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State of the art of mitigation & relation mitigation/adaptation

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Preface

This study was performed within the framework of the 'Knowledge for Climate programme'.
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Abstract

This study has the main purpose to make useful information available for the programming of the Knowledge for Climate (KfC) program. The emphasis has been laid on a broad overview of mitigation options and relations, complemented with more detailed information on new or less known options and insights. The mitigation option biomass gets special attention in this study. The production of biomass has many (positive and negative) relations with other elements of the KfC program like space use and adaptation. Recently a global discussion on biomass usage for biofuels has started (food or fuel). Therefore a separate chapter will be dedicated to the sustainability aspects of biomass. A number of innovative mitigation measures such as aquatic biomass and biomass in combination with Carbon Capture and Storage (CCS) are described in more detail. Furthermore, novel technologies for reducing or offsetting climate change such as air capture and artificial cooling might have a high potential as mitigation option, but need to be examined before implementation could start.

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Summary

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An overview of technical mitigation measures with emphasis on the energy supply side is presented. This overview shows the large number of available and innovative options and the vast potential for reduction of the emissions of GreenHouse Gases (GHG) of these mitigation measures. The effectiveness of many mitigation options is strongly dependent on local conditions and implementation issues. A number of innovative mitigation measures such as aquatic biomass and biomass in combination with Carbon Capture and Storage (CCS) are described in more detail.

Biomass for energy has many different forms and applications. It is one of the mitigation options with a high potential, but at the same time it can have negative environmental impacts and might compete with other forms of land use including food production. This makes bio-energy a promising but complex option, which makes careful evaluation necessary.

Several examples of multifunctional land use show that by combining functions, synergy can be achieved. This could lead to a reduction of potentially negative impacts and thus easier implementation. Furthermore, novel technologies for reducing or offsetting climate change such as air capture and artificial cooling might have a high potential as mitigation option, but need to be examined before implementation could start.

The relations between mitigation and adaptation are complex. Adaptation measures can interfere with mitigation measures, but also beneficial combinations can be formed. Some mitigation options are directly influenced by climate change.

1. Introduction

Climate change due to the emission of greenhouse gases (GHG) has resulted in a dual strategy in order to reduce its effects. On the one hand mitigation measures (measures to reduce the extent of climate change) are taken. Examples are the application of renewable energy production and energy conservation measures which result directly in lower GHG emissions and thereby decrease the cause of climate change. On the other hand adaptation measures are taken. These measures aim at lowering the negative impacts of climate change, for instance by creating water retention areas to counteract more extreme rainfall periods.

The major impacts of climate change are:
- Temperature rise
- Rise of the sea level
- More extreme rainfall and wind regimes (flooding, storms)
- Change in average rainfall and temperature for specific areas
- Loss of land space, especially in coastal areas
- Higher salinity in coastal areas due to higher sea level
- Acidification of ocean water.

The objective of this study is twofold. First, a brief overview of mitigation options on the energy supply side is given. In this overview a number of less known options is also briefly described.

The second objective is to determine the relation between mitigation and adaptation for a number of selected mitigation options with high potential. This information is used to determine knowledge gaps and to define suitable R&D suggestions. Some mitigation options influence the local climate (a.o. by aerosol emissions) and some mitigation options are influenced by climate (wind, solar, heating systems, cooling systems, etc.). These relations are also highlighted.

A large number of mitigation options has been recognized. In chapter 2 an overview is presented of mitigation options which are available or will be available in the short term both on a global and on national scale. This summary will give the basic state of the art of the most important options, to be used as a "primer" for researchers who are not acquainted with the mitigation field.

From this overview a selection of mitigation options will be made and described in more detail if these options have a relevant relation with adaptation, are influencing local climate or are influenced by climate change.

A more detailed state of the art will be given for some large scale options that are rather new compared to the IPCC WG3 report of 2007.

From all renewable energy sources biomass resembles fossil fuel the most and therefore it is relatively easy to implement in existing energy infrastructure. Issues relating to the sustainability of biomass production and conversion limit the potential. Biomass has also many relations with adaptation and is influenced by climate change. On the other hand new ideas on production (aquatic biomass) and on biomass in combination with CCS can have a positive impact on the increase of the role of biomass. For this reason there will be special emphasis in this report on all these aspects of biomass.

To complete the analysis of the relation between mitigation and adaptation some attention will be given to options "in between emission reduction and adaptation". In chapter 6 the state of the art will be given of technologies that capture GHG concentrations directly form the air and options to alter the energy balance of the globe, e.g. by enhancing the albedo.

Finally, in chapter 7 conclusions are drawn and a number of recommendations is given.

2. Mitigation options

Mitigation options related to energy can be divided into energy conservations options (reduction of energy consumption), energy production options (reduction of GHG emissions per unit of energy produced) and carbon capture options (fixation of carbon or CO_2). In this chapter an overview of options and their potential is given.

2.1 Mitigation options – energy conservation

An important route for mitigation is energy conservation. Reduction of the use of energy leads to a decrease of GHG emissions related with energy production. A large number of options is available and applied or being developed in the industrial, domestic, transport and agricultural sector. A brief overview of energy conservation options is given in Table 2.1. A detailed description of energy conservation measures can be found in [ECN, 2007]. In this paragraph, highlights from this study are summarized.

Industry
Energy conservation measures in the industrial sector is roughly divided into more efficient use of energy, both electricity and heat, and the application of CHP (Combined Heat and Power). Many energy conservation measures in the industrial sector are comparable with those for the built environment. Especially, the application of waste heat can lead to a substantial reduction of the use of fossil fuels.

In 2006 the total primary energy (fossil fuel based) consumption in the Netherlands was 3,280 PJ (including 570 PJ for products and chemicals) of which 1,360 PJ was used for heat production only (> 40%). If only the energy applications are considered ca. 50% of the energy carriers is applied for heat production. For the total use of primary energy the conversion losses are about 30%. In the Netherlands ca. 100 PJ of heat with a temperature higher than 50 ^{o}C is wasted on a yearly base in the industrial sector.

Although there is a vast amount of smaller and larger CHP installations in operation with a high overall efficiency, there is still an abundance of unused waste heat especially from industrial processes, energy production and waste incineration. Through optimization of the heat production and heat demand the total consumption of energy carriers can be reduced while maintaining the overall electricity and heat demand.

A strategy for optimization of heat is being developed at ECN and is built up from a number of steps. Crucial steps are the prevention of waste heat production by optimizing industrial and conversion processes and the evaluation of the time and place of waste heat production and heat demand in relation with the quality of the heat.

The steps in the heat optimization strategy are:
- Energy conservation
- Optimization of processes
- Production of electricity (with use of waste heat)
- Waste heat application for cooling

One of the measures for optimization is storage of heat as the time of production of waste heat is often not in line with heat demand. Heat can be stored in aquifers, stored as latent heat (phase transition) and as reaction enthalpy (reversible chemical reaction).

Transport
Reduction of GHG emissions in the transport sector can take place at different stages in the transport chain: reduction of the demand for transport, more efficient transport, more efficient vehicles, efficiency improvement of fossil fuel production and CO_2 neutral fuels. The reduction potential is a summation of non-technical (behaviour, organization of transport chain, logistics) and technical measures (more efficient vehicles, alternative fuels). In the GHG emission reduction scenario's from [ECN, 2007] the application of biofuels as alternative transport fuel has the highest potential. However, a more recent ECN report on sustainable innovation in transport concludes that hydrogen fuel cell and electric vehicles are potentially the most efficient modes of transport in terms of CO_2 emissions per kilometre, although this depends on the energy production process used [ECN, 2009]. Jacobson [2009] reaches the same conclusion, and according to this study, the biofuels investigated only offer a marginal benefit compared to fossil fuel driven transport. In chapter 3 the production and utilization of biofuels is described in detail.

Built environment
The energy conservation potential in the built environment consists of:
- More efficient electric appliances and lightning
- Measures for existing building (e.g. insulation, control systems)
- Energy efficient new buildings
- Alternative fuels for electricity and heating
- Efficient energy conversion

The highest potential for energy conservation is found for electric appliances/lighting, measures in existing buildings and the use of alternative fuels in the built environment [ECN, 2007]. In this report [ECN, 2007] an extensive list of measures can be found for direct or future application. One form of insulation, roofs covered with sedum (green roofs), is described separately in chapter 4 as an example of multifunctional measures.

Agriculture
GHG emissions in the agricultural sector are related to energy consumption for lighting and heating (mainly CO_2 emissions), methane (CH_4) emissions from livestock, nitrous oxide (N_2O) emissions from nitrogen containing fertilizers, and carbon storage in (or release from) the soil and biomass.

Especially in greenhouse horticulture energy conservation measures (insulation, new cultivation practices) and the application of CHP can lead to a substantial reduction of energy consumption. Also spatial planning, including centralized CO_2 and heat supply systems for fertilization and waste heat utilisation, can lead to lower energy consumption.

A reduction of N_2O emissions can be accomplished by more efficient or reduced nitrogen fertilizer utilization. Changing the composition of cattle fodder may lead to lower CH_4 emissions. Carbon storage in soils is discussed in chapter 6.2.4.

Table 2.1 *Energy and GHG emission reduction potentials of mitigation options - energy conservation. Projected global energy related CO_2 emissions without mitigation in 2030: 37-54 Gton CO_2-eq./yr [IPCC, 2007; ECN, 2007]. Projected energy demand in the Netherlands in 2030: 1,700-4,500 PJ/yr [Rabou, 2006]; CO_2-eq. emissions in the Netherlands in 2007 were 205 Mton*

		Potential Global [IPCC, 2007][a]	Potential Netherlands [ECN, 2007]	Potential Netherlands [ECN, 2007]
		Gton CO_2/yr	PJ/yr (primary)	Mton[b] CO_2/yr
Electricity production (supply and conversion)		1.2 - 2.4		19 - 29
Industry		0.7 – 1.5	102 - 106	13
	CHP			
	Process intensification			
	Use of industrial waste heat			
	Sustainable paper production			
	More efficient use of heat			
	More efficient electricity use			
	Innovative processes			
Transport		1.3 – 2.1		9 - 23
	Adaptation transport demand and type of transport		34	2,5
	More efficient transport vehicles		79	5,8
	Behaviour/use		4 - 28	0.3 - 2.1
	Alternative fuels		50 - 101	3.6 -7.2
Built environment		4.9 – 6.1	130 - 245	10 - 20
	Electric equipment/lighting		132	10
	Existing buildings		92	6
	New buildings		17	0.9
	More efficient conversion		8	0.6
	Other fuels (green gas)		-	10
Agriculture		0.3 – 2.4		
Forestry		0.6 – 1.9		
Waste		0.3 – 0.6		

[a] 2030; < 20 US$ per ton CO_2 –eq
[b] 1 Gton = 1,000 Mton

2.2 Mitigation options – energy supply side and carbon storage

In Table 2.2 a list of supply side mitigation options is presented. For each option the major (energy) products are shown; also the global and Dutch potential and (qualitative) effect on adaptation measures are indicated.

The different options are categorized in ocean power, hydropower, solar power, wind energy, nuclear energy, geothermal energy, biomass production, biomass conversion and carbon capture and storage (CCS). Options with a high potential are geothermal energy, CCS options, wind energy, bio- and solar energy.

Some of the mitigation options from Table 2.2 are not applicable in the Netherlands and other options are applicable but can only have limited effect due to the specific circumstances in the Netherlands. Specific for the Netherlands are the lack of height differences, limited land availability and a relatively large surface area situated below sea level. CCS options, wind energy and bio-energy are the options with the highest potential in the Netherlands.

A detailed description of the technical state-of-the-art of tidal energy, wave energy, hydropower, wind energy, geothermal energy and solar energy can be found in [ECN, 2008].

Table 2.2 *Overview mitigation options (energy production, CCS and geo-engineering). Projected global primary energy demand in 2030: 650-890 EJ/yr (2004: 464 EJ/yr) [IPCC, 2007]*

		Product[1]	Potential world [IPCC, 2007]	Potential world	Potential Netherlands
Ocean energy	Tidal energy	E	7 EJ/yr		200 MW
	Wave energy	E			170-315 MW
	RED/PRO	E			2,000 MW
Hydropower	Micro < 1 MW	E			80-100 MW
	Small < 10 MW	E	2 EJ/yr		
	Large > 10 MW	E	60 EJ/yr		
Wind	Off-shore	E	600 EJ/y	95,000 GW	7,000 MW
	Land	E			4,000 MW
Nuclear energy		E			
Solar energy	Photovoltaic	E	1,600 EJ/yr	700 GW	200 MW
	Solar heat domestic	H			
	Concentrated Solar Power	E, H	50 EJ/yr	4,700 GW	0
Geothermal		E, H	5,000 EJ/yr	300,000 GW	65 MW
	Biomass production		250 EJ/yr	200-1,500 EJ/yr	
Biomass - Aquatic	Micro-algae	P, T		200 EJ/yr	16 PJ/yr
	Macro-algae	P, T		6,000 EJ/yr	315 PJ/yr
	Salt/brackish water plants	P			18 PJ/yr
Biomass - Land	Sugar crops	T	250 EJ/yr		
	Oil crops	T			
	Carbohydrate crops	P			
	Ligno-cellulosic crops	F, C			
Biomass conversion					
	Biomass – Thermal conversion	E, H, T			
	Biomass – SNG (digestion)	G			
	Biomass – SNG (gasification)	G			
	Biomass coal co-firing	E			
	Ethanol from biomass	T, P			
	Oil from biomass	T, P			
CCS	Empty gas & oil fields	S	675-900 Gt CO_2		10 Gt CO_2
	Saline aquifers	S	1,000-10,000 Gt CO_2		0,7 Gt CO_2
	Coal beds	S	3-200 Gt CO_2		0,4 Gt CO_2
	Biomass conversion CCS	S			
	Storage in biomass	S			
Air capture	Mineral sequestration	O			
	Air scrubbing	O			
	Ocean fertilization	O			
	Carbon fixation in soil	O			
Artificial cooling	SO_2 injection	O			
	Cloud seeding	O			

[1] E = electricity, H = heat, P = product, T = transport fuel, F = solid fuel, G = gaseous fuel, S = carbon capture and storage, O = Offsetting warming effect of GHG.

2.2.1 Ocean energy and hydropower options

Tidal energy

Two types of tidal energy have been developed. The first type uses the difference in water level height and the second type uses the kinetic energy from tidal flow.

An example of a (Dutch) technology for tidal flow energy generation is the Tocardo. The Tocardo tidal turbines can be compared to “underwater wind turbines”, generating energy from sea currents and tidal flows. The scale is different from wind however: tidal energy devices can be much smaller than wind turbines, as water is much denser than wind. A three meter diameter tidal device can generate as much as a wind turbine of 18 meters diameter. As the tidal devices are fully submerged, they have no visual impact and only a limited environmental footprint. A prototype of the Tocardo turbine has been tested and is being upscaled to commercial capacity.

A large number of different technologies for tidal energy is available and many installations are in operation. The global potential is ca. 2 EJ/yr (≈ 80 GW); the potential for tidal energy in the Netherlands is 5 PJ/yr (≈ 200 MW) [Deltares, 2008].

Wave energy

For the generation of energy from wave movement a vast number of technologies have been developed and tested. It comprises systems attached to the shore as well as systems attached to the seafloor. A number of wave energy plants is in operation mainly in Europe and Asia.

Deep water wave power resources are enormous, between 1 and 10 TW, but it is not practicable to capture all of this. The useful world-wide resource has been estimated to be greater than 2 TW. Locations with the highest potential for wave power include the western seaboard of Europe, the northern coast of the UK and the Pacific coastlines of North and South America, Southern Africa, Australia and New Zealand (see Figure 2.1). The northern and southern temperate zones have the best sites for capturing wave power. For Europe the estimated potential is ca. 320 GW [ETNWE, 2002]. For the Netherlands the potential is estimated at 170-315 MW [Deltares, 2008].

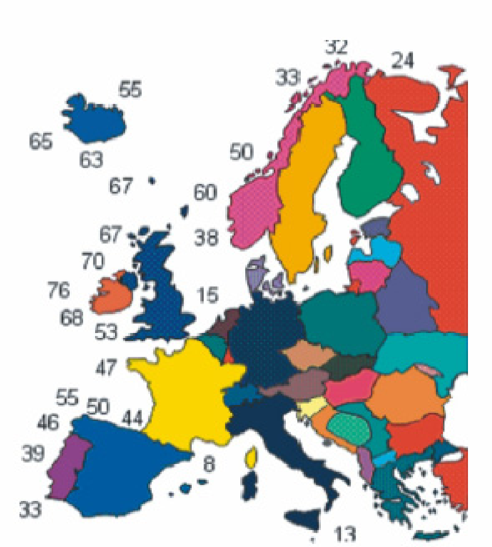

Figure 2.1 *Wave power levels in kW/m of crest length in European waters, [ETNWE, 2002]*

Traditional hydropower
At present the global installed capacity of hydropower, especially larger systems, exceeds 900,000 MWe. Hydropower is of limited importance in the Netherlands due to the absence of large height differences. Only at a few locations in the Southern part a number of small capacity traditional hydropower plants in the rivers are in operation (at present the total installed capacity amounts ca. 40 MW) with an estimated potential of 80-100 MW. No dramatic increase in traditional hydropower capacity in the Netherlands is expected [Deltares, 2008].

Salinity gradient
A new development in hydropower is 'salinity gradient power' or 'osmotic power'. This is the energy retrieved from the difference in the salt concentration between seawater and river water. Two practical methods in development are reverse electrodialysis (RED) where ions are transported and pressure retarded osmosis (PRO) where water molecules migrate through a membrane. Both processes rely on osmosis with ion specific membranes. The key waste product is brackish water. The technologies have been confirmed in laboratory conditions. They are being developed into commercial use in the Netherlands (RED) and Norway (PRO).

Salinity power is one of the largest sources of renewable energy that is still not exploited. Suitable locations are those where sea and fresh water meet. The exploitable potential world-wide is estimated to be 2,000 TWh annually (≈ 230 GW). For the Netherlands a potential of

2,000 MW to 7,000 MW [Deltares, 2008] has been estimated (7,000 MW is the theoretical potential; ≈ 60 TWh); a realistic potential is estimated to be 2,000 MW.

2.2.2 Wind energy

Wind enery is a rather well known option so we only give here some important figures.

Off-shore wind energy
The global installed capacity in 2006 was 890 MW; for 2030 ca. 235 GWe installed capacity is foreseen. For the EU-27 the off-shore wind capacity in 2030 is estimated at 115 GWe [ECN, 2008].

On-shore wind energy
In 2006 there was more than 70 GW installed wind power. Roadmaps have been developed for on shore wind energy. For on shore wind energy in EU-27, 185 GWe installed power is foreseen by 2030 (globally approximately 545 GWe).

The total impact of wind energy both off-shore and on-shore on the GHG emission reduction will be ca. 600 Mton C/yr (= 2,200 Mton CO_2/yr) in 2030 following the foreseen growth in installed capacity. In the figure below a map is shown with favourable and less favourable locations with respect to average wind speed on land throughout the world for wind energy. An average wind speed of at least 7-8 m/s is necessary for economical viable wind energy [IPCC, 2007]; this condition limits the area of suitable wind energy locations.

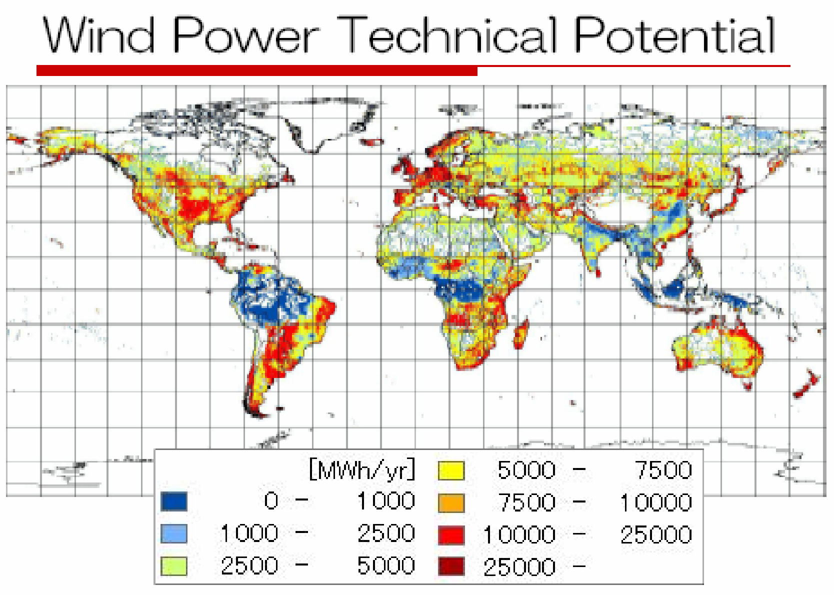

Figure 2.2 *The global technical potential for wind power* *[NIES, 2008]*

The global potential of on-shore and off-shore wind energy is estimated to be 600 EJ (≈ 95,000 GW) [IPCC, 2007].

2.2.3 Solar energy

Photovoltaic systems
In 2007 approximately 10 GWe grid-connected and 3 GWe off-grid systems were installed. The global estimated potential of PV systems in 2030 is ca. 700 GW [ECN, 2008] further increasing to more than 2,000 GW in 2050. The areas with the highest potential for solar energy are shown in the figure below.

Despite the high potential the implementation of PV systems is hampered by the relatively high costs.

The available roof and façade area in the Netherlands is 270-350 km^2 which corresponds with 30 GW (based on 100 Wp/m^2).

Domestic solar heating (hot water systems)
The present global annual yield of solar heating systems for hot water is 0.5 EJ (91 GWh) growing with 20% each year. The installed capacity at present only is 0.2% of the energy requirement for hot water in the EU-27 which means that there is still a large potential unused.

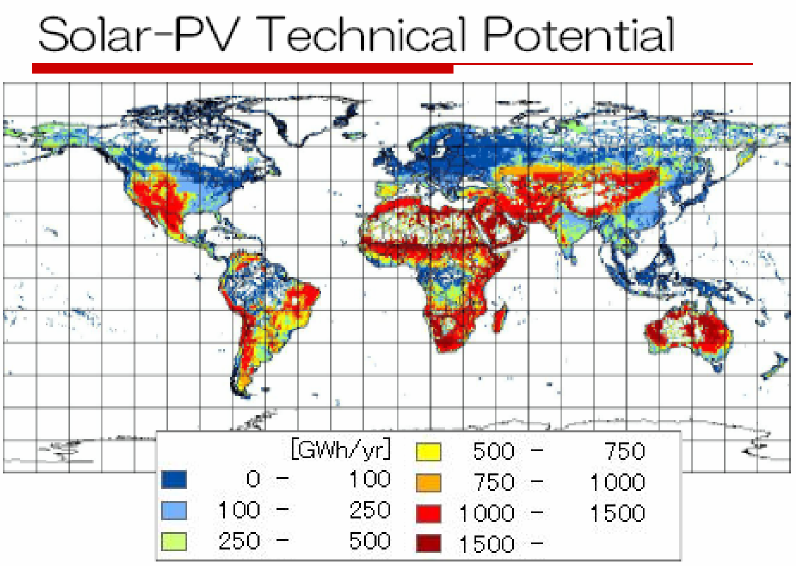

Figure 2.3 *The global technical potential for solar PV,[NIES, 2008]*

Concentrated Solar Power (CSP)
By the use of parabolic mirrors solar radiation is concentrated and directed to a 'receiver' where the heat is used for e.g. steam production. By means of conventional steam turbines or Stirling engines electricity is generated. The efficiencies for converting solar energy into electricity are at present 10-15% (peak efficiency of 21%). One km^2 of land in arid or semi-arid regions can generate approximately the equivalent of a 50 MWe coal or gas-fired electricity plant (125 GWh/yr). In 2006 the total installed capacity was 0.4 GWe. For southern Europe, the Middle East, northern Africa and the Arabic peninsula the estimated total potential is 630,000 TWh/year. Estimates for the global potential indicate up to 4,700 GWe in 2030. Under Dutch conditions CSP is less attractive.

