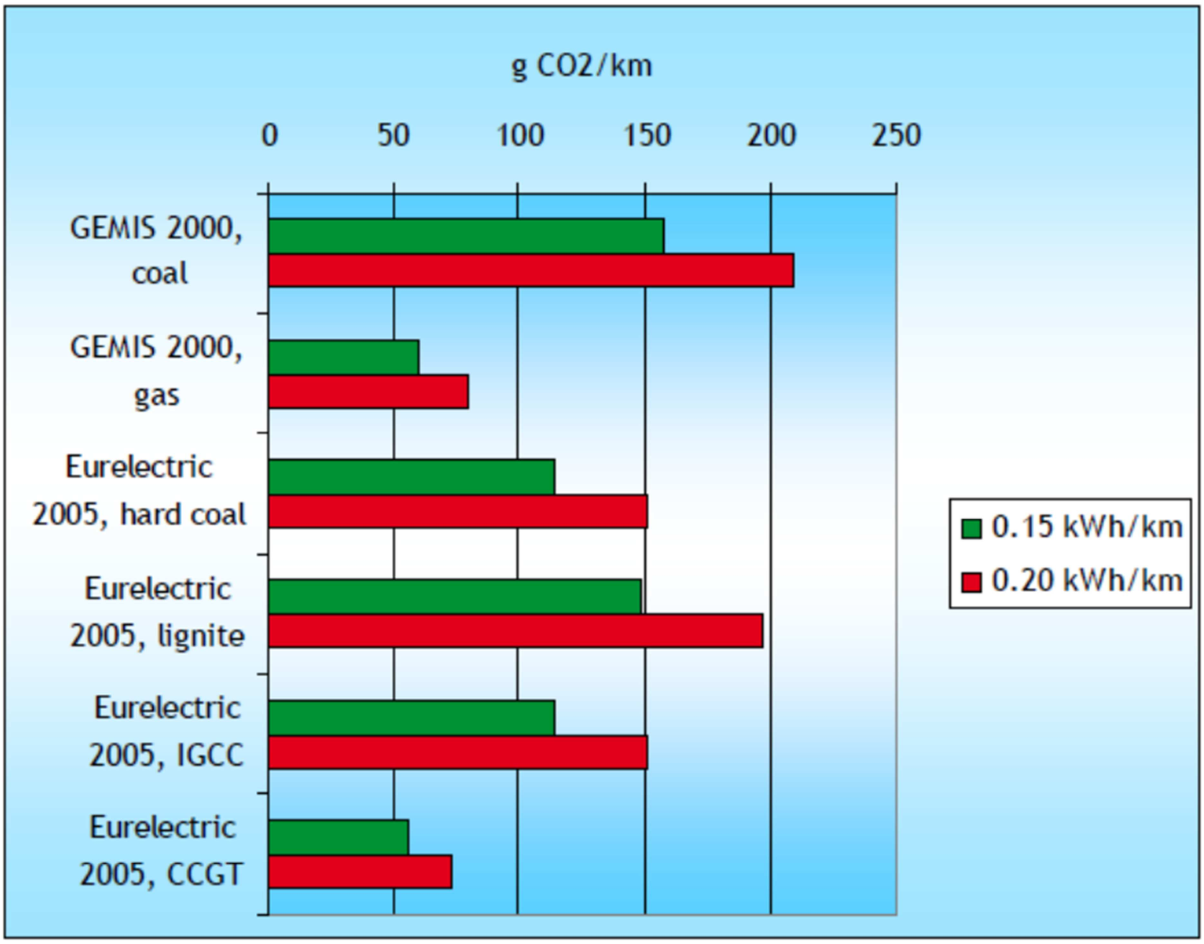


Figure 7.1 - CO_2 emissions per km (well-to-wheel) for various fossil fuel energy sources, with two values for EV average energy use (Data include indirect emissions; an estimate of 5% is assumed for the Eurelectric data) [137].