2.2.4 Geothermal energy

Geothermal energy exploits the heat of deep earth layers, several kilometres below ground level. Low-enthalpy fields (low temperature heat) are used for heating buildings and district heating, whereas high-enthalpy fields (in geologically active areas) allow direct electricity production. In total the global use of geothermal energy (both heat and electricity) amounts to 2 EJ/yr. The estimated global potential is 5,000 EJ/yr (≈ 300,000 GW).

The calculated potential for the Netherlands is large, but only a limited number of projects have been realized or are in preparation due to the relative high costs. One project uses hot water from abandoned mine shafts for heating purposes. The potential in the Netherlands is ca. 1,000 PJ/yr (≈ 65 GW) [Deltares, 2008].

2.2.5 Biomass

Biomass is used as source for food, fibres, building material, feedstock for a variety of non-food products and for energy. A large amount of biomass is available as waste or by-products from agricultural and industrial activities (e.g. food industry, wood processing industry), from household waste and maintenance of parks, forests and roadsides. Biomass can be used for energy by direct conversion into heat and/or electricity, but also after being transformed into solid, liquid or gaseous fuels.

Production of biomass is accompanied by the use of fertilizers and fossil fuels for transport and processing with their accompanying emission of GHG gases. Also the production of biomass for energy purposes competes with other potential uses of land. So even though the application of biomass for energy generation has high potential, because of its complexities it should be evaluated carefully for each specific application with respect to the overall GHG balance, competition with other land use and social aspects.

Biomass grown in an aquatic environment (micro-algae and seaweed), both on land (in basins) or at sea form a relatively new and promising option for mass production of biomass.

2.3 Carbon Capture and Storage (CCS)

CO_2 produced by combustion of fossil fuels can be extracted from the flue gas and stored thereby preventing the release into the atmosphere (see also chapter 5). Storage options are empty gas- and oilfields, aquifers, coal beds and in the ocean. Global estimated storage capacities are:

- Oil and gas fields: 675 - 900 Gton CO_2
- Unmineable coal seams: 15 – 200 Gton CO_2
- Deep saline formations: 1,000 – ca. 10,000 Gton CO_2

For the Dutch situation excellent opportunities are present in depleted gas reservoirs. Total storage capacity has been estimated at 11,000 Mton CO_2, mainly in depleted gas fields and off-shore. Other storage options are depleted oil fields (40 Mton), deep seated coal beds (400 Mton) and aquifers (720 Mton) [DHV, 2008].

So far, CCS technologies in combination with fossil fuel fired energy plants have been investigated. A novel route is the combination of biomass fired energy plants with CCS, leading to a potentially negative CO_2 balance. Another option is fixation of CO_2 in biomass or in olivine and other minerals (see chapter 6).

2.4 Barriers for mitigation options

The anticipated effect and cost development of energy conservation measures and energy generation technologies on the reduction of GHG are often not as expected due to non-technical factors. Two major reasons are effects associated with the development of technological learning (learning curves) (2.4.1) and the rebound effect (2.4.2).

2.4.1 Learning curve

Technology learning is a key driver behind the improvement of available (energy) technologies and subsequent reduction of production costs. Many of the conventional technologies in use today have already been continuously improved over decades, sometimes even a century, for example coal-fired power plants. In contrast, many renewable/clean fossil fuel energy technologies and energy saving technologies still have higher production costs, but lower fuel demands and GHG emissions. As most of these technologies are still quite young, their technological development and resulting cost reduction occurs at relatively high speed compared to the conventional technologies. It is thus anticipated that in many cases the gap between conventional and new technologies can be closed, i.e. a break-even point be reached. Crucial questions are however, whether this point will be reached, and if so, when and under what circumstances (especially how this depends on policy support).

In Figure 2.4 an example of a learning curve is shown (PV modules). It can be seen that the curve flattens out at and even shows an increase in price at increasing installed capacity. This behaviour at this time is also seen in learning curves of other technologies. Explanations for this behaviour can be increased prices for materials, effects caused by (too) fast implementation (no time for improvement or implementation of new developments) and the effects of economic support by the government [NWS/ECN, 2008]. Estimations of future cost developments should therefore be used with caution.

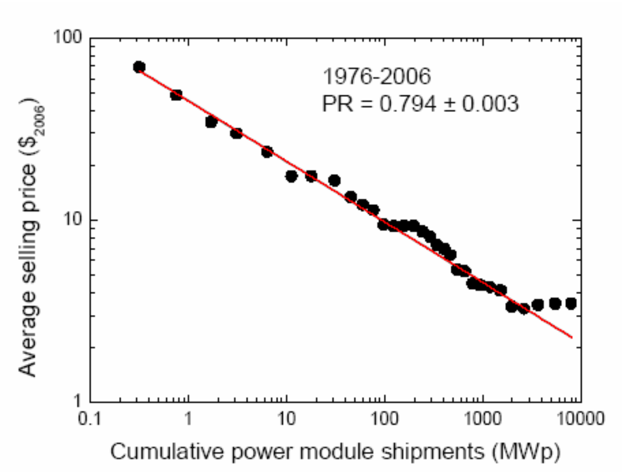

Figure 2.4 *Updated crystalline silicon PV module experience curve showing average module price in 2006 US$/Wp as a function of cumulative power module shipments [NWS/ECN, 2008]*

2.4.2 Rebound effect

The rebound effect is generally expressed as a ratio of the lost environmental benefit compared to the technically expected environmental benefit (when holding consumption constant). The consumption pattern is often influenced by energy conservation measures leading to an increase in energy consumption.

The rebound effect can be distinguished into three different economic reactions:

- Direct rebound effect: Increased efficiency lowers the cost of consumption, and hence increases the consumption of that good.
- Indirect rebound effect: Through the income effect, decreased cost of the good enables increased household consumption of other goods and services, increasing the consumption of the resource embodied in those goods and services.
- Economy wide effects: New technology creates new production possibilities and increases economic growth, thereby increasing overall energy demand.

In the example of improved vehicle fuel efficiency, the direct effect would the increased fuel use from more driving as driving becomes cheaper. The indirect effect would incorporate the increased consumption of other goods enabled by household cost savings from increased fuel efficiency. Since consumption of other goods increase, the embodied fuel used in the production of those goods would increase as well. Finally, the economy wide effect would include the long term effect of the increase in fuel efficiency on production and consumption of a whole range of goods and services throughout the economy, including any effects on economic growth rates.

There are three possible outcomes for the total rebound effect:
1. The actual resource savings are higher than expected savings. The rebound effect is negative. This is unusual, and would only occur if the government imposes more efficient technologies that also have higher costs.
2. The actual savings are less than expected savings. The rebound effect is between 0% and 100%. This is sometimes known as 'take-back', and is the most common result of empirical studies. For example, a rebound effect of 20% means that only 80% of the expected energy savings are achieved.
3. The actual cost savings are negative. The rebound effect is higher than 100%. This situation is commonly known as Jevons paradox and is sometimes referred to as 'back-fire'.

For household heating and cooling, and personal automotive transport the direct rebound effect is likely to be less than 30% (for transport closer to 10%). As demand tends to saturate the rebound effect for specific options will decline in the future. In some studies the overall rebound effect of various energy efficiency options have been estimated at more than 50% [UK ERC, 2007].

2.4.3 Costs of mitigation options in the Netherlands

The selection of mitigation options is a combination of technical potential and costs. Some options with a high potential are not applied at large scale and do not appear in scenario forecasts due to the high costs (even after taken cost reduction according to learning curve into account). In Figure 2.5 the results of a scenario study with different emission constraints is shown [ECN, 2007]. The contribution of renewable energy, almost absent in the reference situation, becomes substantial at higher emission constraints. Within the various options there is a large difference in cost effectiveness. This is visualized in Figure 2.6 where the costs (expressed in €/ton CO_2-eq.) is plotted versus the potential for GHG reduction.

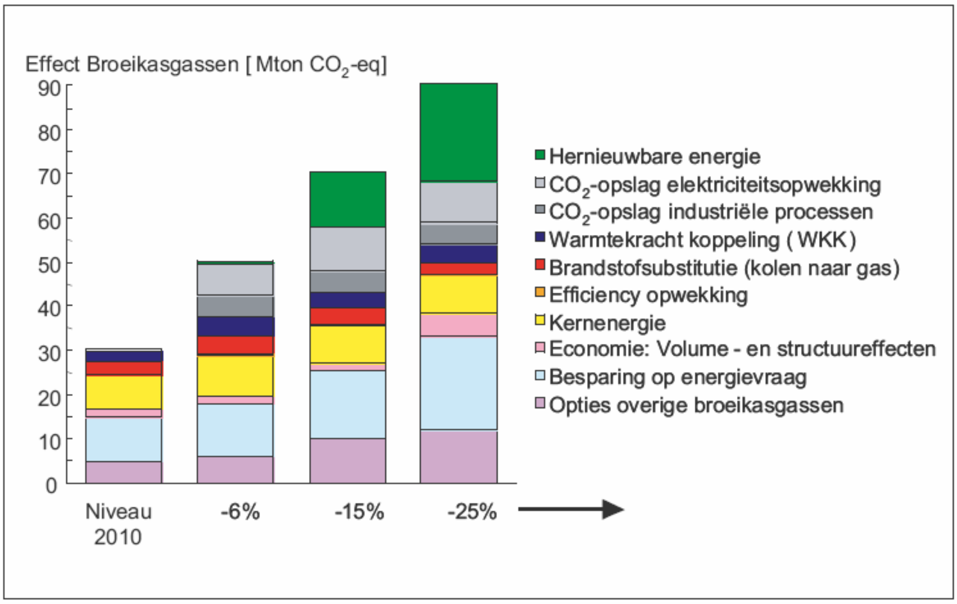

Figure 2.5 *Cost effective solutions for the year 2020 at different reduction targets for the Netherlands [ECN, 2007]*

From Figure 2.6 it can be seen that up to 70 Mton CO_2-eq. reduction is possible at costs lower than 250 €/ton CO_2-eq. The costs for mitigation options show a steep rise above this amount.

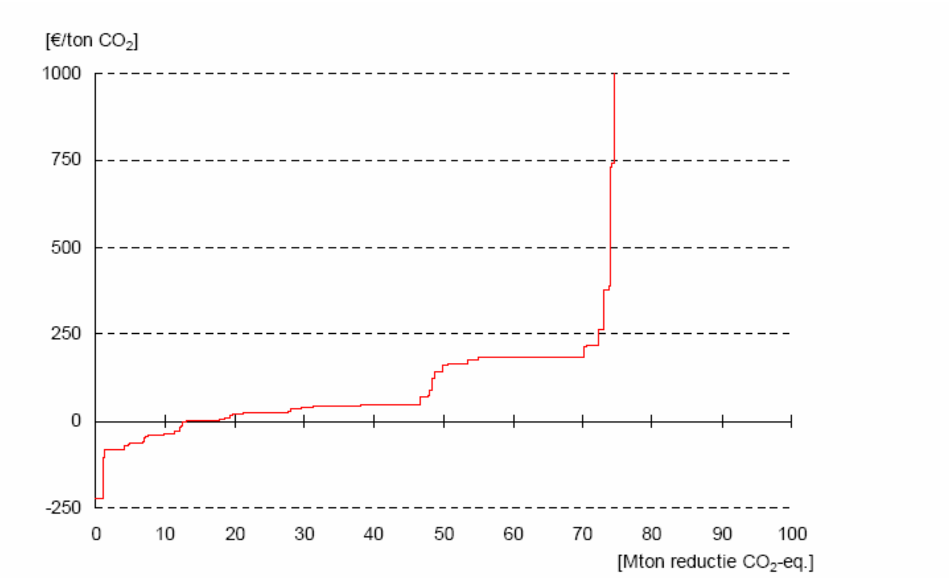

Figure 2.6 *Cost curves of mitigation options in the Netherlands for the year 2020 [ECN, 2007]*

A detailed description of this curve with an overview of costs per option can be found in ECN, 2007. According to IPPC [IPPC, 2007] the total global mitigation potential at carbon prices below 20 US$/ton CO_2-eq. by 2030 for the electricity sector ranges between 2.0 and 4.2 Gt CO_2-eq./yr. For costs up to 50 US$ per ton CO_2-eq. the potential ranges between 3.0-6.4 Gt CO_2-eq./yr.

2.5 Mitigation and energy conservation options relevant for the Netherlands

In Figure 2.7 a division of GHG emission reduction for the Netherlands expressed in Mton CO_2 in 2020 between non-CO_2 gases, CCS, renewable energy, energy conservation and JI/CDM (Joint Implementation/Clean Development Mechanism) is shown for two scenario's, 'flexible and fixed route'. For a detailed description of these scenarios see [ECN/NMP, 2006]. In the fixed route scenario the separate reduction targets for energy conservation and renewable energy are maintained; in the flexible route scenario only the overall target for GHG emission reduction is maintained so the sub-targets for energy conservation and renewable energy are flexible within this constraint.

Figure 2.7 shows that, depending on the scenario, CCS, renewable energy and energy conservation are the three major sectors for mitigation measurement in the Netherlands (JI/CDM are measurements taken abroad).

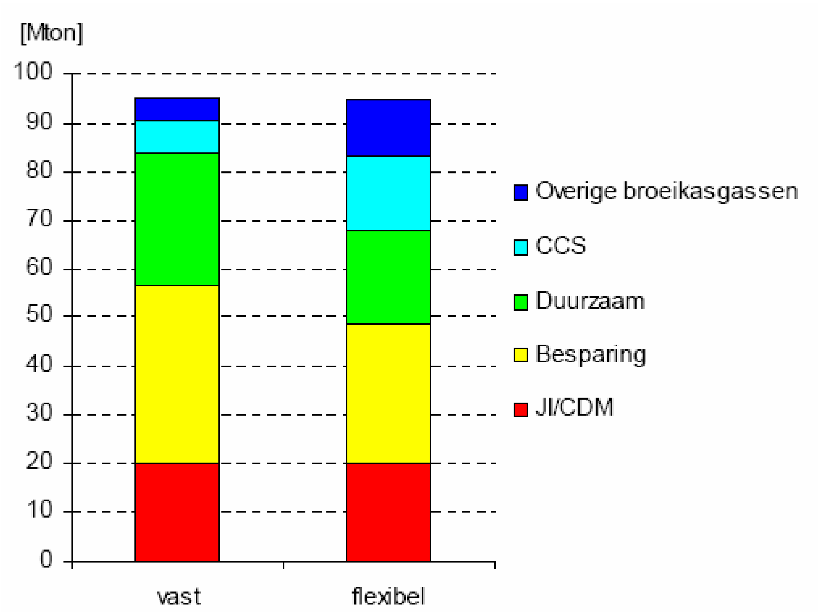

Figure 2.7 *GHG emission reduction in 2020 per theme with or without set sub targets for efficiency and renewable energy [ECN, 2007]*

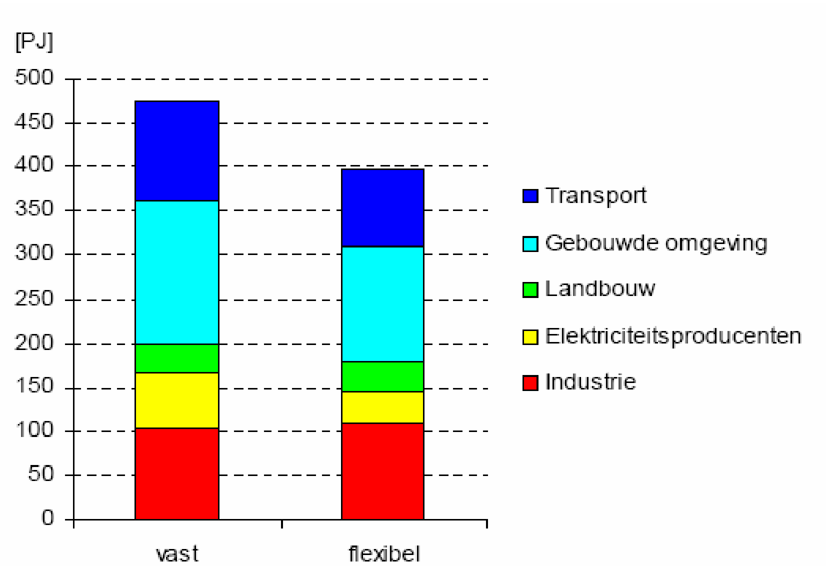

Figure 2.8 *Additional energy conservation per sector in 2020 in relation with the reference scenario [ECN, 2007]*

Concerning energy conservation it can be seen in Figure 2.8 that the highest potentials are to be found in the built environment, transport and industry.

In the following chapter a number of technologies and combination of technologies is presented in more detail. Selection criteria are innovativeness, impact on space utilization and other relations/interactions with adaptation measures, such as alternative land use for water retention or room for rivers. In Table 2.3 a qualitative assessment of potential, innovativeness and extent of interaction with adaptation is given. Based on this table a selection was made for an evaluation of a limited number of mitigation options in the following chapters.

Table 2.3 *Selection by qualitative assessment of mitigation options for more detailed evaluation*

		Potential[a]	Innovativeness[b]	Affected by climate change/adaptation measures[c]
Energy conservation		+	+/-	0 (T, D)[d]
Energy supply side	Tidal energy	0	0	-
	Wave energy	+	+	-
	Traditional hydropower	-	-	+ (R)
	Salinity gradient	+	+	-
	Off-shore wind energy	+	0	-
	On-shore wind energy	+	0	0 (W, L)
	Solar PV systems	0	0	0 (D)
	Domestic solar systems	+	0	0 (T, D)
	CSP	-	+	0 (D)
	Geothermal energy	+	0	-
	Biomass on land	**+**	**-**	**+ (L, T, D)**
	Aquatic biomass	**+**	**+**	**+ (L, T, D)**
CCS	CCS Fossil fuel	+	+	-
	CCS Biomass	**+**	**+**	**+ (L)**

a + = high potential for mitigation, 0 = medium, - = low
b + = innovative, 0 = medium, - = proven technology
c + = affected by climate change/adaptation measures, 0 = medium, - = not affected
d Affected by changes in: T = temperature, D = degree days, R = rain fall, W = wind regime, L = land use

From this qualitative table the options showing high potential and innovativeness or strong interaction with adaptation measures are selected for a more detailed evaluation in the following chapters. These options include biomass and aquatic biomass (chapter 3 and 5) and biomass and CCS (chapter 5).

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3. Biomass and sustainability

3.1 Introduction

Biomass is the major source of food, stock fodder and fiber. It is increasingly considered as a major player as renewable resource of hydrocarbons for use as a source of energy and chemicals (biorefinery). Biomass production can also have negative effects on the environment and on resource availability. The production of biomass has also a complicated relation with climate change. Therefore we have given special attention to these aspects of biomass in this report. An upcoming activity is the cultivation of aquatic biomass (micro- and macro-algae, salt water plants). This subject is dealt with separately in chapter 5.1.

Biomass sources include a wide range of products and by-products from forestry, agriculture and aquatic biomass as well as municipal and industrial waste streams. These are used as feedstock to produce energy (carriers) in the form of solid fuels (chips, pellets and briquettes), liquid fuels (methanol, butanol, ethanol and biodiesel), gaseous fuels (synthesis gas, biogas and hydrogen), electricity and heat.

There are two main applications of bio-energy: transport and stationary applications. Biofuels have a strong potential as alternative to fossil fuels in the transport sector. The currently available biofuels are biodiesel and bio-ethanol (1^{st} generation fuels). Biodiesel is produced from vegetable oil, e.g. oil palm, rapeseed, soybeans etc., and bio-ethanol are produced by the fermentation of sugars which can be obtained from sugar beet and sugar cane or from starch in crops like wheat, maize and potatoes. Second generation biofuels are obtained from non-food lignocellulose crops including waste biomass, the stalks of wheat, corn, wood, and special energy or biomass crops. Many second generation biofuels are under development e.g. bio-hydrogen, bio-methanol, Fischer-Tropsch diesel, bio-hydrogen diesel, mixed alcohols and wood diesel.

Generally specific objectives for using biomass are affected by the quantity and quality of the feedstock available, location of the consumers, type and value of energy services required and the specific co products of benefits. The collection, transport, storage and handling of biomass are still more costly per unit of energy than fossil fuels because prior to conversion, biomass feedstocks have a lower energy density per volume or mass compared with equivalent fossil fuels [IPCC, 2007].

3.2 Biomass use and potentials

Biomass has vast potential as an energy source. It is assumed to be climate friendly because the CO_2 released during the burning is equivalent to that absorbed by the crops during their growth. One of the positive impacts of cultivating biomass crops on the local environment would be for example, to plant former intensively farmed cropland with extensively farmed biomass crops, though this would decrease the land available for food production. Compared to other energy types, biomass can be applied as a solid, liquid and gaseous fuel. Therefore, it can be utilized for all energy related needs. Its excellent storage properties allow for flexible energy supply, both in terms of time and distance [SRU, 2007].

Often the relatively low costs, promotion of regional economic structures and additional income for farmers are the advantages of using biomass over other energy sources. The biomass action plan estimates that doubling of biomass use by 2010 could lead to direct employment for up to 250,000-300,000 people, mostly in rural areas [EEA, 2006; EC, 2005].

However, increasingly there is a hot discussion about the impacts of biomass energy. Recently, in some calculations the net reduction in GHG emissions is questioned when land use for biomass is connected with clearing forests, conversion of peat land and with high fossil energy inputs for machinery, fertilizers and other agrochemicals [WAB, 2008]. In 2007, OECD published a report concluding that food shortage and damage to biodiversity might be the possible consequences if there is a rush on energy crops, without clear measures. Environmental NGO's also published critical reports on biofuels, asking for effective measures and criteria for the sustainability of biofuels [e.g. WWF, 2007].

3.2.1 World use now

Currently, the annual global primary energy demand is estimated as 489 EJ/yr and the global energy supplies are dominated by fossils fuels (388 EJ/yr). Biomass currently provides around 46 EJ which is more than the contribution of hydropower (28 EJ) and nuclear energy (26 EJ). The contribution of biomass is estimated as 10% of global primary energy. Two third of this is consumed in developing countries as traditional biomass for household use [IPCC, 2007]. Only around 8.6 EJ/yr of modern biomass is used for heat and power generation and this share is growing. Biofuels, mainly bio-ethanol and biodiesel, represents 1.5 EJ (about 1.5%) of transport fuel use worldwide. The interest in transport fuels is growing, especially in Europe, South and North America and Asia. While ethanol production has doubled since 2000, biodiesel production has expanded nearly threefold [WAB, 2008].

Figure 3.1 represents the share of energy consumption (in percentage) in EU-27 countries. In 2005 renewables accounted for 6.7 % of EU's gross energy consumption; of which two thirds were biomass and waste. The biomass energy mainly originated from wood and wood wastes [EEA, 2007].

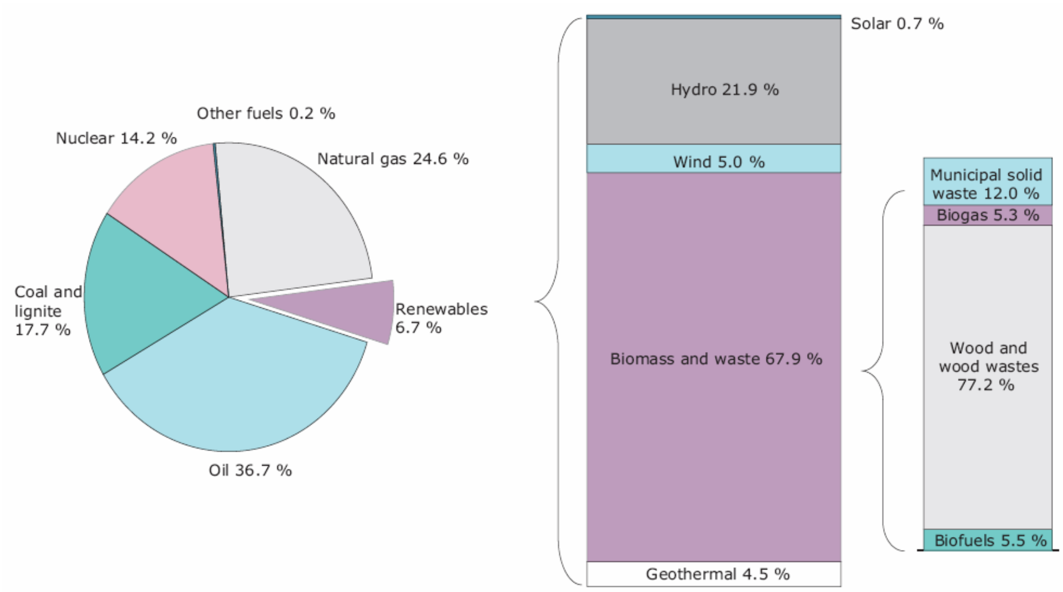

Figure 3.1 *Share of energy consumption by fuel type in 2005, in EU-27 countries [EEA, 2007]*

3.2.2 World biomass potential

There have been many recent studies estimating the world potential of biomass energy; however, they all have shown large ranges of outcomes. For example, the highest biomass potential of 1,500 EJ for 2050 is based on an intensive and technologically developed agriculture [Smeets et al. 2007]. On the other hand, a very low biomass potential for 2050 was calculated, caused by high population growth, high food demands and extensive agricultural production systems [Wolf et al. 2003]. Hoogwijk et al. (2005) estimated an increasing potential over time, to a potential of about 650 EJ. This would be achieved with crop production on abandoned and unused land. When the economical potential of reforestation was considered by the study of Rokityanski et al. (2007), the potential was quite low, around 200 EJ. In the WAB report (2008), the authors took account of the missing points of these studies and made some indicative calculations considering the effect of demand and availability of water, food, energy and influence on biodiversity and economic mechanisms. Their results gave the range of 200-500 EJ/yr. Energy demand models estimate about 50- 250 EJ/yr of biomass use in 2050 if energy demands are supplied cost efficiently at different carbon tax regimes. Regional present use and estimated technical potential for biomass is summarized in Table 3.1. Estimates of regional potentials can vary considerably between different studies.

Table 3.1 *Technical potentials and biomass use compared to primary energy consumption (PEC) from fossil fuels & hydropower (based on the data of Kaltschmitt, 2001)*

	PEC (EJ)	Biomass energy (EJ)				
		Use	Potential	Use/potential	Use/PEC	Potential/PEC
North America	104.3	3.1	19.9	16%	3%	19%
Latin America	15.1	2.6	21.5	12%	17%	142%
Asia	96.8	23.2	21.4	108%	24%	22%
Africa	11	8.3	21.4	39%	75%	195%
Europe	74.8	2	8.9	22%	3%	12%
Former USSR	37.5	0.5	10	5%	1%	27%
Total	**339.5**	**39.7**	**103.1**	**39%**	**12%**	**30%**

It is clear that it is not possible to present the future biomass potential in one simple figure, since a major part of the future biomass resource availability for energy depends on complex and related factors, e.g. land availability which is linked to the growing demand for food, on environmental protection, sustainable management of soils and water reserves and a number of other sustainability requirements [IEA, 2007].

3.2.3 Biomass potential in Europe

EEA in 2006 estimated the environmentally compatible biomass energy potential (ECBEP) which is the quantity of biomass that is technically available for the energy production and creates no additional pressures on biodiversity, soil and water resources. In addition, it should be in line with the current and future environmental policies and objectives. This concept was created after the consideration of a number of environmental constraints (see section 3.2.4) when calculating the available technical potential. Results indicated that even if the stated strict environmental constraints are applied, still a significant amount of biomass is technically available to support the renewable energy targets. ECPEB could increase from about 8 EJ in 2010 to around 12.4 EJ in 2030 [EEA, 2005]. This represents around 16% of primary energy requirements of EU-25 countries in 2030. There was no detailed evaluation about the amount of GHG emissions; however a rough estimation indicates that the use of entire biomass potential would save direct GHG emission of 400-600 Mt CO_2 in 2030 resulting in a reduction of GHG emissions by 20% in 2020 and 40% in 2030 by the EU-25.

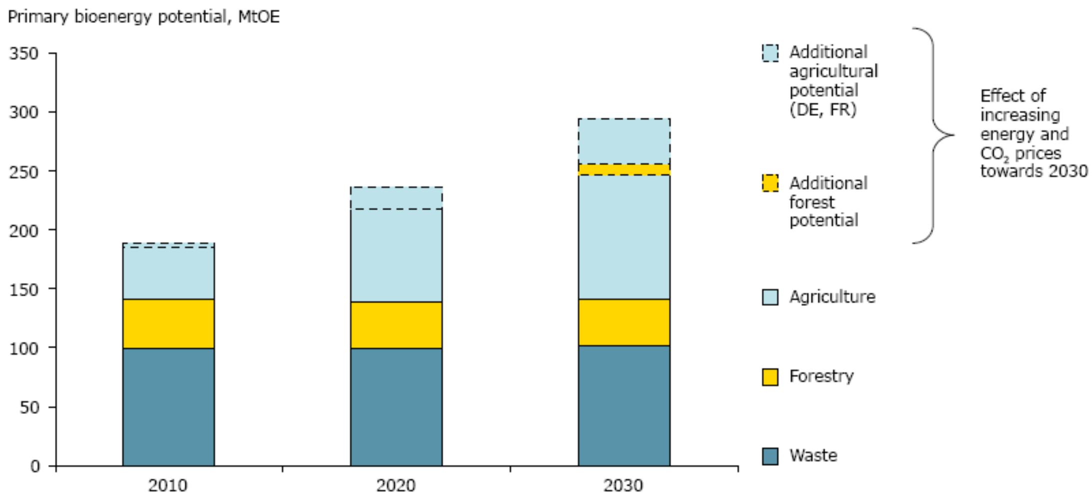

Figure 3.2 *Environmentally- compatible primary bio energy potential in the EU [EEA, 2005] (1Mtoe=0.042 EJ)*

It is predicted that the largest potential for biomass production comes from the waste sector with around 4.2 EJ in the short term but in the long run, it would remain constant over time (Figure 3.2). In the long term, the agricultural biomass has the largest potential which could reach 6 EJ by 2030. This would be the result of the increase of additional productivity, further liberalization of agricultural markets and the introduction of high yield agricultural crops. The biomass potential from forestry is estimated as constant at around 1.7 EJ till 2030 [WAB, 2008].

Table 3.2 *Potential biomass contribution to the energy balance in the Netherlands in 2030 [Rabou et al. 2006]*

Application	Consumption [PJ]	Replacement [%]	Replacement fossil energy carriers [PJ]
Heat	1090	17	185
Electricity	810	25	203
Transportation	540	60	324
Raw materials	560	25	140
Total	3000		852

In the Netherlands, biomass now covers 2% of the energy demand. It is estimated that it could make a much larger contribution, up to 30% in 2030. The Platform Groene Grondstoffen estimated that biomass could supply 60% of transport fuels, 25% of chemicals and materials, 17% of heating requirements and 25% of the electricity demand by 2030. Since the Netherlands has a limited agricultural area, 60 - 80% of the needed biomass raw materials will have to be imported to achieve these estimates (Table 3.2).

3.2.4 Sustainability criteria on biofuels

EU regulations

In 2008, the EU has set ambitious targets for 2020 for the share of renewable energies in total energy and electricity consumption and for biofuels. Currently 4% (2.9 EJ in 2003) of the EU's total primary energy consumption is met from biomass providing 2/3 of the renewable energy production in the EU. The EU intends to increase the share of renewables in primary energy use to 20% by 2020. This could by met with 8.8-10.5 EJ of primary biomass, according to energy projections [EEA, 2005]. Specifically for renewables (a.o. biofuels) as a fraction of the total market of transportation fuels, the target (set in 2003) was 2% in 2005, 5.75% in 2010 and 10% in 2020 [Koper, 2007]. The 2005 target was not met and it seems unlikely that the 2010 target can be reached [EEA, 2008]. In addition, the target of 5.75% biofuel replacement for 2010 would be changed by a 5% target for 2015, of which only 4% can come from agricultural biofuels. Second generation biofuels or other fuel and power technologies would have to make up the rest.

However, in the proposal for the EU directive (2008), the EU take account of the sustainability criteria for biofuels more carefully because of the increased debate in the scientific community whether, or under which conditions, biofuels can be regarded sustainable. The commission proposed that the 10% target should only be met by biofuels that fulfil the sustainability criteria and GHG savings from the use of biofuels, as compared to fossil fuels, must be at least 35% in the first stage. The criteria for GHG savings and concerns of biodiversity are addressed; other environmental concerns and food security issues are not which would be reported only after 2012 [MNP, 2008].

Cramer Criteria in the Netherlands
The Cramer Committee in the Netherlands proposed a list of sustainability criteria with a strong focus on effects on local communities in developing countries [Cramer et al., 2007]. The topics addressed are environmental protection, global warming, food security, biodiversity, economic prosperity and social welfare. The Cramer Committee advised the Dutch government to incorporate these sustainability criteria into relevant policy. The report recognizes, however, that the implementation of those criteria (including the establishment of a certification system) would require careful consideration of the obligations of the Netherlands under EU law.

The topics in the Cramer report are similar to the Fuel Quality Directive by European Parliament in 2007. One of the most important points was that "biofuels should show a GHG reduction of at least 50% for 2011, compared to fossil fuels, in order to offset the negative effects of growing fuel crops, such as negative environmental effects, increased competition for land, water and food, and increased pressure on natural forests and local communities" [EP, 2007]. It shows that the amount of GHG reduction of biomass energy is one of the most important issues at this moment. Therefore, it is essential to have a clear methodology for calculating the GHG balance of biofuels. Especially, for example, the assumed or actual crop yield, CO_2 and N_2O emissions due to land use changes and processes in the production chain might have a significant effect on the results [MNP, 2008]. The determination of N_2O emissions by the use of fertilizers is still an uncertain factor. More accurate measurement techniques are necessary to estimate the overall GHG emissions from agriculture.

3.2.5 Issues determining biomass potential

There are several critical aspects which have strong impacts on the estimation of the overall biomass potential as mentioned above. They are mainly categorized under the issues related with biodiversity, water, food and GHG emissions. In many studies, the effects of those factors were mostly neglected. In a recent study on worldwide biomass assessment, those criteria were taken into consideration [WAB, 2008].

Biodiversity: The effect of crop cultivation on biodiversity depends on the short term negative effects of land use change and the long term effect of future climate change (compared to fossil fuel use, but also compared to other renewable energy use). According to OECD baseline scenario, biodiversity indicators decrease by 11% between 2000 and 2050. However, when most of the biomass energy would be obtained from mainly woody biofuels according to the climate change mitigation strategies, the total biodiversity is 1% less than the baseline. The effects on biodiversity critically depend on the alternative land use; does the growth of energy crops displace rainforest, or desert, or food crops, or something else?

Water: Large variability in regional climate and hydrology requires more detailed and local analysis of the biophysical characteristics for crop production. Climate change might adversely affect the water availability and irrigation potential in many regions, especially in semi-arid and arid areas. Sea level rise will also affect fresh water availability in low altitude Delta regions such as the Netherlands.

Food: Food production and demand is strongly linked to agricultural technology, population growth, economical developments and dietary changes. Generally the biofuel production is not addressed in most of the food demand projections. The production of biofuel affects prices of feed and food. These effects are important in order to assess the social sustainability of biomass energy.

Greenhouse gas emissions: A potential reduction of GHG emission is one of the main drivers for using biomass for energy. Most biomass chains reduce the GHG emissions compared to fossil fuel use; the degree of the effect varies according to type of crop, the crop yields, the type of energy and materials (e.g. fertilizer) used and the land use changes involved (see section 3.3 for more detailed information).

In order to estimate the potential of environmentally compatible biomass energy, [EEA, 2006], determined the following possible environmental pressures on biodiversity, water and soil resources in agricultural, forestry and waste sectors in European countries.

Agricultural biomass: Soil erosion, soil compaction, leaching of nutrients from agricultural land to ground and surface waters are considered as a significant problem in intensive farmlands. Increases in irrigated land bring the issue of the amount of the agricultural water use which might affect the water tables and water levels in rivers and lakes. In addition, there is an increasing competition between agricultural production, urban land uses, tourism and nature conservation in drier regions of Europe. As a result of intensive farming, farmland biodiversity has reduced, as well [EEA, 2007].

Forestry biomass: Biodiversity, soil fertility and acidity of water bodies might be affected by the intense biomass removal from forest. Harvesting biomass from forest might significantly reduce the potential to regulate water flows since residues and deadwoods act as filters to improve water quality.

Waste biomass: Since bio waste and residues are not especially produced for use as an energy source, the use of bio waste to energy recovery options does not increase environmental pressures; to the contrary, it could eliminate some of the pressures eliminated with waste management options, e.g. landfill. If the economic value of energy from bio waste increases over time, this might limit the initiatives minimizing the production of bio waste. The use of bio waste for energy might cause a reduction in recycling which is more environmentally beneficial. In order to prevent additional pressures on the environment, EEA (2006) determined the following environmental criteria which should be considered by EU countries:
Agricultural biomass:

- At least 30% of the agricultural land in EU states should be directed to environmentally friendly farming.
- 3% of currently intensively cultivated land should be considered as ecological compensation areas.
- Extensively cultivated areas are maintained
- Especially bio energy crops with low environmental pressures are preferred.

Forestry biomass:

- There should be no intensive use of protected forest areas.
- Foliage and roots are always left on site

- The amount of removal is determined according to the suitability of the site
- An increase in the protected forest areas is achieved by 5% reduction of area available for wood supply.
- 5% of standing volume is assumed to be left aside as retention trees after harvesting in order to increase the share of deadwoods.

Bio waste biomass:
- Continuation in waste minimization.
- No energy recovery from waste that is currently being recycled and/or reused.
- All household waste will be available for energy production.

3.3 The effects of biomass production/use on the climate

Since biomass has been considered as a potentially important future energy source, the greenhouse gas balance resulting from biomass production and use has received increased attention. It is known that agriculture, forestry and the waste sector releases significant amounts of GHG to the atmosphere (IPCC, 2007a) (see Fig. 3.3). Among a variety of mitigation options for the reduction of GHG emissions in agriculture, forest and waste sector, using the biomass as an energy source is considered as one of the potential option. The potential mitigation effect of using biomass as energy source is based on the fact that the CO_2 that is released upon combustion was previously taken up from the atmosphere during biomass growth. The net benefit of these bioenergy sources for climate mitigation, however, depends on many other factors, related to greenhouse gas emissions resulting from growing, processing and transporting the feedstock, and to indirect land use effects.

A large fraction of the direct emissions are caused by fertilizer use, which results in enhanced emissions of nitrous oxide, a very potent greenhouse gas. Direct GHG emissions could be decreased by using optimal agricultural management practices. The indirect land use effect is an inevitable consequence of using a large amount of arable land to grow energy crops: The carbon balance that results from converting a specific type of land use to the growth of energy crops varies significantly with the initial land use and also with the energy crop grown. For example, Searchinger et al. (2008) reported that the increased demand on crop production could cause significant loss of pristine grasslands and forests in developing countries, which would lead to the loss of carbon sequestration. According to their model calculations, the period until net savings would be reached is long after the period when GHG payback is required (2020-2050). These and related studies therefore highlight the more beneficial climate effects of using waste biomass or biomass grown on degraded land, because that way other potentially beneficial land use is not displaced.

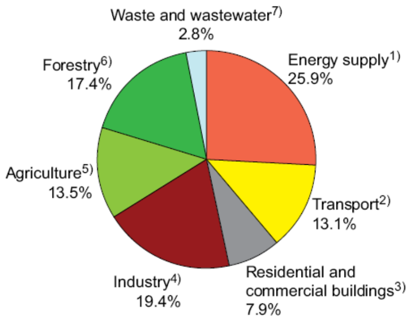

Figure 3.3 *GHG emissions expressed in Gt CO_2 equivalents form different sector.*

1. Excluding refineries, coke ovens which are included in industry. 2) Including international transport (bunkers), excluding fisheries; excluding off-road agricultural and forestry vehicles and machinery. 3) Including traditional biomass use. 4) Including refineries and coke ovens. 5) Including agricultural waste burning and savannah burning (non- CO2). 6) Data include CO2 emissions from deforestation, CO2 emissions from decay (decomposition) of aboveground biomass that remains after logging

and deforestation and CO2 from peat fires and decay of drained peat soils. 7) Includes landfill CH4, wastewater CH4 and N2O, and CO2 from waste incineration (fossil carbon only).

One of the major sources of CO_2 emissions and air pollutants, which should be also mentioned, is biomass burning, since it is a global phenomenon having a maximum in tropical regions. Biomass burning has both man-made and "natural" causes since it includes wild fires initiated by deforestation, lightning, agricultural waste burning, fuel-wood use, charcoal production and fires associated with forest and savanna clearing (Figure 3.4). The vast majority of the world's burning is human-initiated [Andreae and Merlet, 2001].

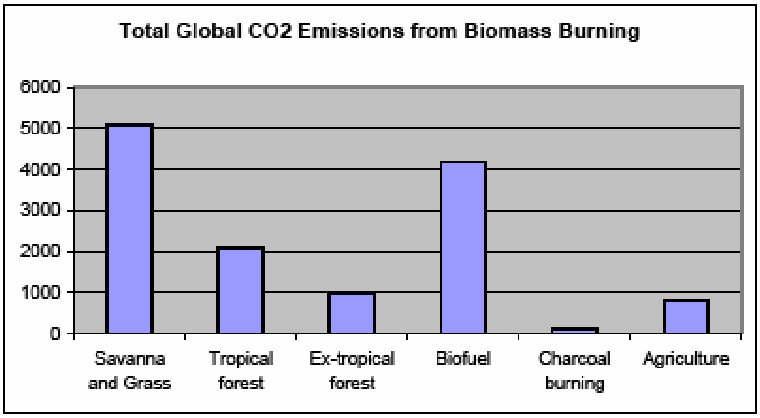

Figure 3.4 *CO_2 released (Tg/yr) by fires of different origin*

Table 3.3 shows the greenhouse gas balance of biomass production and use in Western Europe [Gielen, 2000]. The use of biomass results in a net CO_2 emission reduction (due to carbon storage and substitution of fossil fuels). The emission reduction of 440 to 565 Mt per year must be compared to a Western European CO_2 emission of approximately 3,300 Mt/yr. However, the positive effect on the CO_2 emissions is counterbalanced by the additional emissions of CH_4 and N_2O. Although the authors concluded that both CH_4 and N_2O must be considered in a proper analysis of the potential of biomass strategies for greenhouse gas emission reduction, it should be kept in the mind that there is considerable amount of uncertainty about the estimation of the CH_4 and N_2O emissions.

Table 3.3 *The relevance of West European biomass production for GHG emissions [Gielen, 2000].*

	CO_2 [Mt CO_2/year]	CH_4 [Mt CO_2 eq/year]	N_2O [Mt CO_2 eq/year]
Increasing forest stock/land use change	-340	-	-
Fertiliser use	-	-	200
Imported wood products	25-50	-	-
Increasing product stock	-75	-	-
Landfills	-25	140	-
Enteric fermentation	-	140	-
Manure management	-	40	-
Energy production/recovery	-50 - - 150	-	-
Total	*-440- -565*	*320*	*200*

Figure 3.5 shows specifically the contribution of agricultural activities to the total GHG emission in the Netherland in 2003. As a total, the agricultural sector contributes about 14% to the total GHG emission of the Netherlands, including energy use by horticulture.

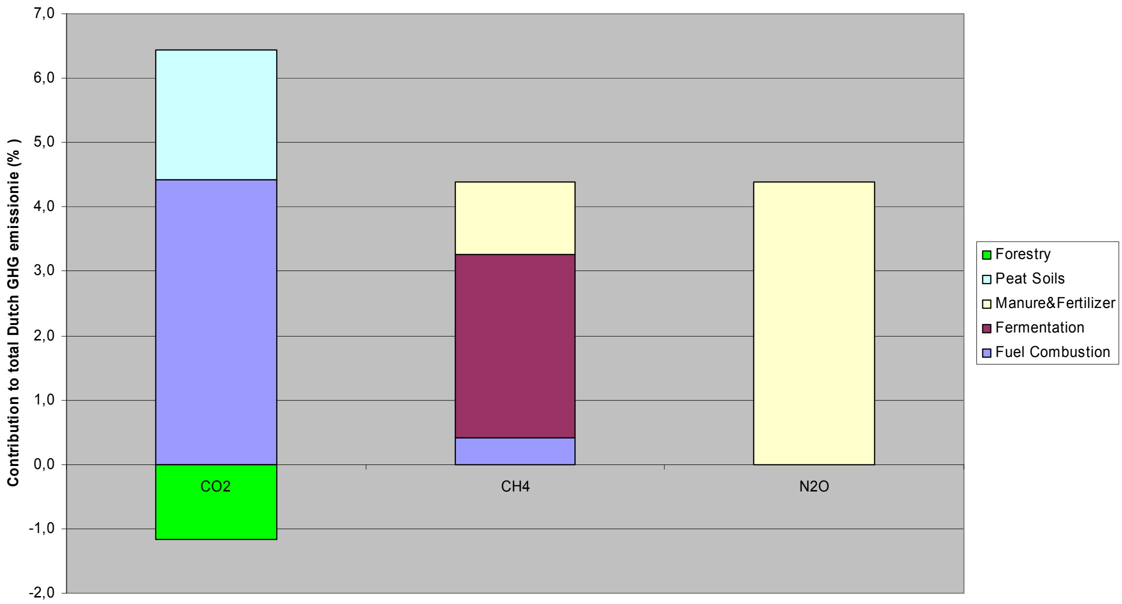

Figure 3.5 *Relative contributions of emissions of CO_2, N_2O and CH_4 from various agricultural activities and processes to the total greenhouse gas emission of the Netherlands in 2003, including the CO_2 emission from heating in horticulture (total contribution 14%) [Bleeker, personal communication]*

Among a variety of mitigation options for the reduction of GHG emissions in agriculture, forest and waste sector, using biomass is considered as one of the potential options. However, some recent studies have pointed out doubts about using biomass as a mitigation option in GHG emission strategies [e.g. Crutzen et al., 2007; Righelato and Spracklen, 2007; Scharlemann et al. 2008; Searchinger et al. 2008; Zah et al.; 2008; Jacobson, 2008].

One of the main environmental costs is related with nitrous oxide emission (N_2O). N_2O is a by-product of fixed nitrogen application in agriculture and is a greenhouse gas with a global warming potential (GWP) 296 times larger than an equal mass of CO_2; it also plays a role in stratospheric ozone depletion. In order to calculate annual N_2O emissions, IPCC provided a simple methodology according to a direct relationship between nitrogen additions and nitrous oxide emissions, which was extracted from many laboratory and field experiments. This approach provides a broad picture of the contribution of agriculture to the countries total emissions. The uncertainties in this estimate, however, are very large, partly because other important environmental variables, such as rainfall, temperature and land management are not taken into account. This results in errors in the estimates of emission factors and other calculated parameters. Crutzen et al. (2007) calculated that growing some of the most commonly used biofuel crops releases around twice the amount of N_2O than previously calculated emissions. For example, rapeseed biodiesel accounts for about 80% of the biofuel production in Europe. The relative warming due to N_2O emissions is estimated at 1-1.7 times larger than the relative cooling effect due to saved fossil CO_2 emissions. For corn bio-ethanol, dominant in the US, the figure is 0.9 to 1.5. Only sugarcane based bio-ethanol (with a relative warming of 0.5 to 0.9) looks a better alternative to conventional fuels, according to their calculations. When N_2O emissions are compared among ethanol-producing crops, grasses and woody coppice become more favourable (Table 3.4). Critics have pointed out that by improving farming practices, N_2O emissions can be significantly decreased, making the net effect of biofuels on global warming more favourable (or less unfavourable). This would however require a (financial or judicial) stimulus to put such improvements in practice.