7.4. Current situation

7.4.1. European situation

Despite rising oil prices and concerns about the climate, energy use for transport is increasing around the world. High growth rates are forecast for most travel modes for decades to come. Two main factors influence the sector's emissions: changes in the volume of travel and changes in the efficiency of the mode of transport used [138].

The European Green Cars initiative is one of the three private and public partnerships (PPP) included in the Commission's recovery package. Under the Green Cars Initiative, the research topics notably target research on electric and hybrid vehicles, including research on high density batteries; electric engines and smart electricity grids and their interfaces with vehicles. Furthermore, the European Commission supports projects on urban mobility which include demonstration of all-electric transport systems in urban settings. The Strategic Energy Technology Plan of the European Commission aims to establish a new energy research agenda for Europe with a main focus on the accelerated development and deployment of low carbon technologies.

In the recently published Second Strategic Energy Review of the Commission, a vision of the future energy system is given, including the decarbonisation of the European energy supply as well as an ending oil dependence of the transport sector [133] [37].

7.4.2. Italian situation

There are a few projects about the development of charging infrastructure for electric cars in Italy. This is what emerges from a survey conducted at the local utilities throughout the country. The survey has shown that, beyond some places like Milan or Bologna, there are just a few projects on the development of charging infrastructure for electric cars. The result is that the number of PHEV and EV in Italy is still far to be considered adequate to support a reduction of GHGs emissions [139] [140].

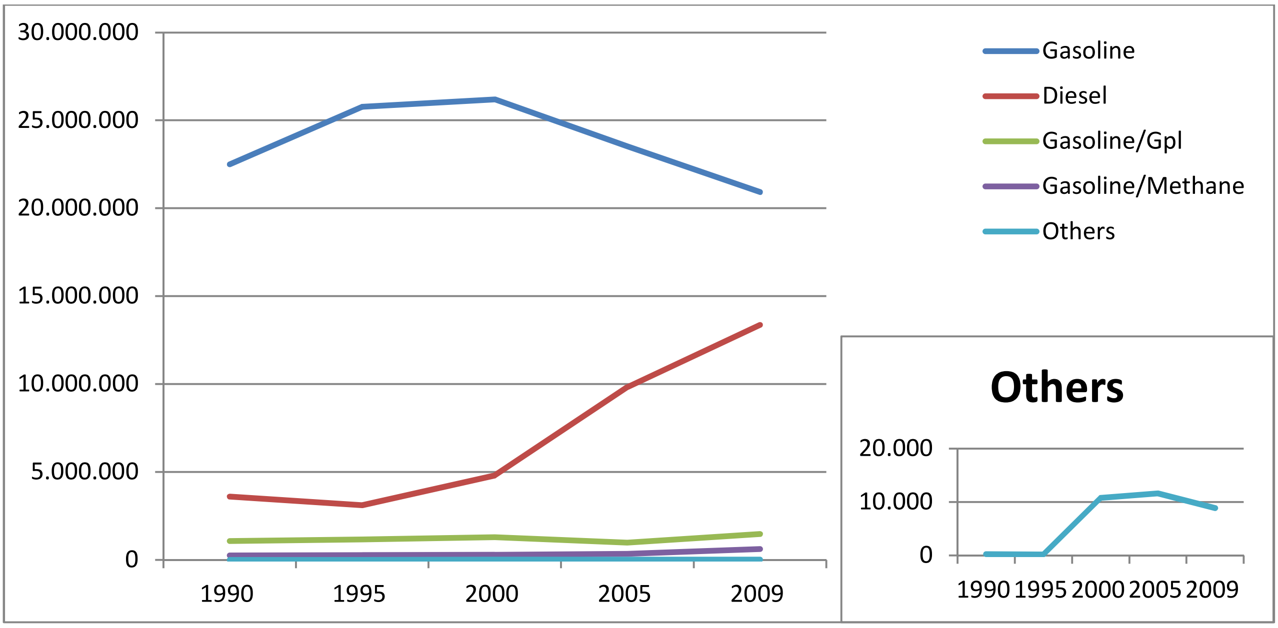


Figure 7.2 - Cars in Italy by categories of fuel [141] [142].

7.5. Potential and future development

Electric vehicles available fleet and potential market key issues for estimating the potential impact of electric vehicles on the electrical grid and in particular on the whole electric consumption are: the identification of the main technical features for the available (short to medium term) fleet of vehicle and the estimation of the potential market penetration evolution of these vehicles in the next years. Since data available at this stage are very limited due to the very few vehicles using the full electric technology, all the conclusions that can be drawn should be taken with the appropriate reservations. In addition, depending also on the future market response, new developments in the electric vehicles technological (e.g. on the battery performances, on the vehicles efficiency and so on),as well as on alternative technologies, can also substantially modify future trends in unexpected ways [143].

Following these issues the Energy Technology Perspectives (ETP) 2008 BLUE Map scenario sets an overall target of a 50% reduction in global energy-related CO_2 emissions by 2050 compared to

2005 levels. In the BLUE Map scenario, transport contributes to this overall reduction by cutting CO_2 emissions levels in 2050 to 30% below 2005 levels. This reduction is achieved in part by accomplishing an annual sale of approximately 50 million light-duty EVs and 50 million PHEVs per year by 2050, which is more than half of all LDV sales in that year. The EV/PHEV roadmap vision reflects the future EV/PHEV market targets set by the BLUE Map scenario. Achieving the BLUE Maps requires that EV/PHEV technologies for LDVs evolve rapidly over time, with very aggressive rates of market penetration once deployment begins. PHEVs and EVs are expected to begin to penetrate the market soon after 2010, with EVs reaching sales of 2.5 million vehicles per year by 2020 and PHEVs reaching sales of nearly 5 million by 2020. By 2030, sales of EVs are projected to reach 9 million and PHEVs are projected to reach almost 25 million. After 2040, sales of PHEVs are expected to begin declining as EVs achieve even greater levels of market share. The ultimate target is to achieve 50 million sales of both types of vehicles annually by 2050 [144].

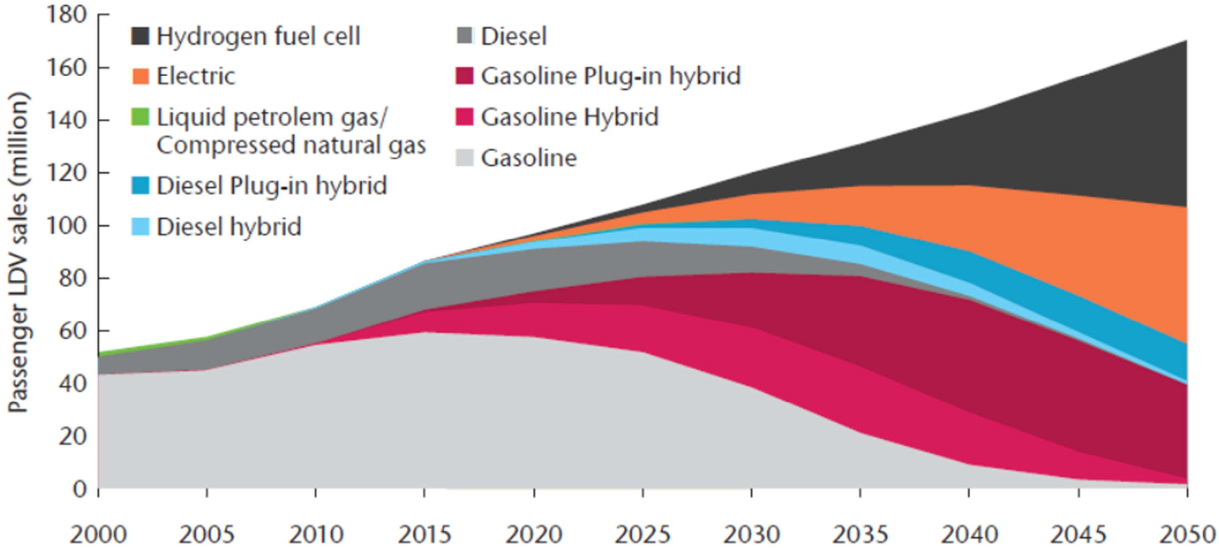


Figure 7.3 - Annual light-duty vehicle sales by technology type, BLUE Map scenario [144].