Table 3.4 *Relative warming derived from N_2O production for crops, crop residues and forages used in the production of biofuels [Crutzen et al., 2007]*

Crop	r_N (gN/kg dry matter)	relative warming (Meq/M)	type of fuel produced
Rapeseed	39	1.0–1.7	Bio-diesel
Wheat	22	1.3–2.1	Bio-ethanol
Barley, Oat	19	1.1–1.9	Bio-ethanol
Maize	15	0.9–1.5	Bio-ethanol
Sugar cane	7.3	0.5–0.9	Bio-ethanol
Residue			
Sugar beet leaves	25	1.5–2.4	Bio-ethanol
Root crops	16	0.9–1.6	Bio-ethanol
Forages, low N	15	0.9–1.5	Bio-ethanol
Forages, high N	27	1.6–2.6	Bio-ethanol

Righelato (2007) pointed out that the carbon sequestered by restoring forests is greater than the emissions avoided by the use of liquid biofuels, and it avoids extra strain on the environment. They concluded that scarce land areas can better be used for forestry than to grow energy crops. A more general conclusion that the climate effects of biomass energy depend on how they are produced was reached by Fargione (2008). Converting ecosystems to biomass producing cropland results in an increase of greenhouse gas emissions compared to fossil fuel use, whereas using waste biomass or biomass grown on abandoned agricultural lands lead to a decrease in greenhouse gas emissions. Searchinger et al (2008) and Delucchi (2006) both calculated the climate effects of the indirect land use effects. They arrive at very different values, but from their analyses it is clear that the indirect land use effect could be the most important factor in determining the overall climate effects of using biomass, since natural vegetation often contains more carbon per hectare than energy crops.

Jacobson (2009) did a comparative analysis of different energy sources for use in the transport sector, based on a range of criteria, including the effect on climate change, air pollution and land use. Bio-ethanol (both 1st and 2nd generation) scored very poor overall (and on the abovementioned criteria) compared to other renewable options such as wind, solar or geothermal energy (to be used in battery electric or hydrogen fuel cell cars). These studies show the need to not only compare energy options with fossil fuels, but also (or especially) with other renewable energy and mitigation options, to prevent a lock-in situation.

It is clear that much work can be done on investigating the greenhouse gas balance and reducing GHG emissions related to agriculture and forestry. This could be effective for mitigation in general and for the effectiveness of biomass as a mitigation option in particular.

The effect of biomass production/use on air pollutants in the Netherlands

In order to fill the knowledge gap between climate and air quality policies, a research program, BOLK (Beleidsgericht Onderzoeksprogramma Lucht en Klimaat), was established in the Netherlands in 2008. An important part of this research was focused on the production and use of biomass energy and their possible effects on the air quality. The main focus was on the effects of biofuels in vehicles, in stationary installations, emissions resulting from cultivation, transport and refining of biofuels.

Supply chain emission of pollutants from biofuels: It is indicated that supply chain emissions of air pollutants, especially of NO_x, NH_3 and PM, from biodiesel and bio-ethanol may be larger than their fossil equivalents (Table 3.5). In contrast, SO_2 emissions from biofuels chains may be lower. Since the production of biofuels is expected to occur mainly outside of the Netherlands, most of the negative effects of the production on air pollution levels will also occur abroad. Most of the emissions from the majority of the biofuel chains come from feedstock production (in some cases, between 50 and 75% of the total emissions). Sugar beet and sugar cane ethanol chains are seen as two exceptions since they are heavy products with high moisture content, and therefore produce high levels of emissions during transport. The use of tractors, nitrogen fertilizer and chemicals and heat in biofuel refineries are the main sources of NO_x, SO_2, NH_3 and PM emissions [PBL, 2008].

Table 3.5 *Estimated chain emissions (well-to-tank) for biodiesel, ethanol and their fossil equivalents (units: Kt) resulting from the production of projected total fuel consumption for road transport in the Netherlands in 2020 (510 PJ) [PBL, 2008]*

	Biodiesel from rapeseed	Biodiesel from palm oil	Diesel fossil	Ethanol from sugar cane	Ethanol from sugar beet	Petrol fossil
	Location of emissions					
	EU	World/EU[b]	EU[c]	World	EU/NL	EU[c]
NO_x	41	20	14	18	24	5
SO_2	0	12	30	5	8	13
NH_3	21	8	0	1	1	0
PM_{10}	9	3	2	1	2	1
NMVOC	2	1	1	1	1	0

The end-use effects (tank-to-wheel) on air polluting emissions from biofuel use in road transport. The effects of bio-ethanol and biodiesel on exhaust air pollutants are still not completely clear. The most common emission components from petrol (Otto or spark ignition) engines using blends of bio-ethanol are NO_x and unburned hydrocarbons (HC) which can contain toxic elements, e.g. aldehydes. The data show considerable variation in emission levels when ethanol is added. The variations are in the range from -50% to +50% for HC emissions, to -50% to +300% for NO_x emissions. They are related to variations in engine technology, biofuels properties and test cycles or test circumstances. For future vehicles, sold after 2010, it is planned that further improvements in engine design, in combination with the use of improved three-way catalytic converters or NO_x adsorption catalysts would prevent the negative effects [Verbeek, 2008].

The most common emission components from diesel engines are NO_x and particulates. Additional toxic components from these engines are poly-aromatic HC and their derivatives. The variation in emissions is larger for passenger vehicles than for trucks, with positive and negative effects on emission levels of NO_x and particulates. For trucks of Euro 3 and older, particulates emissions decrease by between 0% and -70% with increasing biodiesel percentage, depending on the engine type. However, NO_x emissions from trucks show an increase of between 0% and +30% when biodiesel is used [Verbeek, 2008]. The second generation biodiesel, the Fisher- Tropsch (FT) diesel, has a high biofuel quality and contains virtually no sulfur and aromatics and therefore, has significant potential for lower NOx and PM emissions.

Effects of the use of biomass in stationary applications on air pollutants: In general, small to medium-sized installations (up to several megawatt thermal) using biomass, biofuels or biogas, emit relatively high amounts of air pollutants (per unit of heat or electricity), compared to large-sized installations since small-sized installations use less advanced combustion technologies and flue gas cleaning systems and also the emission limit values for small-sized installations are less strict. The number of small-sized bio energy installations is expected to grow as a result of climate policies, e.g. the installations producing biogas from co-fermentation of manure and combined heat and power installations. Although this may reduce CO_2 emission, it can result in higher emissions of air pollutants. Switching from coal to biomass in large-sized installations may lead to unchanged levels of NO_x and NH_3, or decreasing SO_2 emissions [BL, 2008].

Although the current estimations of the effects of biomass production and use on the air quality provide some preliminary knowledge, still the current state of the knowledge does not allow a reliable quantification of emission effects from biofuels and necessary to make further measurements and evaluations.

3.4 The effects of climate change on biomass production

Climate change will most likely have an impact on the availability of biomass. Although the degree of the climate change on agriculture and forestry are often difficult to analyze separately from the non climate influences, the processes, e.g. changes in phenology, length of growing season and northwards shifts of crops and forest species are strongly related with the climate change [IPCC, 2007a]. In Table 3.6 a part of the information represents the summary of the conclusions for agriculture and forestry which is extracted from the literature by lead authors of IPCC [IPCC, 2007a]. Similarly, in Figure 3.7 the main impacts of climate change on crop, livestock and forest production by 2050 were summarized.

Agriculture: In general, longer growing seasons and new crop opportunities in northern Europe and increased photosynthesis and CO_2 fertilization throughout Europe would potentially impact agriculture positively. However, increased water demand and periods of water deficit, increased pesticide requirements and crop damage and fewer cropping opportunities in some regions in southern Europe would counterbalance those positive impacts.

Globally, changes in atmospheric CO_2 levels and increases in temperature would change the quality and the composition of crops and grasslands and also the range of native/ nonnative pests and diseases. The increase in O_3 concentrations caused by climate change would have significant negative impact on agriculture, mainly in northern mid latitudes.

Climate change is likely to change rainfall patterns and the increase in temperature would enhance the water transpiration and evaporation. Therefore, climate change will influence water availability and hence irrigation potentials.

According to the report of IPCC 2007a, key findings of the 2001 Third Assessment Report on agriculture are still important to characterize the effect of climate change:

- CO_2 effects increase with temperature, but decrease once optimal temperatures are exceeded for a range of processes, especially plant water use. The CO_2 effect may be relatively greater (compared to that for irrigated crops) for crops under moisture stress.
- Modelling studies suggest crop yield losses with minimal warming in the tropics.
- Mid- to high-latitude crops benefit from a small amount of warming (about +2°C) but plant health declines with additional warming.
- Countries with greater wealth and natural resource endowments adapt more efficiently than those with less" [IPCC, 2007a].

Forestry: Forests play an important role in mitigating climate change as sinks for CO_2. They are very vulnerable to any changes in temperature, precipitation and extreme weather events. Events such as forest fires have a negative effect because of increased CO_2 concentration in the atmosphere. In addition, for example, although the majority of forests in central Europe grow faster because of the regional warming, extended heat wave of 2003 caused an important reduction in biomass production of forests.

Some of the key findings in respect to forestry, based on 2001 Third Assessment Report, were listed in IPCC (2007a) which are still valid:

- Free-air CO_2 enrichment (FACE) experiments suggest that trees rapidly become acclimated to increased CO_2 levels.
- The largest impacts of climate change are likely to occur earliest in boreal forests.

- Contrary to the findings of the Second Assessment Report (SAR), climate change will increase global timber supply and enhance existing market trends of rising market share in developing countries" [IPCC, 2007a].

The results presented above include typical biofuels crops, such as corn, sorghum and wood. Recent studies indicate that global warming might increase the yield potential of sugar beet if there is no drought. The yield of switchgrass (*Panicum virgatum*) has shown increases with the climate change similar to the grain crops. There is still not yet information about non-food, tropical biofuel crops, e.g. Jatropha and Pongamia, but assumed to respond similar to other regional crops [IPCC, 2007a].

Table 3.6 *Summary of selected conclusions for food, fibre, forestry and fisheries by increase in the temperature [IPCC, 2007a]*

Temp. Change	Sub-sector	Region	Finding
+1 to +2°C	Food crops	Mid- to high-latitudes	- Cold limitation alleviated for all crops - Adaptation of maize and wheat increases yield 10-15%; rice yield no change; regional variation is high
	Pastures and livestock	Temperate	- Cold limitation alleviated for pastures; seasonal increased frequency of heat stress for livestock
	Food crops	Low latitudes	- Wheat and maize yields reduced below baseline levels; rice is unchanged - Adaptation of maize, wheat, rice maintains yields at current levels
	Pastures and livestock	Semi-arid	- No increase in NPP; seasonal increased frequency of heat stress for livestock
	Prices	Global	- Agricultural prices: –10 to –30%
+2 to +3°C	Food crops	Global	- 550 ppm CO_2 (approx. equal to +2°C) increases C_3 crop yield by 17%; this increase is offset by temperature increase of 2°C assuming no adaptation and 3°C with adaptation
	Prices	Global	- Agricultural prices: –10 to +20%
	Food crops	Mid- to high-latitudes	- Adaptation increases all crops above baseline yield
	Fisheries	Temperate	- Positive effect on trout in winter, negative in summer
	Pastures and livestock	Temperate	- Moderate production loss in swine and confined cattle
	Fibre	Temperate	- Yields decrease by 9%
	Pastures and livestock	Semi-arid	- Reduction in animal weight and pasture production, and increased heat stress for livestock
	Food crops	Low latitudes	- Adaptation maintains yields of all crops above baseline; yields drops below baseline for all crops without adaptation
+3 to +5°C	Prices and trade	Global	- Reversal of downward trend in wood prices - Agricultural prices: +10 to +40% - Cereal imports of developing countries to increase by 10-40%
	Forestry	Temperate	- Increase in fire hazard and insect damage
		Tropical	- Massive Amazonian deforestation possible
	Food crops	Low latitudes	- Adaptation maintains yields of all crops above baseline; yield drops below baseline for all crops without adaptation
	Pastures and livestock	Tropical	- Strong production loss in swine and confined cattle
	Food crops	Low latitudes	- Maize and wheat yields reduced below baseline regardless of adaptation, but adaptation maintains rice yield at baseline levels
	Pastures and livestock	Semi-arid	- Reduction in animal weight and pasture growth; increased animal heat stress and mortality

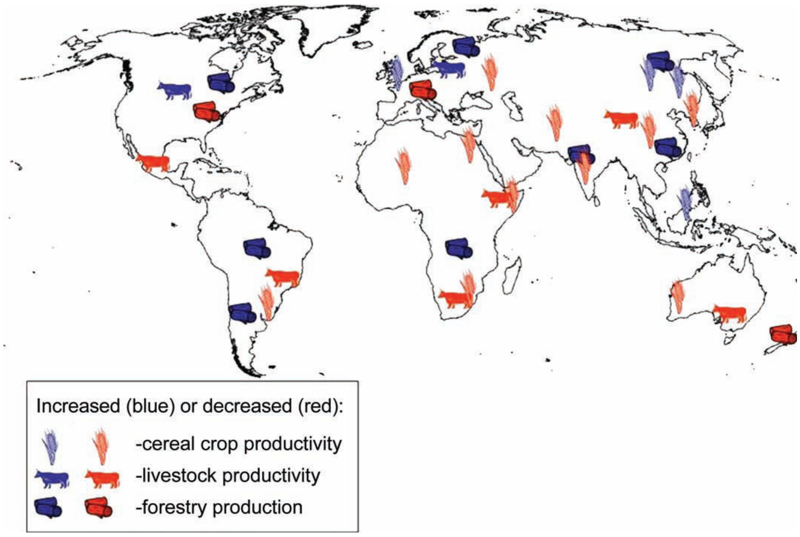

Figure 3.6 *Main effects of climate change on the productivity of crop, livestock and forestry by 2050 based on the literature and expert judgment of the lead authors of IPCC report [IPCC, 2007a]*

3.5 Effects of adaptation strategies on biomass production

The agriculture and forestry sectors are very vulnerable to the climate changes. Vulnerability to climate change in these sectors depends on exposure and sensitivity to climate conditions and the capacity to cope with changing conditions. The adaptive capacity to climate generally influenced by the changes in the wealth, human capital, information and technology, material resources and institutions. Generally national policies are often developed on the basis of local risks, needs and capacities, international markets, subsidies and trade agreements.
Some of the adaptation options for the agricultural and forestry sector which was suggested by IPCC (2007) are listed below:

Agricultural sector:
- Altering varieties and species to those with increased resistance to heat shock and drought.
- Altering fertilizer rates to maintain crops quality consistent with the climate
- Altering amounts and timing of irrigation and other water management practices
- Wider use of technologies to use water more effectively in areas with rainfall decreases
- Water management against water logging, erosion and nutrient leaching in areas with rainfall increases
- Altering the timing and location of cropping activities
- Improving the effectiveness of pest, disease and weed management practices
- Development and use of varieties and species resistant to pests and diseases
- Using seasonal climate forecasting to reduce production risk.

If these adaptation strategies are used, separately or combined, they have the potential to offset the negative effect of climate changes on the agriculture sector. According to several adaptation studies, although the benefits of adaptation vary with the crops and across regions and temperature changes, they provide 10% yield benefit when compared with yields without adaptation [IPCC, 2007a].

Forestry sector:
- Hardwood/softwood species mix, timber growth
- Shifting to species or areas more productive under the new climatic conditions
- Changes in management intensity

- Landscape planning to minimize fire and insect damage
- Prescribed burning to reduce forest vulnerability to increased insect outbreaks
- Non-chemical insect control (e.g. baculoviruses)

Under moderate climate changes, these strategies have the potential to reduce the negative economic consequences of climate change. However, it should not be forgotten that there is a likely to be a gap between the potential adaptations and the realized actions [IPCC, 2007a].

In addition to the implementation of existing knowledge and technology in response to changes in climate (autonomous adaptation), it is also essential to increase the adaptive capacity by institutions and policies to establish or strengthen conditions for effective adaptation and investment in new technologies and infrastructure [IPCC, 2007a].

The Netherlands is particularly vulnerable to climate change in agriculture, forestry and water ecosystems and the adaptation is necessary in these sectors. A wide variety of options are present and some of them are already starting to be implemented. Some of them extracted from MNP report (2006) and related to biomass production are listed below:

Agricultural sector
- The choice of crop variety and genotype
- Growing different crops which are more resilient to environmental pressure
- Water storage on farmland in times of excess water supply

Forestry sector:
- Species composition, spacing, thinning and water management
- Introducing new, more environmental stress resistant species
- Limiting timber imports to prevent the spread of pests and diseases from southern countries
- Retention of winter precipitation to relieve summer drought stress

Water sector:
- Using aquatic biomass
- Designing areas for land retention and storage of freshwater. This will result in increased competition with agricultural sector. Retention areas can possibly have a function as biomass production area.

Lankheet project: In the woodland area of Lankheet in the eastern part of the Netherlands, covering an area of 3 ha, an area constructed in 2006 functions as reed land to purify the river water. This study suggests that diffuse loads of nutrients from agricultural use could be reduced very easily. Surface water can be stored temporarily at moments of high peak flows or released during the lower flows in summer. The filtered water is used to bring the groundwater on level. In addition, non-food biomass is planned to be used as an energy source in the form of bio-ethanol (Figure 3.7).

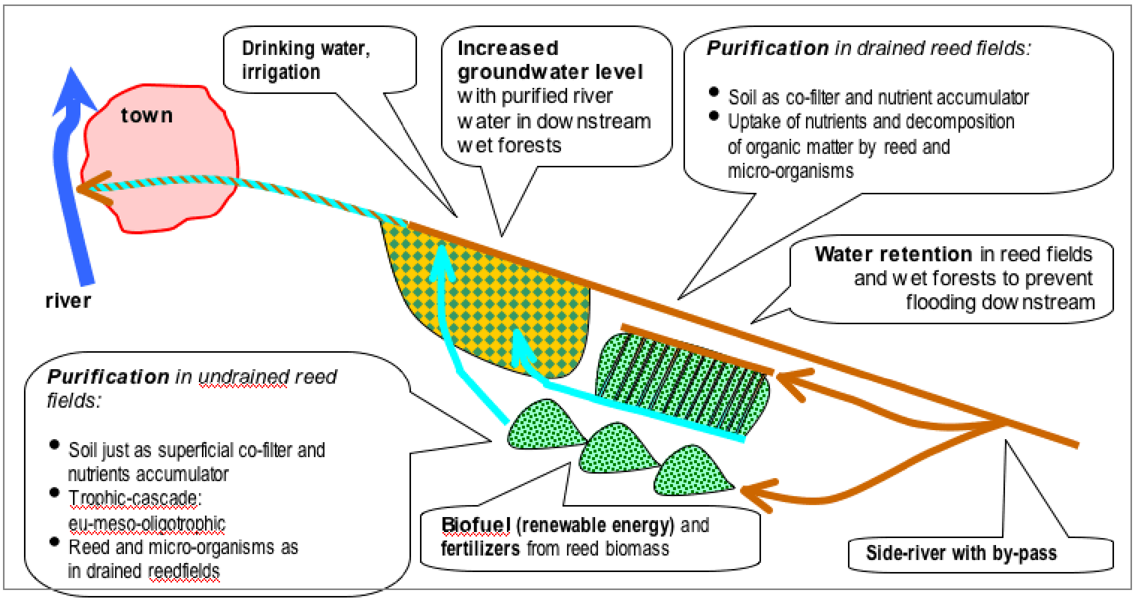

Figure 3.7 *Demonstration of Lankheet project*

3.6 References Chapter 3

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4. Other mitigation options

4.1 Other mitigation options and the relations between adaptation, mitigation and climate change

Several mitigation options are relatively new or are part of a combination of different techniques and functions, such as multiple land use and combinations of biomass production, energy generation, noise reduction, reduction of air pollution (dust, NO_x), energy conservation, safety in transport etc. In this chapter a number of these options are described in more detail.

4.1.1 Roads, railways, dikes etc.

About 3% of the surface area in the Netherlands is occupied by highways and railways (including verges and slopes). At present a limited number of wind turbines is placed along side highways and a few PV projects in combination with anti noise screens have been realized. In a recent study new options with their potential in an integrated infrastructure and energy generation approach are evaluated. It shows that a large unused potential of energy generation exist as energy generation is considered as one option in the multifunctional use of transport infrastructure. The following energy generation options are considered:

- PV
- Heat collectors
- Biomass
- Wind energy

PV

The most promising application of PV seems to be the combination with noise screens. Some older screens do not comply anymore with the noise reduction standards due to increasing traffic. By applying PV systems on these existing screens the noise reduction level will be higher and will again comply to the standards. Per km of highway ca. 190 kW_p PV capacity can be installed resulting in 540 GJ electricity per year. The maximal theoretical (technical) potential in the Netherlands for combining PV systems with infrastructure is 2,560 GWh/year. Apart from grid connected PV systems there are also specific applications for autonomous systems, for instance for powering traffic signs or lighting (in combination with LED's).

Heat collectors

The dark surface of asphalt roads can be used as heat collector. Several systems for collecting heat have been developed and tested. Most of these systems use water flowing through pipes underneath the asphalt surface as heat transfer medium. In this way the road is cooled in summertime and damage to the surface can be reduced. Heat can be stored in subsurface aquifers and used in winter time for heating of roads, fly-overs or bridges or for supplying heat to nearby buildings. Per m^2 road surface 0.8 GJ heat can be effectively produced. The potential in the Netherlands is 0.7 PJ. An additional positive environmental side effect is that by using stored heat in winter time the amount of salt for de-icing can be reduced. Important issues regarding this option are its energy efficiency and practicability, since installing the heat collectors will have very high energy costs.

Biomass production

Road side verges can be used for the production of biomass, either grass or fast growing trees. One km of highway has an area of 1 ha of verges (5 m at each side). Approximately 6 ton of dry material per ha per year can be produced.

Side effects of growing biomass are noise reduction, capture of fine dust and other emissions and a 'natural' collision systems (if the trees are harvested every 2-4 years and remain small) and less polluted run-off water. A disadvantage might be that birds and small mammals will forage more in the road verges thereby increasing the risk of accidents.

Wind energy
Large and small wind turbines can be placed alongside highways, on fly-overs and bridges. The potential of large wind turbines is estimated at 19,000-30,000 GJ/km.year. The effect on the landscape however will remain one of the bottlenecks for implementation.

Integrated concept for high-ways in combination with energy generation
An interesting concept from the perspective of energy, environment and multiple use of space is partial or complete overall span of highways. On top of the roof small wind turbines and PV panels can be placed. Due to the overall span 'cheap' asphalt can be used as rain is no problem, de-icing is no longer necessary and noise is reduced. Alongside the roofed highway biomass can be grown merging the highway in the surrounding landscape. Especially in inhabited areas this concept could be advantageous. The air extracted from the tunnel can be cleaned lowering the emission of dust and other pollutions.

An interesting side effect is that fuel consumption will decrease, if both directions are separated, due to less air resistance.

Table 4.1 *Potential yield for different energy options expressed in GJ/km highway per year*

Option	GJ/km	Non-energy aspects
PV systems	540 (electricity)	Noise reduction
Heat exchanger	10,000 (heat)	Reduction salt use for deicing
Biomass	65-100 (fuel)	Noise reduction, higher safety
Windturbines	11,000-20,000 (electricity)	
Integrated concept	Ca. 30,000	Landscape, reduction of air pollution, noise and salt use for de-icing, higher safety, reduction fuel consumption

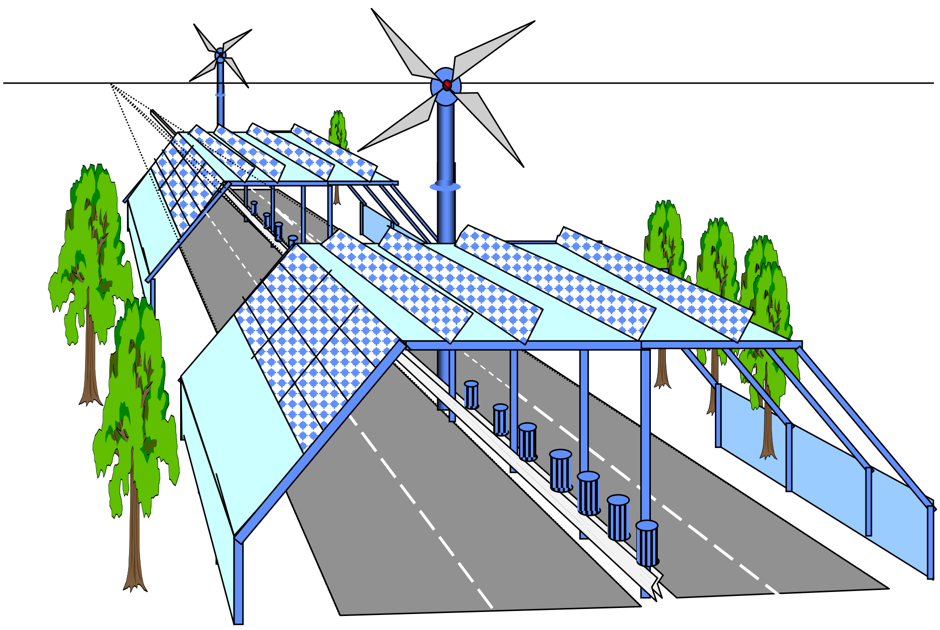

Figure 4.1 *Artist impression of a highway with several forms of energy production and control measures for air and noise pollution.*

Multifunctional dikes

Four consortia have made designs to renovate the Afsluitdijk to future safety demands as one of the adaptation measures needed. In all designs a multifunctional approach was followed to combine the improved protection function of the Afsluitdijk with nature, energy production, tourism, transport facilities and industry. In Table 4.2 the main features of the different designs are summarized to show the various components.

Table 4.2 *Examples for multifunctional construction of dikes [RWS, 2008]*

	Design 1	Design 2	Design 3	Design 4
Major features	Brackish inner lake	Storm shield	Stronger dike	Kwelders
Biomass production	Reed, brackish aquatic plants aquaculture			biodiesel from algae
Energy production	Tidal energy (8 MW) RED (25 MW) PV (75,000 m^2; 6 MW)	Tidal energy (100 MWh/yr) Blue E (600 MW; 1,200 GWh/yr) PV 10 GWh/yr Wind 3-5 MW	RED (200-250 MW) PV 10 GWh/yr Wind Valmeer (140 MW)	Tidal energy 1-2 MW RED 100-1,000 MW
Tourism/transport	Water sports		Superbus, recreation	Ecological tourism
Water storage	Higher level IIsselmeer		Higher level IJsselmeer	
Nature	Wetlands	Brackish water area	Brackish water area	Reed wetlands

All designs show the potential of combining various functions within a limited area. Several ideas from these designs, such as wind energy and PV systems are easily applicable on other (river)dikes. In one of the designs the Afsluitdijk is not made higher but much wider. This option create more space for nature, agriculture, recreation and biomass production.

4.1.2 Near-shore energy island

Many concepts for energy island for the coasts are thinkable. Most of these concepts have in common that several functions are combined such as energy generation, energy storage, cultivation of aquatic biomass, coastal protection, industrial activities etc.

One of the concepts proposed is described here. This island has a total surface area of 60 km^2 (6 km x 10 km) and combines energy generation by wind turbines with energy storage through a ‘valmeer centrale’, space for industrial activities, tourism, aquatic biomass cultivation and coastal protection. The wind turbines pump the water out off the artificial lake. If there is a demand for electricity water flows from outside into the lake and propels water turbines. In this way an artificial island is created with an ‘inverse’ reservoir. The water level of this lake varies between 30-40 m below sea level. The lake has a surface area of 40 km^2. The chosen capacity of the lake (30 GWh) is determined by the expected supply flexibility to the electricity grid.
In the proposed energy island part of the interior is reserved for aquaculture, but could also be used for the cultivation of seaweed. Assuming 5 km^2 as cultivation area for seaweed the yield could be as high as 5,000 dry ton per km^2 year (315 TJ_{prim} per year).

Figure 4.2 *Impression of an energy island*

In general the need for energy storage is part of mitigation strategies. The need for technical facilities increases when electric capacity of fluctuating power sources like wind and PV are more than 30% of the installed capacity. But storage competes with several other possible measures. Stronger international grids are most promising because other European countries have electricity storage facilities (pumped hydro).

Earlier studies (EZ, Elektriciteit en opslag) have indicated that electricity storage systems have strong effects on the use of base load coal and nuclear power plants. So if storage is implemented to support wind energy and PV, coal and nuclear plants will also profit, unless measures are taken to give precedence to renewable power, as is e.g. done in Germany.

4.1.3 Green roofs

Roofs of buildings, both domestic and industrial, can be refurbished into green roofs. Extensive green roofs exist of a thin layer of substrate on which grass, herbs, moss and/or sedum is planted. Maintenance is limited to a once a year check of the water drain and removal of seedlings of trees and other plants.

Positive effects are:

- Water retention by absorption of the first volume of a heavy rain shower (the remaining part of the water runs off) and slow release of the absorbed water through evaporation. In this way the peak burden of the sewer system by heavy rainfall and the total amount of run off water is lowered,
- Improvement of air quality by uptake of fine dust and ammonia,
- Increase of the life-time of the roof construction (protection from UV-radiation),
- Cooling in summer and isolation in winter; leading to energy conservation,
- Decrease of noise,
- Increase of biodiversity,
- Visual aspects.

Roofs with an angle of less than 7^{o} are most suitable for the water retention function. Roofs with higher angles can be used with additional measures.

The buffer capacity of green roofs has been tested. Ca. 55% of the rainwater is absorbed during longer periods. Moreover, in the case of peaks in rainfalls it has been shown that a considerable amount is retained, the runoff is delayed and water is slowly released reducing peaks both in volume and time in runoff rainwater. This decreases the peak volumes and absolute amounts of water that are going into the sewer system. It has been estimated that the overflow volume will decrease with ca. 20% and the yearly runoff of clean rain water to the RWZI (sewage water treatment plant) with 7% (in the case that 25% of the roofs are 'green'). 100 m^2 of green roofs can absorb 50 m^3 of water per year.

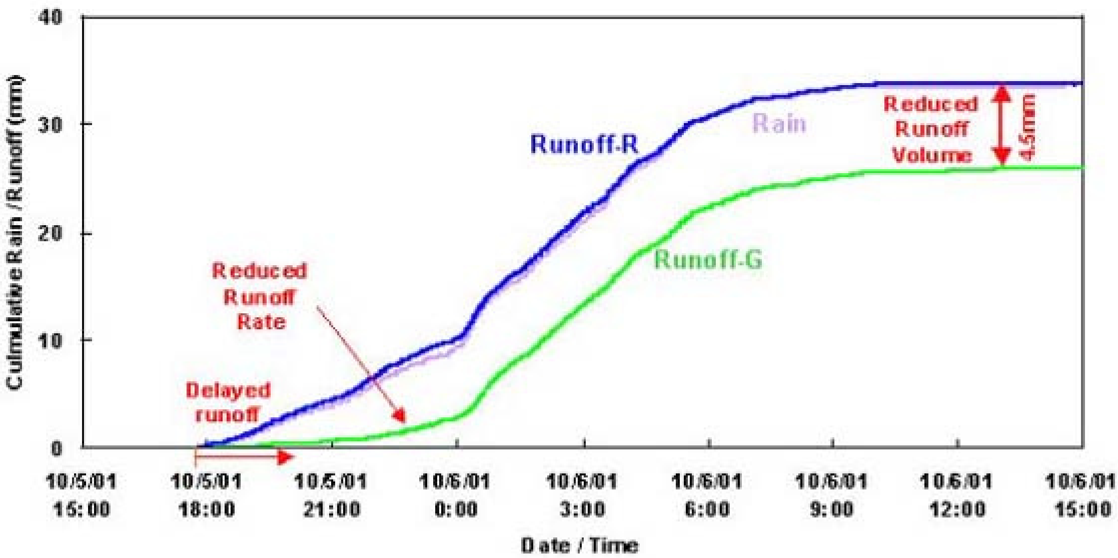

Figure 4.3 *Ratio amount of rain and run off for green roofs (green line) in relation with standard roofs (blue line) [Rotterdam, 2007]*

Effect on air quality

Due to the high surface area and the slowing down of air movements 10-20% of the dust is removed in urban areas. 100 m^2 of green roofs have the same effect as one tree.

Reduction of electricity consumption for cooling in summer and gas for heating in winter. The heat effect of urban areas is reduced (covering 6% of the roof area with green roofs leads to a reduction of summer urban average temperature of 2 ^oC).

The noise reduction by the isolation effect of green roofs has been measured 8 db and noise reflection is reduced with 3 dB. The combination with solar panels is possible by using plants adapted to shaded areas. The solar panels are placed in a frame above the vegetation. The cooling effect of the green roofs even increases the efficiency of the solar panels. So no choice between PV systems or green roofs has to be made.

Potential: In the Netherlands the total area for flat roofs is ca. 100 km^2 and for inclined roofs ca. 160 km^2.

4.2 Effects of mitigation options on climate change

The most obvious effect of the mitigation options is the reduction of GHG emissions by lowering the energy consumption (with its accompanying GHG emission) or by generating energy with no or lower GHG emissions compared to energy generation from fossil fuels. Furthermore, a number of options are aimed at storing CO_2, such as re-forestry and CCS.

To predict the quantitative effect it is important to consider rebound effects and learning curve effects as this can lower the expected performance of specific mitigations options. The newly developed CO_2-tool of Senter-Novem can be used as a LCA instrument to estimate the actual

GHG emissions taking many -though not all- aspects into consideration. This tool is not taking into account the alternative land use and the duration of the biomass production on the specific site. This could lead to strongly underestimated GHG emissions from biomass (see previous chapter).

Some mitigation options not only reduce GHG emission by replacement of fossil fuel based energy generation, but can also act as a carbon sink (biomass in combination with CCS).

The shift from fossil fuel based energy generation to renewable energy generation also affects other environmental aspects such as aerosol, NO_x and SO_2 emissions.

The well-known and newer mitigation options are in principle sufficient to reduce the GHG-emissions and stabilize the GHG-concentration in the atmosphere. Related to adaptation strategies the speed of implementation of mitigation options is decisive for the effect on the stabilization levels. A slower implementation leads to a higher stabilization level and thus to a larger need for adaptation. Mitigation policies are not yet optimized for fast implementation. At this stage the work is focused more on targets than GHG-reduction.

In recent studies [Hansen, 2008] it is questioned what a save stabilization level could be. A 2 ^{o}C temperature rise could well be too much to keep land ice stable in the long run. These studies are suggesting that on the long term a much higher sea level rise is possible compared to the levels assumed in current adaptation policies. In reaction to this it is desirable to investigate mitigation strategies that are able to reduce GHG emissions to much lower levels. Work on this type of mitigation strategies is in an early stage.

It is likely that deep reduction technologies are needed. Apart from already known zero-emission technologies there will be need for negative emission technologies such as the combination of biomass conversion and CCS or air capture technology (see chapter 6). Large scale implementation of these kinds of technologies may increase the pressure on biomass production and the related sustainability issues.

4.3 Effects of national adaptation measures on mitigation

A number of adaptation measures are proposed for climate change. Several of the proposed measures are related to alternative use of land (water retention, more space for rivers, ecological main structure, strengthening river- and sea dikes). All spatial related measures are directly linked with possibilities of biomass production and other space demanding renewable energy sources. Several adaptation measures can be designed as multi-functional systems combining the actual adaptation purposes with energy generation, space for industrial activities, development of natural habitats, tourism etc. A number of examples of multifunctional system designs are given in this report.

Proposed adaptation measures are:
- More space for water:
    - Regional water system
    - More room for rivers
- Spatial planning driven by risk assessment
- Preventing heat islands, providing cooling for cities
- Construction of climate proof buildings
- Ecological main structure
- Reforestation
- Widening coastal defense band
- Strengthening of river- and sea dikes
- Revising sewer systems

- Change of water intake points
- Water storage and –retention in urban areas
- Cooling towers for power plants
- Water storage on agricultural land
- Increase of the water level of the IJsselmeer
- Intensification sand suppletion coast

A number of adaptation measures will have a direct impact on some of the mitigation options. Water retention basins can be used for the production of 'water resistant' biomass such as willow, reed or aquatic biomass. In periods of high water supply the plantations are flooded without lasting damage. The use of aquaculture in agriculture areas can provide opportunities to rise the water level or to accept a larger variability in water levels. Retentions areas can also be combined with on-land wind energy.

The adaptation strategy can provide new opportunities for some mitigation options. Mitigation options are normally researched and implemented on a non integral basis. In this way a number of options that seems to be too costly or too small, is not researched. An integral approach of options in a non mitigation framework can proof otherwise. Infrastructure development and water management (for adaptation) can offer attractive opportunities for extra mitigation.

To integrate mitigation measures in adaptation (or other) policies it is necessary to know which options are relevant in the mitigation strategy. Sometimes costly options that are not really needed in the mitigation strategy are submitted to other strategies as "costly but necessary". On the other hand some options that are needed can be implemented faster and more cost effective as part of a wider strategy. Proper calculations in interdisciplinary studies are needed to find optimal combinations.

4.4 Effects of climate change on mitigation options

Climate change can affect the efficiency or yields of mitigation options due to changes in temperatures, wind regime, CO_2 concentrations in the atmosphere, different demand for heating and cooling, change of intensity and amount of rain fall. The effects of climate change on biomass production are described in chapter 3.

Temperature

As the degree days are decreasing due to climate change the demand for heating will decrease, also for the energy consumption in greenhouses. This will lead to a decrease in gas consumption and a shift in the use of CHP. On the other hand it is expected that the demand for cooling in the summer will increase thereby increasing the electricity consumption.

Within limits, a positive effect of a higher mean temperature is the higher yield of biomass in the Netherlands; this is not necessarily the case globally.

In 2006 ca. 250 PJ of waste heat was 'removed' with cooling water from power plants in the Netherlands. Due to an increase of the temperature of the water in the rivers and less (constant) water supply in the summer the present cooling system of power stations in the Netherlands will become more problematic. Several times over the past years, power plants had to be shut down or to reduce the production level to prevent the river temperature from exceeding maximum values. The average temperature rise of the cooling water is 7 ^{o}C, whereas the maximal river water temperature should not exceed 30 ^{o}C to prevent damage to flora and fauna.

Future power plants should either be located near the coast line so seawater can be used for cooling or be equipped with cooling towers to guarantee the year round supply of electricity.

In an adaptation strategy the site selection of power plants should take an important place.

Combined heat and power (cogeneration, CHP) is less vulnerable in situations with high surface water temperatures. CHP is providing heat for industries and this heat use will continue. But some CHP-systems are providing heat to buildings, houses or greenhouses. Additional cooling facilities are needed if the electricity of these plants is needed.

Higher summer temperatures will increase the demand for air cooling. Cold water storage in shallow aquifers in the winter is one of the energy efficient technologies to cool buildings. Implementation in grids could be considered. Shallow aquifers can also be used to store heated water to reduce energy consumption in the winter. The use of aquifers is subject to spatial planning.

When electric air conditioner systems are used, combination with solar cells could be considered. A policy to this aim could create an important (European) market for PV-systems with relatively low societal costs.

Rain fall and water management
The predicted changes in precipitation will result in more extremes in rain fall. Especially in the built environment this will lead to under capacity of the sewer system and overflow situations. The average mean water flow in the major rivers is expected to increase, but at the same time more peaks both in maximum and minimum water supply will occur. This will make electricity production with traditional hydropower stations less reliable. As the capacity of hydropower in the Netherlands is limited this effect is less important.

The effects of extremes in water supply can be counteracted by more water retention areas. These areas can be combined with the extensive production of biomass (like reed and willow). Every ha of new water retention area can yield 5-10 tonnes of dry biomass per year.

However, little is known about the consequences of the transformation of agriculture land into retention areas with respect to carbon storage/release from the soil and the behavior of nutrients. Combination of this type of water management with the new possibilities of aquaculture could be an opportunity.

Agriculture and forestry are also mentioned as a possibility to store more carbon in the soil. Studies in this field suggest that this mitigation option has a considerable potential on a global scale (see chapter 6). Adapted water management will have influence on the carbon uptake of the soil and these effects should be considered. Also influence on the transportation of substances in the soil and the groundwater can be expected.

In general, with ongoing global warming, wet areas are expected to become wetter, and dry areas drier. The net global effects on agriculture (and thus also on agriculturally based biomass energy) are expected to be negative, though with large regional variations.

4.5 References chapter 4

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5. New mitigation options

A number of new important options for mitigation have evolved since the IPCC report of 2007. These options might be attractive for deep mitigation in relation with the adaptation strategy. In this chapter these new options are described. These options are aquatic biomass (5.1) and biomass and CCS (5.2). The latter paragraph includes a description of the production of Substitute Natural Gas (SNG) from biomass.

5.1 Aquatic biomass

Aquatic biomass can be divided into the cultivation of micro-algae, macro-algae (seaweed) and (salt)water plants. These plants have in common that they grow in a wet environment and are used as (ingredient for) food and feed, specialties and feedstock for bio energy.

5.1.1 Micro-algae

Micro-algae are small (ca. 2-20 μm) unicellular organisms. More than 100,000 different fresh- and saltwater species have been identified. At present a limited number of species (for example *Dunaliella* and *Chlorella*) is commercially being cultivated for predominantly food and feed (a.o. feed for aquaculture) applications and to a lesser extent for the production of specialties, such as food grade colorants and ingredients for cosmetics. The present total market volume is approximately 10,000 ton dry material per year (100-200 million € per year).

Extensive R&D is being performed on species with high oil content for the production of algal biodiesel. It is expected that within 2-3 years commercial cultivation of oil-containing micro-algae's could be effectuated.

Although different cultivation concepts exist (closed and open reactors), only open pond systems will be considered in this report. The costs for open ponds cultivation is considerably lower compared to closed reactor systems, which makes this concept more attractive for the production of bulk products such as biodiesel. Open pond systems consist of a race-way shaped basin lined with concrete or plastic. A paddlewheel is used to mix the culture both in horizontal and vertical direction.

Micro-algae use sunlight as energy source, CO_2 or simple organic components as carbon source and extract other necessary elements (N, P, trace-elements) from the water. This makes the combination of cultivation with waste water purification possible. There are also efforts to use the manure surplus as nutrition source for micro-algae cultivation. In this option a closed loop for feed production is an interesting perspective.

A major drawback for open pond cultivation is the risk of contamination. The common strategy to achieve monocultures is to keep the micro-algae at extreme culture conditions (high salinity, nutrition or alkalinity). This however limits the number of species that can be grown in open ponds.

Advantages of micro-algae in comparison with land plants are:
- up to fivefold higher yield per hectare (energetic efficiency is 5-6 % of PAR (Photosynthetically Active Radiation); land plants 1-3 % of PAR);
- soil quality is unimportant so area not suited for agriculture can be used;
- no nutrients are lost to the environment (if plastic liners are used)
- cultivation can be combined with waste water purification;

- seawater can be used for a large number of micro-algae species;
- CO_2 can be added to the culture in an efficient way through injection systems resulting in higher biomass yields.

In general production yields are between 20 and 60 ton dm (dry material) per ha per year (average 45 ton dm per hectare per year), depending on the type of species and geographical location. In the case of algal biodiesel production an oil content of 50 wt% is assumed for optimized conditions. This means that ca. 22 ton biodiesel can be produced per hectare per year.

The remaining algal biomass can be used as substrate for anaerobic digestion for the production of biogas. The digestate from digestion can be used as nutrient for algae cultivation and thereby closing the cycle for a number of nutrients. Dry algal matter consists roughly of 50 wt% carbon which means that for the production of 1 ton of dry algal matter 1.8 ton CO_2 is consumed.

The potential for micro-algae production is dominated by land availability. In the estimation of the potential contribution of micro-algae cultivation in Table 5.1 only land not suitable for agricultural use is considered.

LCA analysis of open pond systems showed that GHG emission reduction by replacing fossil fuel based diesel by algal biodiesel is 83% (fossil fuel based diesel: 83 g CO2eq/MJ; algal diesel: 14 g CO2eq/MJ). Cultivation of algae in closed photo bioreactors has a less favourable effect on the reduction of GHG due to the higher energy consumption during cultivation; per MJ biodiesel approximately 70 gram GHG are reduced in relation with fossil fuel based diesel [Ecofys, 2008].

The potential for micro-algae cultivation is determined by availability of land space and fresh or salt water supply. Low quality land not suitable for agriculture can be used for micro-algae cultivation.

In the following table the production figures of algal biomass and oil from algae under Dutch and semi-arid/arid circumstances are summarized.

Table 5.1 *Potentiel yield in mass and energyand GHG reduction potential of micro-algae cultivation for biodiesel production [Ecofys, 2008; PGG, 2006]*

	Unit	Netherlands	Semi-arid/and arid locations
Yield algal biomass	ton dm per ha per year	30	45-70
Oil content	wt% of dry algal biomass	50	50
biodiesel yield	liter per ha per year	12,000	18,000
biodiesel yield	GJ per ha per year	390	585-780
Available area	ha	20,000[c]	130,000,000[b]
Potential	EJ (biodiesel)		90
Potential [PGG, 2006]	PJ (biodiesel)	7	
Potential [PGG, 2006]	PJ (biomass)	16	
GHG reduction[a]	gram CO_2 eq. per MJ	69	69
GHG reduction	ton CO_2 eq. per ha per year	26.9	53.8
GHG reduction potential	Mton CO_2 eq. per year	0.5	7,000

[a] relative to fossil fuel based diesel; not including the additional emission reduction due to biogas production for energy generation from algal residue.
[b] estimated area of arid and semi-arid with no other economic function.
[c] estimation for 2030.

5.1.2 Macro-algae (seaweed)

Macro-algae are marine plants and belong to the lower plant species. Seaweed has no roots, stem or leaves, but a thallus, stipe (stem-like structure) and a holdfast. Some types have gas-filled structures to provide buoyancy. The biochemical composition of seaweed differs fundamentally from that of land based plants; some types phycocolloids are specific for seaweeds and commercially exploited. Examples are agar, alginates and carragenes). Other applications are fertilizer (Maerl), source for inorganic salts (iodine and bromide salts), ingredients for cosmetics, textiles and pharmaceuticals and feedstock for energy productions.

Three families of seaweeds are distinguished: red (*Rhodophyceae*), green (*Chlorophyceae*) and brown seaweeds (*Phaeophyceae*). Seaweed can reach length of several meters up to 60 m and are attached to solid structures like rocks or float freely. A number a species (200 of which 10 intensively) is commercially exploited in Asia (China, Japan, Phillipines, North and South Korea, Indonesia), Europe (France, UK, Norway) and South-America (Chili) mainly for food(supplement) applications. The best known seaweed(products) in the food sector are Nori (*Porphyra purpurea*), Wakame (*Undaria pinatifida*) and Kombu (*Laminaria hyperborea*).

The present market volume for seaweeds is ca. 2 million ton of dry material annually (20 million ton wet seaweed) with a total turn-over of 6 billion US$. Part of this amount (ca. 50 %) is harvested from wild populations and part is obtained from cultivation sites. Cultivation is mostly done by attaching seaweed to horizontal or vertical lines submerged in the sea. The ropes are anchored to solid constructions like off-shore wind turbines or concrete blocks at the sea floor. Several innovative cultivation systems are being developed, for example the combination of seaweed cultivation with aquaculture. In this specific situation the fish manure serves as nutrient source for seaweed. Also multi-layer cultivation is being developed leading to higher production yield per hectare and lower production costs per ton. An overview of cultivation systems can be found in [ECN, 2006].