Table 7.1 - Global EV and PHEV sales in BLUE Map, 2010–2030 (millions per year) [144].

	2012	2015	2020	2025	2030	2040	2050
PHEV	0.05	0.7	4.7	12.0	24.6	54.8	49.1
EV	0.03	0.5	2.5	4.4	9.3	25.1	52.2

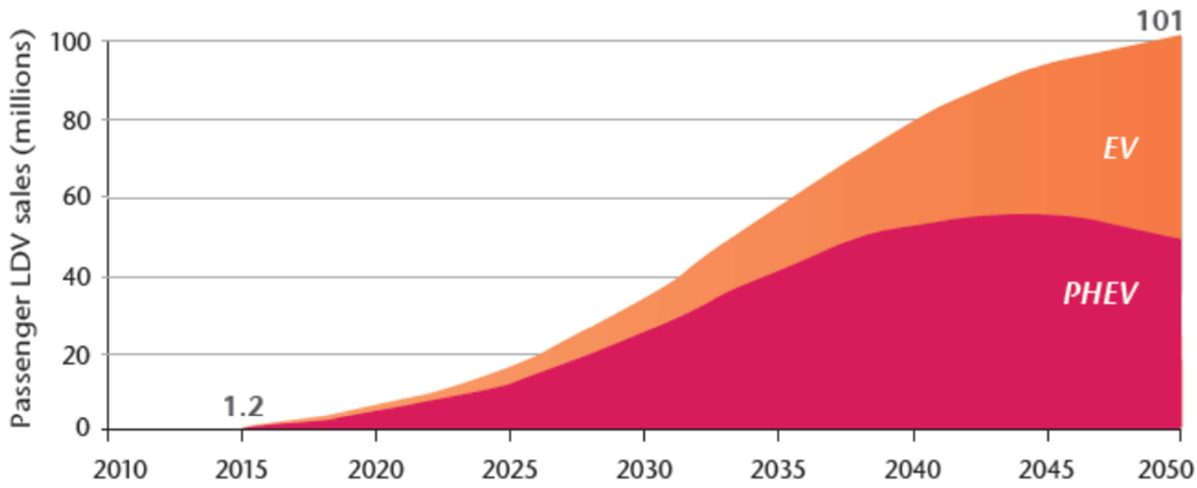


Figure 7.4 - Annual global EV and PHEV sales in BLUE Map scenario [144].

It is important to note that for the near- to medium term (2010 to 2020) data in the figures above, the BLUE Map scenario was revised in 2009 to account both for the economic crisis that began in 2008, which decreased projected car sales, as well as for PHEV/EV product plans announced since the ETP was published, which suggest the possibility of a higher level of EV sales through 2020 (IEA 2009). This is an ambitious but plausible scenario that assumes strong policies and clear policy frameworks, including provision of adequate infrastructure and incentives.

While it may be possible to reach CO_2 targets in other ways, if this target level of EVs and PHEVs relying on low-carbon electricity is not introduced, then other low CO_2-emitting solutions will be needed. Altering the BLUE Map strategy in this way will likely result in an equally or even more difficult challenge.

In order to achieve the deployment targets in Table 7.1, a variety of EV and PHEV models with increasing levels of production is needed. Figure 7.4 demonstrates a possible ramp-up in both the number of models offered and the annual sales per model. This scenario achieves 50 000 units of production per model for both EVs and PHEVs by 2015, and 100 000 by 2020. This rate of increase in production will be extremely challenging over the short time frame considered (about ten years). However, the number of new models for EVs and PHEVs in Figure 7.5 easily fits within the total number of new or replacement models expected to be offered by manufacturers around the world over this time span (likely to be hundreds of new models worldwide) and typical vehicle production levels per model. A bigger question is whether consumer demand will be strong enough to support such a rapid increase in EV and PHEV sales.