Production yields vary from 10-50 tonnes dry material per ha per year depending on species, circumstances and cultivation system. Critical yield conditions are the presence of nutrients, under water light intensity, seawater temperature and resistance against storm and wave damage and predating fish. An ecological important positive effect of seaweed cultivation might be the function as natural hatchery for sea fish.

The global potential for seaweed cultivation is large. The limiting factors are the concentration of nutrients in the ocean and logistics. Part of the open ocean is known as 'desert', due to the lack of nutrients (dark blue areas in Figure 5.1). These areas are less suitable for cultivation unless fertilization is applied. Also logistic considerations limit the area suitable for cultivation. The global potential for seaweed cultivation is summarized in Table 5.2.

Production costs estimates are strongly influenced by the yield per hectare and cultivation system. An overview of literature data on production costs [ECN, 2008] showed that the costs vary between 20-410 € per ton dry seaweed. For near-shore large scale cultivation 20-50 US $ per ton dry material has been estimated.

Table 5.2 *Global Potential of seaweed cultivation [Ecofys, 2008]*

	Unit	NL Potential	Global Potential
Horizontal lines between offshore infrastructure	ha		550 million
	EJ/year		110
Vertical lines nearshore	ha		370 million
	EJ/year		35
Floating structures in open sea	ha		50,000 million
	EJ/year		≈ 6,000
Line cultures Netherlands [ECN, 2006]	ha	500,000	
	PJ/year	315	

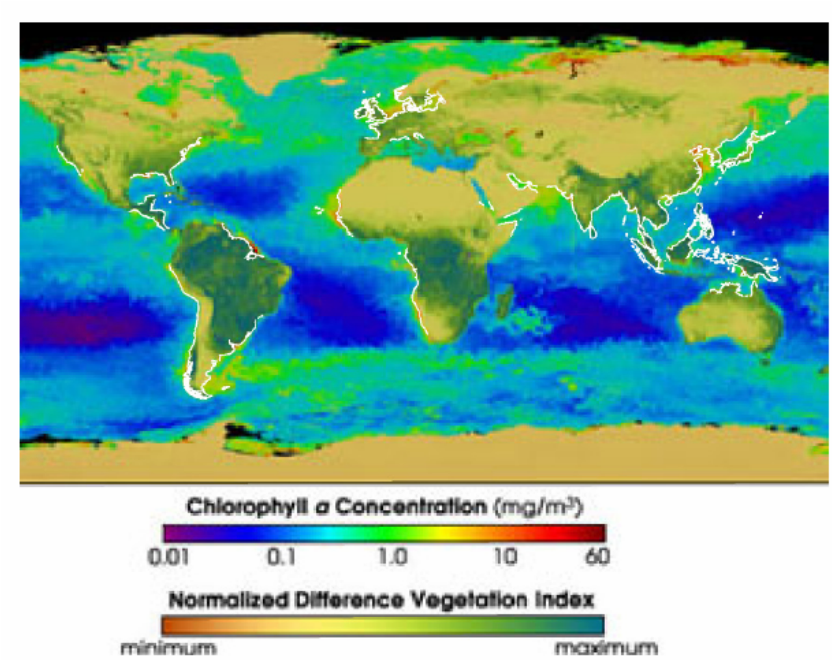

Figure 5.1 *Global overview of chlorophyl concentration in the oceans [Ecofys, 2008]*

The potential of the Netherlands is often linked to the foreseen area for off-shore wind farms (2,000 km^2 in 2015 and 5,000 km^2 after 2050). In several studies a surface area of 5,000 km^2, which equals $\pm$ 10% of the Dutch part of the North Sea (total area is 57,000 km^2), is used to estimate the potential of seaweed cultivation. Seaweed cultivation at this scale can yield up to 10-25 million ton of dry material. In the case that the produced seaweed biomass is solely used for energy generation this amount equals 125-315 PJ_{prim} per year (corrected with 10% for cultivation, harvesting and transport).

Specific seaweed species have temperature ranges for optimal growth. Some macro-algae can not survive if the temperature exceeds a certain limit. A higher temperature will affect the type of species that can be cultivated; other species will be better suited for a higher temperature. It can be expected that exotic species will benefit from an increase in water temperature and slowly become ‘indigenous’ species. These new seaweed species might include new opportunities for cultivation.

5.1.3 Water plants

The third category of plants is water plants. Both fresh water plants and salt/brackish water plants are considered.

The Netherlands has a relatively large area of waterways, lakes, wetlands, rivers etc. One of the measures of the adaptation policy is the creation of water storage basins thereby increasing the area of inland water. Part of the standard maintenance activities is the removal of water plants from waterways in order to ensure the water flow capacity. A positive effect of removal of water plants is that nutrients taken up by the plants are removed from the ecosystem.

Water plants are suitable as feedstock for anaerobic digestion, yielding biogas.

An estimate of the potential (targets) of water plants in the Netherlands has been made [PGG, 2006]. In Table 5.3 a summary of the results of this study is shown (16 GJ per ton dry material; 10% of the energy content is used for cultivation, harvest and transport; production yield 10 ton dry material per ha per year).

Table 5.3 *Potential of fresh water plants in the Netherlands [PGG, 2006]*

	Area (ha)	Biomass production (ton dm)	Energy potential (PJ)
2015	50,000	500,000	7.2
2030	150,000	1,500,000	21.6

On the boundary between fresh and salt water a wide variety of indigenous plants grow. Some of these plants are traditionally harvested and used as vegetable (zeekraal, lamsoor). The plants can also be used for energy production. Several traditional agricultural crops are known to have a relatively high salt tolerance [website Oase]. An indication of the potential is shown in Table 5.4. For the estimation of the GHG reduction potential it is assumed that the biomass is used as feedstock for anaerobic digestion for the production of biogas. The biogas is subsequently converted in a gas engine for the production of electricity and heat.

At present, globally over 1 billion hectares of land are becoming saline. Each year an increase of 10 million hectares is observed. Climate change will accelerate the salinisation process in coastal areas as a result of seawater intrusion.

Table 5.4 *Potential of salt/brackish water plants in the Netherlands [Ecofys, 2008]*

	Area (ha)	Biomass production (ton dm)	Energy potential (PJ)
2015	60,000	600,000	8.6
2030	125,000	1,250,000	18.0

5.1.4 Aquatic biomass and climate change

The production of aquatic biomass has a high potential in yield and therefore the accompanying GHG emission reduction when the biomass is used for energy generation or for replacement of fossil fuel based products. The estimated energy potential adds up to ca. 370 PJ of aquatic biomass in the Netherlands and more than 6,300 EJ biomass globally (excluding fresh and salt water plants). The by far highest contribution to the potential yield is from seaweed cultivation due to the restricted land availability of the other options (micro-algae and water plants).

In Table 5.5 the qualitative effect of climate change and adaptation measures for aquatic biomass in the Netherlands are given.

Table 5.5 *Qualitative effects of climate change and adaptation measures on aquatic biomass in the Netherlands*

	Climate change					Adaptation
	Temperature increase	Higher CO_2 concentration	Sea level rise	Salinisation of land	More turbulent weather	Increase water storage area
Mirco-algae	+	+	nr	0	0	0
Seaweed	+	0	0	0	-	nr
Fresh waterplants	+	+	nr	-	0	+
Salt waterplants	+	+	+	+	0	0

nr = not relevant
\+ = positive effect (higher yield, higher land availability)
0 = no effect
\- = negative effect

Temperature increase
Although higher temperature often leads to a higher biomass yield, many species have specific temperature regions for optimal growth. By selection of plants with optimal growth at higher temperature the overall biomass yield will increase.

CO_2 concentration
An increase in CO_2 concentration in the atmosphere will result in higher biomass yields for micro-algae cultivation and water plants. If CO_2 injection is part of the production process there will be no effect. The effect on seaweed is more complicated.

Sea level rise
Near shore seaweed cultivation sites can be a factor in the coastal defense strategy by reducing the impact of waves on the shore line. A rise in sea level will hardly effect cultivation of seaweed. It can be expected that the area of salinated land will increase due to the rise of the sea level. Therefore land availability for cultivation of saltwater plants will increase at the expense of traditional agriculture.

If aquaculture is replacing agriculture in certain areas the flexibility of water level management in those areas can increase. The storage capacity of these areas can become more important.

5.2 Biomass and CCS

Carbon Capture and Storage (CCS) is one of the mitigating technologies. The principle behind CCS is that CO_2 is removed from the carbon cycle and stored. Biomass coupled with CCS offers the potential for negative CO_2 emissions and functions as a carbon sink[1,2]. This makes this technology potentially attractive if deeper reductions are necessary to decrease GHG-

[1] Remark: CO_2 from biomass is currently excluded from the Emission Trading System (ETS) [Groenenberg, 2008].
[2] Some references use the abbreviation BECS (=Biomass Energy and Carbon Capture and Storage).

concentrations after stabilization. This chapter gives a short overview of available information about the technologies, costs, potentials and current research issues on this subject. The presented information is based on a limited literature search on biomass and CCS and in-house knowledge on the subject.

5.2.1 Technology description

Many technological routes are available for biomass in combination with CCS. All the basic CCS technologies being developed for fossil fuel systems, such as gasification and oxy-fuel combustion, could in theory be applied to bio-energy systems [Rhodes, 2005] as the principle and processes are the same. The main application of CCS will be for large carbon dioxide sources, like fossil fuel power plants, fuel processing plants and other industrial plants like iron, steel, cement and bulk chemical plants due to the significant effect of scale on the capture and storage costs. There are four basic systems for CCS, which are illustrated in Figure 5.2.

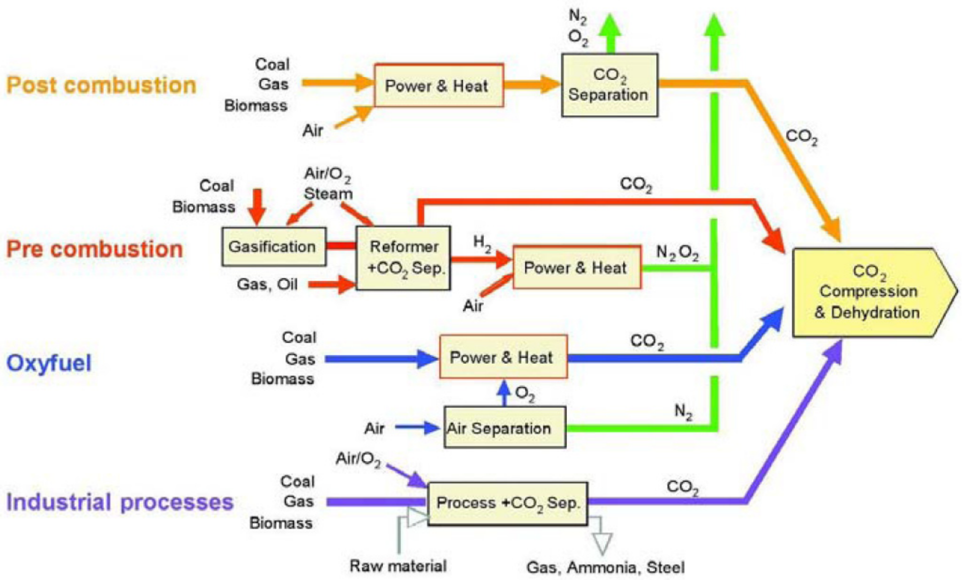

Figure 5.2 *Carbon capture technologies [IPPC, 2005]*

Post combustion capture (PCC) is capturing the CO_2 from flue gas, produced by a combustion process. The flue gas passes separation equipment and CO_2 is removed. The CO_2 is stored and the remaining gas (mainly water vapour) is emitted into the atmosphere.

Pre-combustion capture is the separation of CO_2 from syngas that is produced by a gasifier. The remaining carbon monoxide (CO) and hydrogen (H_2) can be used as a feedstock for other applications.

Oxyfuel combustion capture is the combustion of fuel with nearly pure oxygen. The flue gas contains mainly CO_2 and water. CO_2 is therefore relatively easy to remove.

In **industrial processes** CO_2 removal is necessary for several processes. Examples are the purification of natural gas, production of ammonia, alcohols and synthetic liquid fuels. Since industrial processes concern high concentrations of CO_2, these processes can be very cost-effective.

Considering the overall state of the art of these technologies (for fossil fuels), oxyfuel combustion is in the least developed stage and not ready yet to be demonstrated. Recently an oxyfuel pilot plant of 30 MW_{th} has been realized in Germany [Vattenfall, 2008]. The pre-combustion and post combustion technologies are further being developed and can be considered ready for demonstration. None of the technologies are currently applied on a commercial full scale [Harmeling, 2008; McKinsey, 2008].

Biomass contains relatively low concentrations of carbon and high concentrations of hydrogen and oxygen compared to coal. This is one of the reasons of the relatively low heating value compared to this fuel. During combustion therefore a higher ratio of CO_2 per unit of energy is released. In combination with CCS this disadvantage becomes an advantage. For biomass-CCS specific, three main technological routes are possible:

- Biological processing with capture of CO_2 by-products to produce *e.g.* liquid fuels
- Biomass gasification with shift and CO_2 separation to produce *e.g.* hydrogen;
- Biomass combustion to produce electricity with CCS, either by oxyfuel or post-combustion capture (PCC) routes.

These three basic routes can be combined or integrated, for example, by gasification with CCS of residual biomass from biological processes, or by syngas conversion to liquid fuels with CCS, or by burning hydrogen-rich syngas to produce electricity with CCS [Rhodes, 2007]. The several routes for biomass are illustrated in Figure 5.3. In this figure biological processing includes a.o. anaerobic digestion and fermentation to ethanol. An technical and economic advantage of ethanol production is that a pure CO_2 stream is formed as byproduct, which can be stored without the necessity of a capture process.

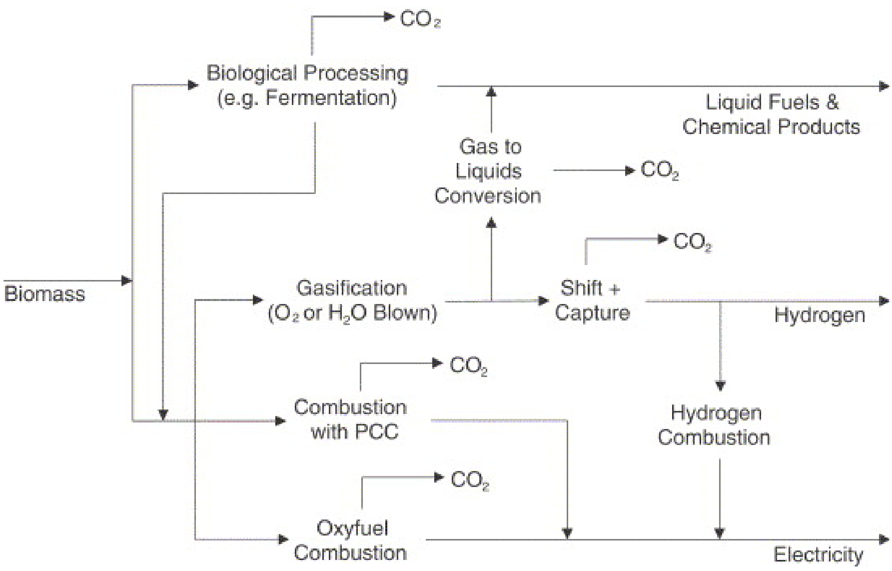

Figure 5.3 *Routes to biomass with CO_2 capture [Rhodes, 2005]*

Additional opportunities, not shown in the figure above, exist from potential soil enrichment with biomass derived char. There are concepts that focus on distributed carbon storage build on the conversion of biomass into long-term carbon sequestering charcoal. The carbon can be sequestrated by using the charcoal as soil amendment in forest and arable lands to improve soil productivity [Möllersten, 2007].

The cost of CO_2 removal is strongly dependent on the plant size. Local stand-alone CHP biomass plants will usually be smaller than coal fired power plants due to the limited feasibility to sell and use heat. Therefore biomass stand-alone plants are relatively small in scale (<100 MW_e), resulting in relatively high cost of removal of CO_2. Full CCS costs could amount to 110 US$ (≈ 77 Euro) per ton CO_2 avoided. Significantly larger biomass plants could potentially benefit from economies of scale, bringing down costs of the CCS systems to levels broadly similar to coal plants [Rubin, 2005]. It is estimated that the cost per ton of CO_2 removed doubles for each order of magnitude reduction in the size of the plant. Biomass can however also be co-

combusted in coal-fired power plants. Co-combusted biomass benefits from the scale effects of coal in terms of higher efficiency and lower costs. If CCS is applied to such a process, the cost of applying CCS to the biomass components would be significantly lower than applying CCS to biomass combustion alone [IEA, 2008]. A recent report [McKinsey, 2008] indicates a cost range of around 30-47 [3] Euro/ton CO_2 based on CCS for fossil-fired installations.

Table 5.6 summarizes the advantages and disadvantages of biomass in combination with CCS.

Table 5.6 *Advantages and disadvantages over biomass and CCS*

Advantages	**Disadvantages**
• Biomass in combination with CCS leads to negative CO_2 emissions (sink) • Biomass has already a low sulphur content (CCS solvents need high sulphur removal)	• Capital intensive • Loss of efficiency • Needs large amounts of biomass (to be imported) • For fossil fuels: end of pipe technology • Leakage risks (leading to lower public support) • Storage capacity need extra exploration

5.2.2 Possibilities of Biomass and CCS in the Netherlands

The next paragraphs will focus on the possibilities of biomass and CCS in the Netherlands. A necessary condition for large-scale application of biomass is a world-wide trade and logistic infrastructure. Evenly important is the necessity to guarantee (by certificates and verification) that the biomass is produced in a sustainable way. See Chapter 3 of this inventory for the sustainable biomass production potential. In the subsurface of the Netherlands and the Dutch continental shelf (DCS) there is an estimated storage capacity available for 11,000 Mton CO_2 [DHV, 2008][4].

Biological Routes

From the biological routes, digestion of manure and other wet streams is currently widely applied in the Netherlands. The produced gas is currently mainly combusted in gas engines to produce power and low temperature heat. There are possibilities to upgrade the gas to natural gas quality by cleaning the gas, removing the CO_2, and injecting it to the natural gas grid. The theoretical maximal potential in the Netherlands is estimated to be 50-60 PJ/yr, which is relatively small compared to the total annual natural gas consumption in the Netherlands, which is around 1,500 PJ/yr. There are several cases in the Netherlands where this gas is injected into the natural gas grid (medium pressure grid). Digestion occurs currently on a relatively small scale and is a diffuse source of CO_2. The potential of digestion is indicated to be 2 Mton CO_2/yr reduction in 2020 (based on the National Optiedocument) and is limited by the local availability of wet biomass streams due to relatively high transportation costs compared to dry biomass streams[5]. For digestion of wet biomass streams to produce bio-SNG the costs in 2020 per ton of CO_2 are estimated to be relatively high: 236 Euro/ton (without CO_2 storage) [Platform Nieuw Gas, 2007].

Next to digestion there is a potential for ethanol produced from biomass by fermentation. During the fermentation process CO_2 is formed and currently released into the atmosphere. This CO_2 could be captured and stored. For first generation bio ethanol plants, roughly one ton of CO_2 is emitted per ton of produced ethanol [Den Uil, 2008]. Currently, there is around 800

[3] Exchange rate December 2008.
[4] It is reported that 40-60 Mton CO_2/a in the Netherlands can be captured and stored at a price of 10-40 Euro/ton in 2050. Current Dutch total emissions are around 180 Mton CO_2/yr, estimated to be increasing to 250 Mton/yr in 2050 without climate policy [Damen, 2007].
[5] There are no numbers available on the cost and potential of CCS in combination with digestion.

kton/a ethanol production capacity planned to be operational in 2011 in the Netherlands [Milieudefensie, 2008], with CO_2 capture this would be equal to a potential capture of an additional 0.8 Mton CO_2/yr, next to the reduction associated with the substitution of fossil transportation fuels. This number can be increased if more installations are realized after 2011.

Gasification Routes

Especially for polygeneration facilities which apply gasification technology to produce power as well as syngas as an intermediate, for *e.g.* methanol and Fischer-Tropsch fuels, there are perspectives as the CO_2 capture is an integrated part of the process necessary to obtain a non-CO_2 diluted syngas containing carbon monoxide and hydrogen.

One of the technologies in development in the Netherlands (ECN) and Switzerland (PSI) is Bio-SNG made via the gasification route. The technology is currently in the research and pilot phase. Bio-SNG is a substitute natural gas made from biomass sources[6]. It can be made by a digestion route (small scale, 100-600 Nm^3/hr) or gasification route (large scale, 1,000-100,000 Nm^3/hr). In both cases CO_2 has to be separated before the SNG can be added to the (existing) natural gas network. It is envisaged that it is possible to have a natural gas substitution of 8-12% by SNG [Platform Nieuw Gas, 2007] in the Netherlands. The bio-SNG route via the gasification route offers the possibility for large scale CO_2 separation and storage. Coal to SNG has already been demonstrated by Dakota Gas (USA). In this specific case, CO_2 (with H_2S) is removed by a Rectisol unit and used for enhanced oil recovery (EOR).

In the Netherlands currently around 40 billion Nm^3/yr of natural gas is consumed. In Europe and Eurasia this is approximately 1,200 billion Nm^3/yr [BP, 2008]. Assuming a substitution of 10% and with a CO_2 emission factor of 1.8 kg CO_2/Nm^3 natural gas [SenterNovem, 2006], the current potential without CO_2 storage would be for the Netherlands around 5 Mton/yr (including 30% losses for production and transport of the biomass) and for Europe around 150 Mton/yr. With CO_2 storage these number would be around respectively 10 Mton/yr and 440 Mton/yr. For 2030 the costs and technical potential for the Netherlands are estimated to be 115 Euro/ton CO_2 for SNG production without CO_2 storage with a potential of 17 Mton/yr. If CO_2 storage will be applied, the CO_2 removal costs are estimated to be 60 Euro/ton and a potential of 35 Mton/yr. Both scenarios assume a substitution of 20% by Bio-SNG of natural gas in 2030 [Platform Nieuw Gas, 2007].

Recently, initiatives are published by the power producing sector for the realization of power plants based on gasification technology that can be fired on coal, gas and biomass [Nuon, 2008; Essent, 2008]. These options are presented as CCS ready and offer opportunities for the combination of biomass and CCS. The potential will depend on the amount of biomass that can and will be co-fired.

Combustion Routes

Co-firing of biomass (wood pellets, residues) in pulverized coal fired power plants is currently occurring extensively in the Netherlands (30 PJ in 2006 and 15 PJ in 2007 [CBS, 2008]). If coal is substituted by biomass almost no CO_2 is emitted per MJ compared to coal over the whole process chain [CML, 2008]. In the Netherlands 8 Mton of coal is used for power production in 2006 [Energiened, 2007]. This is equivalent to an emission of 18 Mton of CO_2 per annum. Assuming 10% and 20% co-firing on mass basis, a CO_2 reduction of around 1.9 and 3.7 Mton/a respectively can be achieved *without* CO_2 storage. *With* a CO_2 storage facility (based on post-combustion capture), an additional reduction by capturing 1.3 and 2.6 Mton/yr can be achieved for the biomass contribution (assuming a specific CO_2 emission factor of 1.7 ton CO_2/ton biomass [Broeikasgassen, 2008], no production losses taken into account). The total reduction potential is then around 3 and 6 Mton/yr.

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[6] About 0.36 Nm^3 of methane can be produced from 1 kilogram of biomass [Rabou, 2008].

Oxyfuel combustion installations fired on coal for power generation have an interest in the United Kingdom and Germany. Co-firing biomass with coal seems the most efficient option due to the required large-scale application for oxyfuel combustion as a result of the necessity of the capital-intensive air separation unit (ASU). The possibility and feasibility to retrofit existing power plants with oxyfuel burners is subject of ongoing research. For the planned coal-fired power station in the Rotterdam region, the option to install oxyfuel burners is indicated [Electrabel, 2007].

5.2.3 Biomass and CCS Research Issues

The developments and research on CCS are very internationally oriented[7]. The research is mainly focused on CO_2 capture from fossil origin. The research attention on biomass and CCS is rather limited and is mainly based on process modeling and economic evaluations (*e.g.* Uddin, 2007; Mollersten, 2002; Larson, 2007; Rhodes, 2005; Williams, 2007; Azar, 2006).

The Dutch national CATO and CAPTECH research programs involve a number of relevant parties (Utrecht University, ECN, UCE, Shell, Kema, Procedé, University of Twente, TNO) on CCS research in general. Besides the involvement in national research frameworks, there is a broad participation on an international level.

[7] Examples of international CCS research frameworks are: Coal21 (Austria), CO2CRC (Australia), The Clean Power Coalition (Canada), the Energy Carbon Sequestration Program (USA), FutureGen (USA), COORETEC (Germany), CLIMIT (Norway), Cleaner Fossil Fuels Programme (UK) [Harmelen, 2008].

Table 5.7 gives an overview of involvement in several research programs. Specific biomass and CCS related research issues[8] are:

Overall
With respect to potential of biomass and CCS a general overview of the possibilities, potential and costs for the Netherlands does not yet exist.

Post combustion
The effect of biomass (co)-firing on power plants with post combustion CCS is expected to be limited. The effect of higher fraction of small size particulates on the sorbent (due to higher slip of particulates through the dust removal (ESP)) is currently unknown.

Pre-combustion
Several international modeling studies have focused on this subject (*e.g.* Uddin, 2007, Williams, 2007). The potential and effect of biomass co-gasification plants with CO_2 capture on the energetic, operational and emission performance for the Netherlands is unknown.

Oxyfuel
Main research topics are the influence of biomass firing on the combustion characteristics and ash behavior for oxyfuel concepts. These aspects are currently investigated in *e.g.* the EU BOFCOM project (Biomass, Oxyfuel and Flameless Combustion) coordinated by ECN [BOFCOM, 2006]. One of the issues is the slagging and fouling encountered in oxyfuel firing as well as ash quality. DTU (Denmark) is also reported to be working on a project on oxyfuel combustion of coal and biomass [DTU, 2007]. They are working on the general understanding of general combustion characteristics, ash characteristics, corrosion of heat transfer surfaces of boilers and flue gas treatment of SO_2 and NO_x.

[8] Specific biomass related research items on the fuel conversion, like *e.g.* (co-)combustion, gasification, flue and producer gas cleaning are not described in this inventory, but are also research issues worldwide to enable the use of biomass.

Table 5.7 *Dutch involvement in CO_2 capture projects [CATO, 2008]*

Program	Consortium Partners	Program/sponsor	Research topics (CO_2 part only)
Dutch projects			
CATO	ECN, KEMA, Shell, TNO, UTwente, UU, UCE	BSIK	Sorbents, solvents, membranes, systems integration
CAPTECH	ECN, KEMA, Shell, TNO, UTwente, UU, UCE, Procedé	EOS-LT	Sorbents, solvents, membranes, systems integration
C-CLEAR	ECN	EOS-LT	Pre-combustion, sorbents
CATHY	ECN	EOS-LT	Catalysts membrane and sorbent reactors
International projects			
ENCAP	TNO, UTwente	EU-FP6	Post-combustion capture, membranes
CASTOR	TNO, UTwente	EU-FP6	Pre-combustion and denitrogenation
CAPRICE	TNO	EU-FP6	Post-combustion capture, storage
CACHET	ECN, Shell	EU-FP6	Sorbents and membranes for pre-combustion.
GCEP	ECN	Exxon , GE et al	Advanced membrane reactors
Dynamis	TNO	EU-FP6	Preparing the ground for Hypogen
CCP1/CCP2	Shell	Oil companies	Membranes, sorbents
NanoGLOWA	KEMA, UTwente	EU-FP6	Membranes for CO_2 removal
CAESAR	ECN	EU-FP7	Pre-combustion
CESAR	TNO	EU-FP7	Post-combustion
DECARBit	TNO, Shell, TUD, NUON	EU-FP7	Pre-combustion: benchmarking, capture, turbine, denitrogenation

5.3 Conclusions

Aquatic biomass

- Seaweed cultivation offers a vast, still unexploited, potential for biomass production.
- Production and utilization off micro-algae is due to its independence of soil quality not competing with food production and can be performed anywhere with sufficient supply of sweet and/or sea water.
- Aquatic biomass can be applied without major negative effects of climate change and adaptation measures.

Biomass and CSS

- Biomass in combination with CCS offers the potential for deep CO_2 removal as it has negative CO_2 emissions.
- The CCS technologies available resemble the technologies needed for fossil feedstocks.
- The carbon form biomass sources also can be sequestrated by using the charcoal as soil amendment in forest and arable lands to improve soil productivity.
- When the application of this kind of technologies becomes a necessity for deep GHG reductions, the (sustainable) availability of biomass is a point of attention.
- A drawback for small-scale biomass stand-alone application is that the costs can be relatively high due to the poor economy of scale.
- For the short-term, co-firing of biomass in coal-fired power plants equipped with CCS (post, pre and oxyfuel combustion capture) seems the most feasible option, as this option takes advantage of the economy of scale, resulting in lower costs.

- For the long-term, more dedicated large-scale biomass conversion technologies, *e.g.* bio-SNG and bio-Fischer Tropsch fuels, can be of interest.

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6. Between emission reduction and adaptation

6.1 Introduction

The emission of greenhouse gases leads to an increase in their atmospheric concentration, which in turn influences the Earth's radiative balance, giving rise to (mostly) adverse consequences. Traditional mitigation strategies usually attempt to decrease greenhouse gas emissions, while adaptation strategies are designed to adapt society to, and protect it from the consequences. The topics of this chapter attempt to address the processes in between [Parson, 2006]: Air capture tries to decrease the atmospheric concentration independent of emissions, and artificial cooling methods try to counterbalance the warming by an equivalent amount of intentionally provoked cooling. This way the connection between emissions and resultant climate changes is weakened. The term geoengineering is often used to refer to planetary scale environmental engineering methods, aimed at counteracting the undesired side effects of other human activities [Keith, 2001]. It is sometimes restricted to techniques for increasing Earth's albedo, but more broadly, the term can include efforts to accelerate some of the natural processes for removal of CO_2 from the atmosphere [Goss Levi, 2008]. In this report, we distinguish methods that exert a negative radiative forcing on climate (and thus cause cooling) from methods that attempts to capture CO_2 from the air for subsequent storage. The former we call here 'intentional cooling' and the latter 'air capture'. They are fundamentally different in that air capture seeks to address the cause of climate change, whereas intentional cooling is an attempt at counterbalancing [Pielke Jr, 2009]. Table 6.1 highlights how different stages of the cause-effect relationship of climate change can be influenced by different types of measures.

Table 6.1 *Between the "traditional" roles of emission reduction (i.e. prevention) and adaptation (i.e. protection) in responding to climate change, there are at least two additional measures that could in principle be considered: air capture and subsequent storage, and artificial cooling (also known as "geo-engineering")*

Process / problem	Measure / solution
Emission of greenhouse gases	Emission reduction
Atmospheric concentration	Air capture and storage
Global warming	Artificial cooling
Undesired impacts of global warming	Adaptation

In 2008 a group of papers dealing with this topic was published in Philosophical Transactions of the Royal Society. An overview of the potential of a range of methods is given in a recent paper by Lenton and Vaughan [2009]. A schematic of different options to intervene in the climate system is given in Figure 6.1 (from Lenton and Vaughan, 2009). Note that they use a very wide definition of geoengineering, even including afforestation under this heading; this is not usually the case.

An overview of possibilities will be given, with a focus on those that appear the most promising and those that have been most widely discussed. The options being discussed here include:
Air capture (6.2):

- Mineral sequestration
- Air scrubbing
- Ocean fertilization
- Carbon fixation in soil

Artificial cooling (6.3):

- SO_2 injection in the stratosphere
- Cloud seeding in the marine boundary layer
- Cloud seeding of cirrus clouds

For a method to be able to contribute to alleviating climate change, it has to be energy-efficient: It should cost less energy to displace or counteract the effects of an equivalent amount of CO_2. The idea of putting reflective particles or mirrors (sunshades) in space [Angel, 2006] is deemed too futuristic and expensive to become a serious candidate in the near or mid-term future, and is therefore omitted from this review, even though it could in principle be effective [Lenton and Vaughan, 2009]. The framing of these possibilities in an overall policy portfolio will be discussed in the last paragraph (6.4).

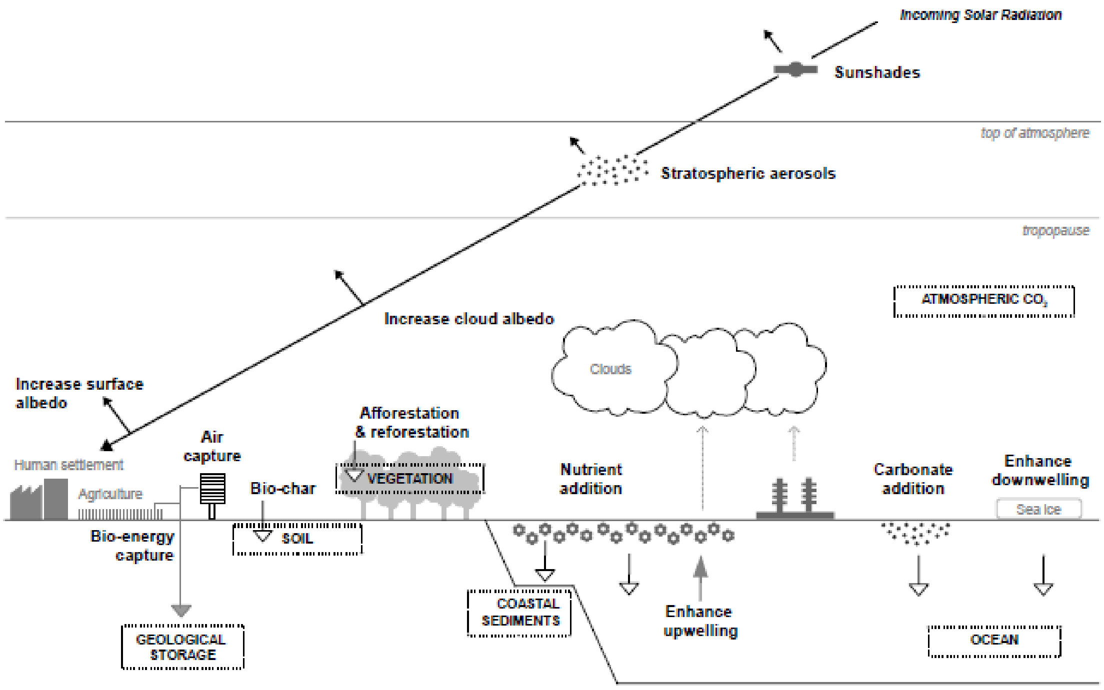

Figure 6.1 *Schematic overview of the climate geoengineering proposals considered. Black arrowheads indicate shortwave radiation, white arrowheads indicate enhancement of natural flows of carbon, grey downward arrow indicates engineered flow of carbon, grey upward arrow indicates engineered flow of water, dotted vertical arrows illustrate sources of cloud condensation nuclei, and dashed boxes indicate carbon stores. From Lenton and Vaughan [2009], not to scale*

Lenton and Vaughan [2009] provide a ranking of different options, reflecting their potential to provide a negative radiative forcing (i.e. cooling of the climate). On the century timescale (up to 2100), this ranking looks as follows, in decreasing order of effectiveness:

Sunshades Stratospheric aerosols Cloud α mechanical	>	Air capture Desert α	>	Grassland α Cropland α Bio−char Afforestation	>	Fe fertilisation Settlement α P addition N fertilisation	≫	Carbonate addition Cloud α biological Urban α	≫	Upwelling Downwelling

Where α stands for (increasing the) albedo (reflectivity), Cloud α mechanical refers to cloud seeding of the marine boundary layer, Cloud α biological refers to periodic iron fertilization of the Southern Ocean in order to increase cloudiness, and Fe fertilization refers to iron fertilization in order to increase the drawdown of carbon. The comparison is based on gross effect, i.e. energy expenditures needed to make the method work are not taken into account. For energy intensive methods such as space based sunshades and air capture methods, including the effect of this energy expenditure could make a substantial difference in their ranking.

6.2 Air capture and storage

Air capture generally refers to the capture of greenhouse gases, principally CO_2, from ambient air. It is different from, and generally less efficient than capturing the CO_2 from a concentrated air stream, such as from the exhaust of a power plant. The latter is referred to as carbon capture and storage (CCS).

Air capture technologies may be divided into those that mimic (and attempt to speed up) natural processes (e.g. CO_2 capture by minerals or biomass), and those that employ a new process (e.g. CO_2 capture by air scrubbing).

6.2.1 Mineral sequestration

There are several naturally occurring minerals that react with and fixate CO_2 from the air, most notably metal silicates that form upon reaction with CO_2 the corresponding metal carbonate and solid silica. The best known of these is olivine ($(Mg,Fe)_2SiO_4$), which is found in e.g. peridotite rock formations. The reaction is exothermic (i.e. energy producing) but slow. It requires energy to speed up the reaction to meaningful rates, and its energy use is close to the break-even point of equivalent CO_2 displacement [IPCC SRCCS, 2005], though different sources come to different conclusions in this respect [Kelemen and Matter, 2008; Schuiling and Krijgsman, 2006]. According to Lackner (2002; 2003), once the CO_2 is bound to the mineral, it won't return to the atmosphere: the sequestration is practically permanent. In the case of leaching, additional CO_2 would be bound in the transformation of solid magnesium carbonate to dissolved magnesium bicarbonate [Lackner, 2002].

6.2.2 Air scrubbing

Several air scrubbing devices have been proposed. The US firm Global Research Technologies, together with Professor Klaus Lackner, is developing a wind scrubber which passively captures the CO_2. Air moves through panels of hanging fabric coated with a proprietary material that captures the CO_2. Then the doors close, and the fabric strips are sprayed with a sodium carbonate solution that binds the CO_2 and becomes sodium bicarbonate. The water is drained off and an electrodialysis process strips CO_2 from the sodium bicarbonate, which subsequently has to be stored. However, the process currently produces as much CO_2 from coal-generated energy usage as it strips from the air, so it is not (yet) at the stage of useful deployment [IPCC WG3, 2007], though different calculations come to different conclusions regarding the CO_2 efficiency of the process [e.g. Zeman, 2007; Baciocchi et al., 2006].

Different cost estimates have been made, varying between $140 (US) per ton CO_2 [Keith et al., 2005] and $100 (US) per ton CO_2 [Lackner, as cited in Pielke Jr., 2009] to an expected $30 (US) per ton CO_2 in the future [Lackner, as cited in Pielke Jr., 2009]. However, these cost estimates are generally based on gross CO_2 captured, thus implicitly assuming carbon free or carbon neutral energy sources to be used for the air capture. Depending on the energy and CO_2 efficiency of the air capture, these energy sources may or may not be put to better use by directly off setting fossil fuel energy. Resolution of this efficiency question is therefore critical to assessing the potential use of this (or any) technology in a mitigation portfolio.

6.2.3 Ocean fertilization

In large parts of the ocean, phytoplankton growth is limited by certain nutrients, notably iron. The idea behind this scheme is to fertilize those areas with iron to induce extra plankton growth. Upon plankton death, the assimilated carbon sinks to the deep ocean and is thereby 'lost' from the carbon cycle [Coate et al, 1996].

Another, related scheme is based on the fact that many phytoplankton species emit dimethylsulfide (DMS), which is purported to play a role in aerosol formation in the marine boundary layer, via oxidation to sulfuric acid and methane sulfonic acid (MSA) [Charlson et al, 1987]. Increased amounts of aerosol exert a cooling effect on the climate, due to direct reflection of sunlight and their role in cloud formation. Wingenter et al. [2007] suggested that by fertilizing the DMS producing phytoplankton in the Southern Ocean, local temperatures could be significantly decreased, aiding in the prevention (or slowing down) of the melting of the Western Antarctic Ice Sheet.

These schemes are amongst the more controversial ones discussed here, because of the potential side effects on oceanic ecosystems, and the uncertainty of its actual intended effect [Weart, 2008]. Based on modeling studies, iron fertilization of the ocean can play only a small role in managing the carbon cycle in the coming century [Zeebe and Archer, 2005].

6.2.4 Carbon fixation in soil

Large amounts of carbon are cycled through agricultural production systems. Therefore, a small increase in carbon fixation and/or a decrease in carbon release (respiration) could lead to a substantial decrease of the net emission (or increase the sequestration) of carbon over time. The current agricultural practices greatly influence the amount of soil organic carbon that is sequestered (for a certain amount of time) and the amount of greenhouse gases emitted. Compared to conventional agriculture, organic agriculture is generally found to result in increased storage of soil organic carbon and increased soil fertility, but in decreased crop yield [Clark et al., 1998; Maeder et al., 2002; Snyder et al., 2007; Melero et al., 2008], though contradictory findings have also been reported. Through the myriad of interdependencies, the establishment of clear cause-effect relationships that govern the climatic effects of agricultural systems have proven to be an elusive goal.

The IPCC WG3 report [2007] mentions the following mitigation options as most promising in agriculture:

- restoration of cultivated organic soils
- improved cropland management
- improved grazing land management
- restoration of degraded lands

Most of the effects are through increased soil carbon sequestration. Mitigation strategies in agriculture often have consequences for adaptation and/or vulnerability to climate extremes. These consequences could be positive (e.g. increased carbon sequestration by increasing the soil organic matter or adding biochar to the soil reduces the impact of droughts) or negative (e.g. heavy dependence on biomass energy increases the sensitivity of energy supply to climate extremes) [IPCC WG3, 2007]. The reverse can also be the case: adaptation measures can have (positive or negative) consequences for mitigation. These interactions should be carefully considered when looking into policy options.

Additional carbon can be sequestered in soil through the production of biochar. It is based on low temperature pyrolysis (burning in the absence of oxygen) of biomass. By adding biochar to soil, carbon is stored for millennia [Lehmann, 2007]. Biochar also helps retaining nutrients and fertilizer, potentially reducing emissions of nitrous oxide, a potent greenhouse gas. Crop yield is increased by its application to soil improvement [Renner, 2007]. Increased water retention as a consequence of biochar application may render certain soils less sensitive to droughts. In such cases, biochar application has value as an adaptation strategy as well as mitigation.

A modest CO_2 drawdown of ~8 ppm over 50 years could be achieved by replacing slash-and-burn agriculture with slash-and-char and use of biomass waste for biochar production [Lehmann et al., 2006]. This could also have the positive effect of preventing more (tropical) forest from being burnt, preventing even more greenhouse gas emissions, while preserving biodiversity.

By combining biochar production with energy production from biomass, the potential in both prevented fossil fuel emissions and carbon fixation is even greater. When pyrolysis of biomass is used to produce energy, 50% of the carbon can be added to the soil as biochar, where it will decompose only very slowly (over centuries/millennia) to return to the atmosphere as CO_2. Lehmann [2007] claims that with low temperature pyrolysis, emission reductions are greater if biochar is put back into the soil instead of being burned to offset fossil fuel use. It could produce 3–9 times more energy than is invested in generating the energy. The carbon- and energy-efficiency is central to the potential use of the strategy, and there is a need to have different groups investigating this issue to increase our confidence in its potential. It appears to be a promising strategy, especially because most side effects of biochar application are strongly positive: Increased soil fertility was the main reason that centuries ago it was applied ('terra preta') by Native Americans in the Amazon.

The global potential is closely tied with the scale of biomass production, if not only waste products are to be used. The net environmental effects, however, are also strongly dependent on how the needed biomass is produced. Even though this technique appears promising, it is not a silver bullet: "Much remains unknown about how charcoal influences the dynamics of native soil organic carbon and its loss as CO_2. As long as this remains the case, strong advocacy for the addition of charcoal or biochar to soil to offset human-induced CO_2 emissions remains premature." [Wardle et al, 2008].

6.3 Artificial cooling

Schemes to intentionally modify the climate have been proposed and investigated since at least 50 years, but not always for the same purpose: Some early ideas have focussed on increasing temperatures in high latitudes, whereas most current ideas aim to decrease temperatures, in an effort to offset global warming resulting from human emissions [Schneider, 2008; Weart, 2008, Goss Levi, 2008]. Some options with the latter aim will be discussed here. Most of these ideas are based on increasing the Earth's albedo (reflectivity), which causes less sunlight to strike the Earth's surface, thereby exerting a cooling effect. In order to maintain the cooling effect these options should be continuously operated.

6.3.1 SO_2 injection in the stratosphere

The possibility of influencing the global radiative balance by injecting sulphate aerosol in the stratosphere has received a lot of attention since Paul Crutzen's editorial essay in 2006 [Crutzen, 2006]. It is based on a similar effect as occurs after a strong volcanic eruption, which brings large amounts of SO_2 and sulphate aerosol into the stratosphere. These have a cooling effect by reflecting a fraction of the sunlight back into space. Stratospheric aerosol has a much longer lifetime (~years) than the same aerosol would have in the lower atmosphere (~weeks). This means that in the stratosphere much less material is needed to achieve the same radiative effect. The aerosol would become relatively well mixed during its lifetime.

The analogy with the effects of volcanic eruptions gives scientists a head-start in understanding the potential (desired and undesired) effects. This scheme has received the most attention from scientists thus far. In particular, the resulting stratospheric warming (due to local scattering and absorption could lead to a complex set of changes in atmospheric dynamics (e.g. strengthening of the polar vortex). Stratospheric ozone loss could be enhanced [Robock, 2008]. High latitudes could actually end up warming in winter as a consequence of the extra stratospheric aerosol [Kenzelmann, 2007]. Since one of the main risks that are to be averted by such schemes is the loss of polar ice, this would be a very problematic side effect.

6.3.2 Cloud seeding of the marine boundary layer

John Latham (1990) proposed the idea to seed marine clouds with sea salt aerosol in order to increase their reflectivity. By intentionally increasing the number of sea salt particles, the clouds that form will exist of more, and thus smaller, cloud droplets. The resulting clouds reflect light more effectively than unperturbed clouds with less and bigger droplets (first indirect effect). These clouds may also exist longer because drizzle formation is suppressed (second indirect effect). The effects are greatest in areas with little aerosol present, but with a high cloud occurrence. Examples of such areas are east of South America, East of Southern Africa and East of the United States. The idea is not to form new clouds, but to make naturally occurring clouds more reflective. Bower et al. (2006) used a simple model, mimicking marine stratocumulus clouds, to assess the validity of the scheme and perform sensitivity analyses. Their theoretical calculations provide support for the physical viability of the albedo enhancement.

A map of the expected effect on radiative forcing (*ΔF*) from increasing the number of aerosol particles (*N*) to 375 cm^{-3} is shown in Figure 6.2 (from Latham et al., 2008). Areas with persistent marine stratocumulus clouds and low a background aerosol concentration exhibit a relatively large radiative forcing. The difference in aerosol concentration between the control simulation and the fixed value of 375 cm^{-3} is typically larger in the Southern hemisphere compared to the Northern hemisphere. In Northern latitudes with persistent cloud cover (e.g. Northwest of Scandinavia) the aerosol concentration would need to be increased to larger values to achieve a comparable radiative forcing as in many regions of the Southern hemisphere.