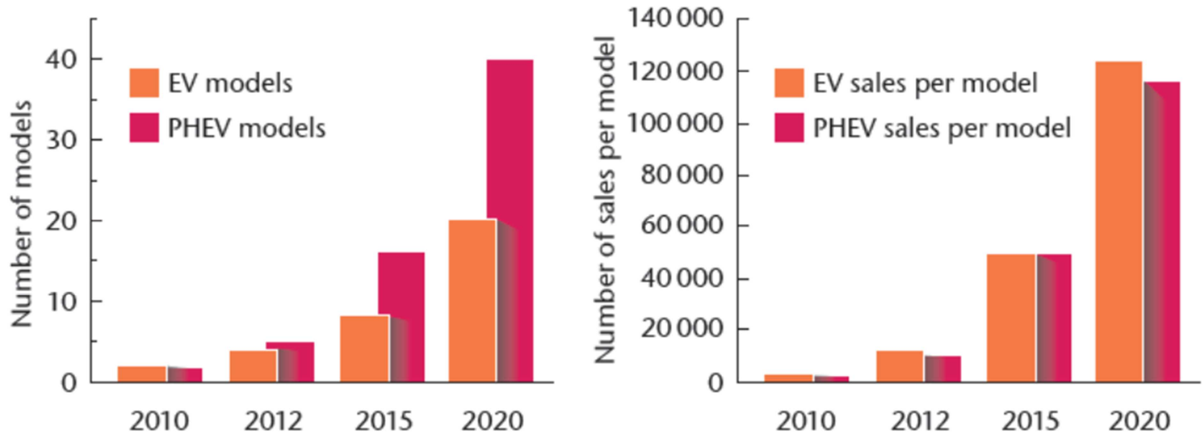


Figure 7.5 - EV/PHEV number of models offered and sales per model through 2020 [145].

7.6. Electric cars as a wedge of PolyGame

There are available in literature different emission factors for different models of hybrid vehicles, PHEV and EV. As described above, there are several problems to define the emission factors for these types of cars. We consider an emission factor of 120 gCO_2/km for the worst case and an emission factor of 40 gCO_2/km for the best emission factors varying the type of car choice, status and availability technology and the sources used to produce electricity [146]. We know that the average cars emission factor is about 170 gCO_2/km, the number of cars in Italy is 36.371.790 and the average path for each car is 11.100 km / year [147] [148]. We obtain:

Table 7.2 - Electric cars as a wedge of PolyGame.

Emission factor (gCO2/km)	Number of cars replaced (new technology cars)
120	9 millions
40	3,5 millions

8.

CONCLUSIONS

Through this study, it was possible to do evaluations on the applicability and functionality of different options useful to reduce CO_2 emissions. Several aspects were treated and calculations have been done to understand the feasibility of the different wedges. The data obtained are useful in guidance: since many aspects were not considered or were studied in a generic way, in order to get a more reliable evaluation more detailed assessments are recommended.

Due to the vastity of the topics analyzed and their complex relationships with several aspects of contemporary life there are several limitations that affects this study. First of all, economical and political implications were not taken into account, hoping that for good solutions funds can be collected and efforts can be done. Moreover, there are several data sources available for these topics and sometimes they don‘t agree among them, although in this thesis mainly reliable sources were used such as peer reviewed papers and articles and important reports. The results show that the technologies and methodologies for reducing emission of pollutants can lead to satisfactory results, an interesting aspect of the data obtained is also the immediate availability of the these wedges. For some of them are necessary further developments in the near future, an improvement that can increase their potential for reducing emissions. Some of these options are already spread, so, improving their action means to increase their diffusion and to improve their management, other methods such as electric drives and biofuels need instead having a strong effort to spread them sufficiently to influence the areas where they are going to work.

“It is a sin not to do what one is capable of doing”.

José Martì

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