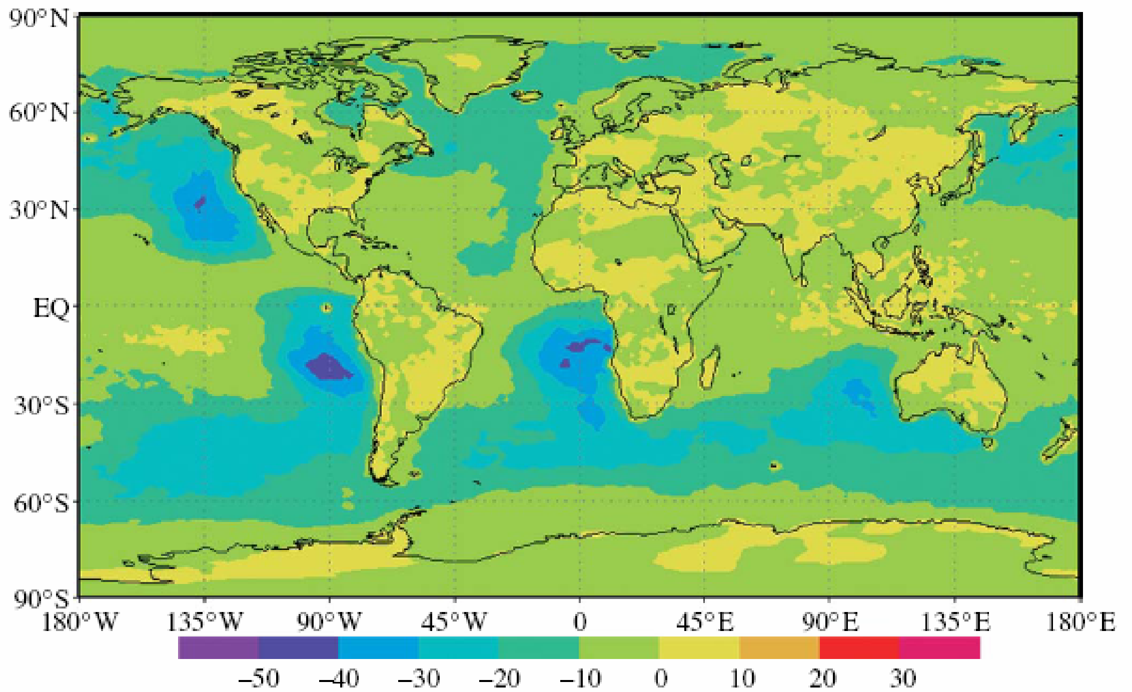

Figure 6.2 *Three-year mean difference in radiative forcing (W m^{-2}) between the control simulation and that in which the number of aerosol particles is fixed at 375 cm^{-3} in regions of low-level maritime cloud. From Latham et al. (2008)*

The effect on the radiative forcing of spraying sea salt aerosol to brighten existing clouds shows a dimishing return as the spray rate is increased; this can be clearly seen in Figure 6.3. This is mainly due to the fact that with increasing aerosol concentration, a smaller fraction of particles will activate into cloud droplets. The steep rise of this 'response curve', combined with the immediacy of the effect, make this (and similar) option(s) very suitable when faced with climate emergencies. Lenton and Vaughan [2009] charged that Bower et al. [2006] and Latham et al. [2008] underestimated the albedo change required to provide a given radiative forcing.

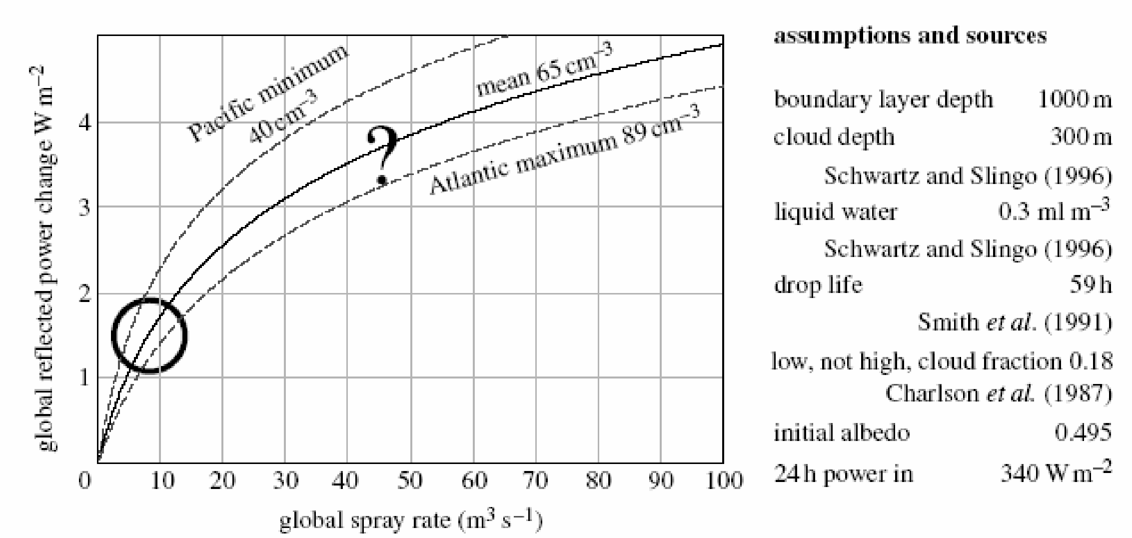

Figure 6.3 *Global cooling as a function of spray rate for the assumptions in the right-hand side table, non-intelligent spraying and the range of initial nuclei concentration suggested by Bennartz (2007). The circle shows warming since the start of the industrial revolution. It could be reversed by spraying approximately 10 m^3 s^{-1}. The question mark is a guess for the effect of twice pre-industrial CO2. From Salter et al., (2008)*

This scheme has the advantage that it is based on increasing the amounts of a natural, benign substance: sea salt. This does not necessarily mean that it has no side effects, but they are -at first sight- expected to be relatively minor compared to other, more invasive schemes. This could prove an advantage in terms of public acceptance, should it be proposed to be put in practice at a large scale. Side effects are mainly dynamical in nature (due to the albedo enhancement) and the regional changes in radiative forcing are expected to invoke other regional changes (e.g. even stronger land-sea temperature gradients).

Since Latham first proposed the idea, a limited number of other researchers have investigated this scheme. Salter et al. (2008) developed an idea for the engineering hardware needed to employ this scheme at a global scale. It is based on unmanned wind-driven spray vessels. Sea water is filtered and lead to micro-nozzles with piezoelectric excitation to produce small droplets. Upon evaporation in ambient air they leave a microscopic sea salt particle behind. In this design, the energy needed would be supplied by Flettner rotors, in which the wind movement (relative to the ship) is translated into a lift force by the vertical spinning motion of large cylinders, making use of the so called Magnus effect. Salter et al. (2008) report on two Flettner-ships having sailed over the oceans in the 1920s. No reasons for its discontinued use (besides the economic depression in the thirties) are given. Even though this technology may work in principle and is backed up by theory, it is in need of thorough investigation to verify the claims made, especially since large amounts of energy are required to generate enough sea spray. Salter et al. (2008) do not discuss quantitative details regarding the energy needed and how this is provided for. However, the technique can be readily shown to be energy efficient, in the sense that the amount of solar energy reflected is expected to be orders of magnitude larger than the energy needed for spray production, assuming commercially available spray generation techniques. This scheme is also amongst the cheaper of the options discussed in this chapter, though a precise cost estimate can not be provided at this stage.

6.3.3 Cloud seeding of cirrus clouds

Another geo-engineering scheme that has very recently been proposed is based on the modification of cirrus clouds [Mitchell and Rasch, 2008]. Cirrus clouds only scatter a small fraction of solar radiation back into space, but are very effective at trapping longwave radiation coming from the Earth' surface, in a similar manner as greenhouse gases do. Thus, on average and in contrast to low clouds, cirrus clouds cause warming of the atmosphere. By adding ice nuclei to the upper troposphere where cirrus clouds form, the expectation is that bigger ice crystals would be formed, leading to a quicker disintegration of the clouds as a consequence of their higher fall speed. This scheme is thus not based on enhancing the Earth's albedo, but rather on decreasing the greenhouse effect of high cirrus clouds by decreasing their lifetime and spatial coverage.

Delivery of the seeding substance to the upper troposphere may be achieved by commercial airplanes. This idea has not yet been thoroughly investigated, but the principles involved make it a worthwhile option to be further explored. The fuel consumption of the planes should be taken into account. However, the role of ice in cloud processes is extremely poorly understood, so this scheme starts with a delay compared to the others described.

6.4 Implications for mitigation and adaptation

Air capture and artificial cooling schemes make it possible to dampen the increase in greenhouse gas concentration and temperature rise, respectively, independent of emission reduction and adaptation policies. These four classes of measures to respond to the threat of climate change, as identified in Table 6.1, are not mutually exclusive, but each of them lowers the necessity for the other measures to be implemented: For example, if the expected greenhouse warming is cancelled by controlled aerosol cooling, less and/or different adaptation measures are required.

Adaptation depends strongly on the local climate, and even with a near-perfect cancellation of global temperature by means of artificial cooling, the local climate will likely change (see also 6.4.1). Society will have to adapt to those changes. Regional climate change due to the increased concentration of greenhouse gases is inherently uncertain, and the regional consequences of artificial cooling schemes even more so, as much less research effort has gone in that direction. Prevention of disastrous sea level rise is likely to be one of the main reasons to employ artificial cooling schemes. Sea level rise would require strong adaptation measures, which could perhaps be omitted if such a rise can indeed be prevented from happening. However, changing land-sea temperature gradients and changing precipitation patterns may still require adaptation measures.

6.4.1 Potential consequences of geoengineering

Air capture techniques are meant to remove part of the CO_2 from the atmosphere, and as such deal with one of the primary causes of current climate change, without creating other climate effects. Depending on the technique, there are effects on landscape, environment (e.g. from mining) and ecology (e.g. biomass sequestration) that will have to be addressed. Many options under consideration are close to the break-even point for energy consumption versus CO_2 capture, rendering them not yet useful in combatting climate change. Once this break-even point will be significantly surpassed, these options may offer great potential. However, local environmental degradation may have to be balanced with desired global effects on climate, creating a challenge for decision making (e.g. the 'nimby' effect).

Artificial cooling schemes are meant to cancel part of the warming, but leave the greenhouse gas forcing as it is. There are for the most part no direct effects on landscape or the environment, but side effects on climate are to be expected. Any Artificial cooling scheme, and air capture to a lesser extent, will have the following consequences/challenges that will have to be addressed before implementation:

- Side effects
- Geopolitics
- Effect on mitigation efforts
- Rebound effect (only albedo enhancement schemes)

Side effects

Large scale intervention in the global climate will cause side effects, not all of which are known, or even knowable [Schneider, 2008]. Besides research into the desired effects of such interventions, potential side effects should also be thoroughly investigated. Albedo enhancement schemes share at least one side effect: Balancing the temperature by decreasing the incident solar radiation will reduce global average precipitation [Robock, 2008]. Land and ocean will not likely cool at the same rate, causing changes in atmospheric circulation and changes in regional climate, irrespective of a stable global mean temperature. Ocean acidification due to enhanced dissolution of CO_2 is not halted by artificial cooling schemes. Even though the amount of solar radiation incident on the Earth only changes by 1-2% in the case of full scale deployment, the amount of direct (as opposed to indirect or diffuse) radiation decreases much more (on the order of 10%), which results in solar energy production becoming much less efficient.

Caldeira (2008) writes: "Geoengineering schemes that have been proposed heretofore are unlikely to perfectly reverse both hydrological and temperature effects of greenhouse gases. However, initial simulations suggest that a high-CO_2 world with geoengineering is likely to be closer to the pre-industrial world than a high-CO_2 world without geoengineering. Of course, the Earth is much more complicated than our models, so if geoengineering schemes are implemented, we should expect some perhaps ugly surprises."

Geopolitics and governance

If the climate can be wilfully controlled, as these schemes propose to a certain extent, who will decide on what climate to aim for? Is there a chance to reach global consensus on the desired climate? Early interventions in local weather, e.g. cloud seeding to provoke precipitation, quickly caused arguments between groups with different objectives regarding their desired weather [Weart, 2008]. In light of the difficulty in International climate negotiations, the hurdles in the decision-making process regarding the optimal global climate seem formidable [Schneider, 2008]. This is further complicated by the long time frames involved: If the rise in atmospheric greenhouse gas concentrations is not halted soon, then Artificial cooling schemes may need to be employed for hundreds of years[9] in order to keep a relatively stable climate.

Effect on mitigation efforts

The incentive for mitigation measures may be decreased by the prospect of being able to either capture the CO_2 or cancel (part of) the consequences [Robock, 2008; Keith et al., 2006]. As Parson (2006) puts it: "In a dynamic optimization framework, improving future options usually reduces the desirability of near-term mitigation efforts." And knowing that these options (may) exist (in the future) will "reduce the political pressure for near-term efforts, by providing well-

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[9] The average lifetime of CO_2 in the air is ~200 years, though about 20% remains in the atmosphere for millennia (Archer).

founded supporting arguments for those who oppose near-term efforts to any degree and for any reason.” [10]

Conversely, mitigation efforts may be reinvigorated if the general public and policymakers become aware of the desperate measures scientists are exploring. The eventual effect of geoengineering on mitigation efforts will depend, amongst others, on the decision making process and on market forces: What are the relative costs and benefits of emission reduction versus an equivalent amount of provoked cooling or air capture? Besides financially, “costs and benefits” should of course also be addressed in terms of climate effects.

Rebound effect
If for any reason (war, economic depression, etc) the artificial cooling is suddenly stopped, conditions will return to what they would have been without the aerosol-induced cooling. In that case, the full force of the warming that was masked by the engineered cooling will manifest itself within a very short timeframe. Thus, employing geoengineering schemes with continued greenhouse gas emissions could lead to severe risks for the global climate system [Matthews and Caldeira, 2007].

6.4.2 Framing the technology

Because of the above mentioned consequences of large scale climate intervention, the employment of such technology should not be decided upon lightly. However, in light of the potentially serious consequences of climate change (e.g. melting of the polar ice caps and subsequent sea level rise), society may at some point benefit from the availability of emergency measures. If mitigation efforts fail to keep the climate within safe limits, the risks of geoengineering should be compared to the risks of greenhouse gas-induced climate change. The artificial cooling schemes, once implemented, will have an almost immediate effect on the climate. Thus, deployment could be delayed until ‘dangerous’ climate change is imminent.

It is important, however, to have thoroughly investigated the mechanisms and consequences of the emergency strategy well before the societal pressure for implementation increases. This is needed in order to be able to effectively curtail the dangerous consequences of global warming, once needed, and to avoid, as much as possible, that the cure is worse than the disease. The right panel of Figure 6.4 (reproduced from Keith, 2009) shows schematically how artificial cooling could be implemented as an emergency measure. The left panel shows the scenario where it is used as a substitute for mitigation, thereby allowing the risks mentioned above to grow without bound.

The timing of eventual deployment is crucial: Too early causes unnecessary side effects, whereas too late may render the changes that are going on practically irreversible. Hence, detailed knowledge of the broader climate system is required, especially about the response of the large ice sheets. This is an area where detailed knowledge is still lacking, but where non-linear response is expected to be particularly strong, and where some changes may be practically irreversible [Hansen et al., 2008].

[10] Although mitigation and geoengineering schemes are not mutually exclusive, there are strong voices (e.g. in conservative lobby groups, but also in high level government positions such as the US EPA) that favor geoengineering *instead of* -rather than *in addition to*- mitigation: “To the skeptic, geoengineering offers a relatively painless, relatively cheap alternative to costly and unpopular regulation.” (www.metatronics.net/lit/geo2.html) “Imagine no restrictions on fossil-fuel usage and no global warming!” (Los Alamos National Laboratory press release)

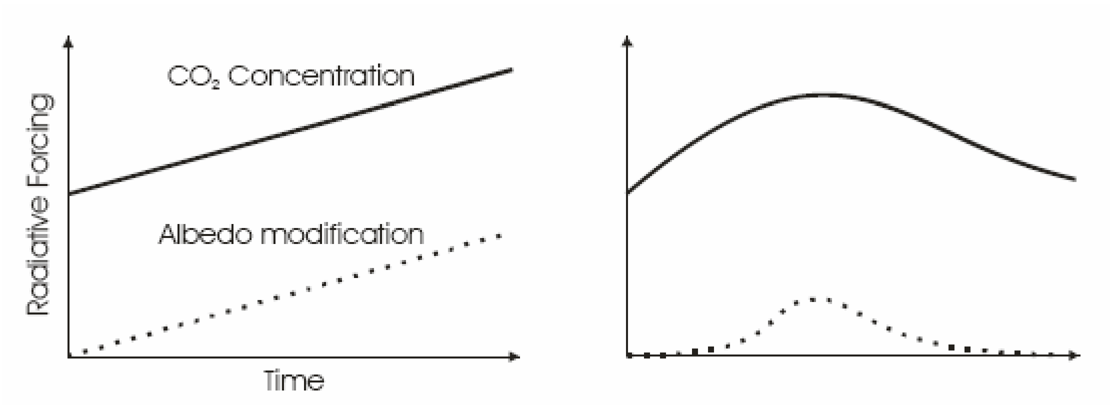

Figure 6.4 *Schematic illustration of the distinction between geoengineering as a substitute for mitigation (left panel) and geoengineering as a supplement to mitigation used as a means to reduce the risks of climate change during period of the peak radiative forcing (right panel).(from Keith, 2009)*

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7. Conclusions and suggestions for further research

The main conclusion of this report is that there are enough mitigation measures (energy conservation, energy production and carbon capture and storage) with sufficient potential to limit climate change. A world wide energy system with no or even negative emissions is technically possible using a combination of options. The challenge will be to implement them sufficiently fast. Some rather new, but important mitigation options and discussions are highlighted:

- the biomass potential in the light of sustainability
- the new biomass potential from aquatic biomass
- the possibility of energy supply options with negative CO_2 emissions (biomass/CCS combination)
- multifunctional options
- air capture
- intentional cooling ('geoengineering')

The relation between mitigation and adaptation is complex and has many different aspects. A large number of mitigation and adaptation options will be competing for land use (for example retention areas and biomass production). Land availability and the 'one-function only' responsibility of organizations seem to be limiting factors for large scale and fast implementation, especially in densely populated and regulated areas. Therefore a new approach for multi-functional land use with shared responsibility of stakeholders and integration of functions should be developed.

Good examples of an integrated and multi-functional approach are:

- Large scale implementation of green roofs in the built environment for peak shaving and retention of extreme rain fall in combination with insulation, noise reduction, improvement of air quality and a local cooling effect.
- Covered highways in combination with solar panels, wind energy, biomass production, noise reduction, improved air quality, higher traffic safety and lower fuel consumption.
- Water retention areas in combination with nature development, biomass production, aquaculture, wind energy and tourism.

Most large mitigation options have limited direct influence on adaptation. On the other hand there are positive integration possibilities between adaptation and a number of mitigation options. Examples of these are:

- biomass and water management
- infrastructure (roads, dikes, waterways, railways, etc.) and wind or solar energy
- energy conservation and building construction
- water management in the built environment and building construction

The main relation between mitigation and adaptation is the effect of mitigation on climate change. Due to the slow implementation of mitigation measures and due to the inertia of the climate system, climate change will happen and adaptation is necessary. Apart from emission reduction, it seems possible to limit the amount of climate change with certain measures such as GHG capture from the air and albedo enhancement. The state of the art for both options is presented. Albedo enhancement by aerosols, such as sea salt or stratospheric sulphate, seems to be a possibility to limit climate change in an affordable way, but still needs further investigation, both into its intended and unintended effects. These kinds of options could play an important role in designing adaptation strategies.

Biomass
Biomass is an important renewable energy option that can be used for the production of heat, power and transport fuels, as well as (source for) biomaterials (bioreferinery). At present, 10% of the global energy demand is provided by biomass. Production and use of biomass, especially for biofuels, are growing at a very rapid pace and it is estimated that it would continue to grow, although the future role of bio energy depends on its competitiveness with other renewable energy options and with fossil fuels, and also on agricultural policies worldwide.

Enhancing bio energy globally could help in both combating climate change and improving the security of energy supply, though the former depends on a number of compounding factors, such as agricultural practices and alternative land use. Therefore, well-established certification schemes need to be in use internationally to secure sustainable production of biomass and biofuel, because of the possible negative environmental effects during its production, processing and application.

The maximum potential use of biomass energy is estimated around 30% of the global energy demand by 2030. It should be kept in mind that estimates of the biomass potential vary over a wide range, since a major part of the future biomass resource availability for energy depends on complex and related factors, e.g. land availability which is linked to the growing demand for food, on environmental protection, sustainable management of soils and water reserves and a number of other sustainability requirements. In principle the economic biomass resource potential seems very large on a global scale. However, only a part of this potential will be available because it has to meet a wide variety of sustainability criteria. A new promising form of biomass production is offered by aquatic biomass both on land and at sea.

The greenhouse gas emissions from agricultural activities consist for a large fraction of CH_4 and N_2O. Especially the uncertainty in N_2O emissions is hampering a reliable evaluation. A large contribution to greenhouse gas emission reduction can be made by lowering the N_2O emission caused by the use of fertilizer (for instance by stimulating organic agriculture). A large contribution could also be made by increasing the amount of carbon stored in the soil, which is however difficult to evaluate and thus difficult to control.

Suggestions for further research:

- Mitigation options are normally researched and implemented on a non integral basis. In this way a number of options that seems to be too costly or too small, is not researched. An integral look at options in a framework wider than mitigation alone could proof otherwise. Infrastructure development and water management (for adaptation) can offer attractive opportunities for extra mitigation.
- Mitigation options on cooling and heating are directly influenced by climate change and can be an integral part of an adaptation strategy. The consequences on optimal spatial planning above and under the ground need to be examined.
- Adaptation strategies often include new infrastructure or new water management. Combination with mitigation options can be attractive in these cases. Research could highlight promising combinations in these areas.
- The possible shift in agriculture towards aquaculture could create good opportunities for more flexible water management. This subject is not covered in the research programs that are developed at this time.
- In mitigation research there is little attention for scenarios with a higher implementation speed. For the design of adaptation strategies (and for the greenhouse gas stabilization level and thus for maximum temperature reached) it is important to know how fast reductions can be reached and under which conditions. This knowledge is also crucial in the case of climate emergencies, such as increased melt of the polar ice cap.
- Methods to offset the main characteristics of global climate change, for instance with sea salt or sulphate aerosol, need to be more thoroughly researched. The level of adaptation

needed could be limited and made more manageable by using such options to dampen the temperature overshoot, if it is beyond certain boundaries. These options are likely amongst the fastest in terms of reducing climate change, which makes them very relevant in a climate emergency scenario. However, possible side effects of these options need to be investigated, as well as costs and management procedures before it can play any role in a climate response strategy.

- Apart from the adaptation agenda it is necessary to strengthen the research on sustainable biomass production. Biomass could be an important option for energy production and climate mitigation. The amount of biomass needed will put the current potentials under high pressure.
- The total greenhouse gas balance of biomass energy should receive more attention, specifically including indirect emissions relating to the change in land use and resulting change in carbon storage, and agricultural practices.
- The relation between the use of fertilizer in agriculture and the emission of N_2O is still a point of discussion, due to the lack of accurate measurements and due to the large variability stemming from the strong dependencies on several factors, often related to farming practices. As N_2O emissions play an important role in the determination of the overall greenhouse gas emission balance of biomass this issue should be addressed in the short term.
- Methods to increase the amount of carbon fixation in soil, e.g. through the use of alternative farming practices or the application of biochar, should be thoroughly investigated.
- The effect of transforming agricultural land into (or using it for) water retention areas on carbon storage and nutrient behaviour is not well known.
- Multifunctional use of space can be an attractive and cost effective approach for combining different mitigation options in relation with adaptation measures. A number of pilot-projects should be started in the short term and used for monitoring and optimisation.
- The potential of aquatic biomass should be investigated, e.g. by starting with pilot off-shore and near-shore cultivation projects for seaweed to assess technical constraints and economic and ecologic impact.
- Investigating the overall greenhouse gas emission of biodiesel production with micro-algae.
- It is recommended to perform a study to the potential and costs of the combination biomass and CCS for the Netherlands, which could provide insight into how the (scarce) biomass can be utilized most efficiently in terms of costs per ton of CO_2 reduction.