Business from technology

Future of bioenergy, scenarios and challenges

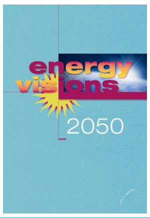
Lecture 13.8.2012
JSS Course RE2: Optimization of Bioenergy Use

Ilkka Savolainen
Research Professor
VTT Technical Research Centre of Finland

Grand challenges of global energy (1)

Demographic change

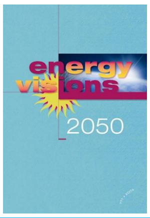
- Growing population
    - The world population is growing from present 7 billions to 9 billions by 2050 mainly due to increase in developing countries
    - The population of present developed countries is roughly constant (about 1 billion)
    - Some countries have decreasing population: Japan, Russia (Population of USA is increasing)
- Ageing
    - Structure of population is getting older, the share of young people is decreasing and the share of old people is increasing
- Urbanization
    - Half of world population live already in cities
- Access to energy for all
    - Still 1.5 billion people have no access to modern energy services (contradiction with Millenium Development Goals)



Grand challenges of global energy (2)

Economic change
- Globalization: Mobility of knowledge, capital and goods between countries, the development of information technologies contributes
- Trade flows increase strongly
- Strongly growing economic output especially in rising developing countries (China, India, Brazil etc.)
- Consumption expectations of new large middle class in developing countries create large demands for products and services
- Relative economic weight of USA, Europe and Japan will decrease

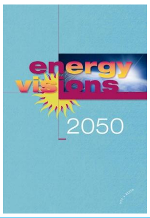
- Reliability of energy supply is a necessity



Grand challenges of global energy (3)

Growing energy demand under
- Limited and concentrated energy resources => Energy security is crucial
  - Oil reserves are very limited and concentrated
  - Gas reserves are somewhat larges but limited
  - Coal reserves large
- Strict ghg emission reductions
  - increase low emission electricity demand
- Also other environmental constraints

- Non-OECD countries have the fastest growing market with new innovative solutions



Challengies in energy systems and economies

Halt global warming
- Great inertia in natural and anthropogenic systems

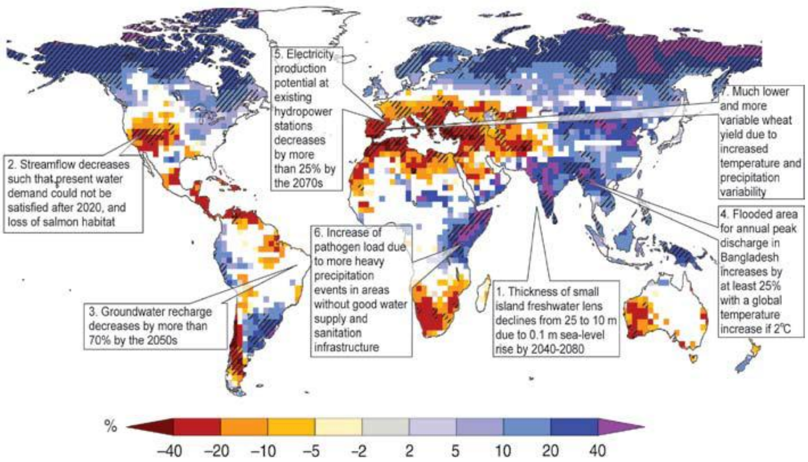
Reduce health effects due to air pollutants
- Inertia in anthropogenic systems

Reduce energy poverty
- Globally, about 1.5 billion people are without modern energy services.

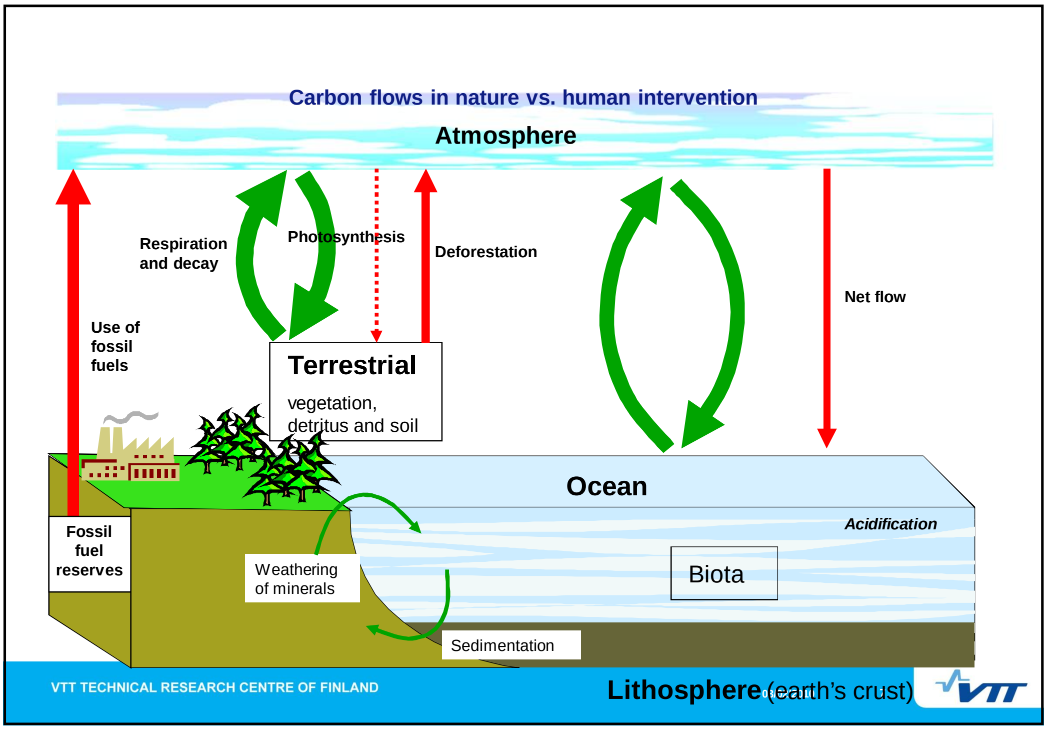
Improve energy security
- Expected rise and fluctuations in oil price
- Renewable energy, e.g. biomass, can be used to ruduce the dependency of imported energy (and create jobs in rural areas)

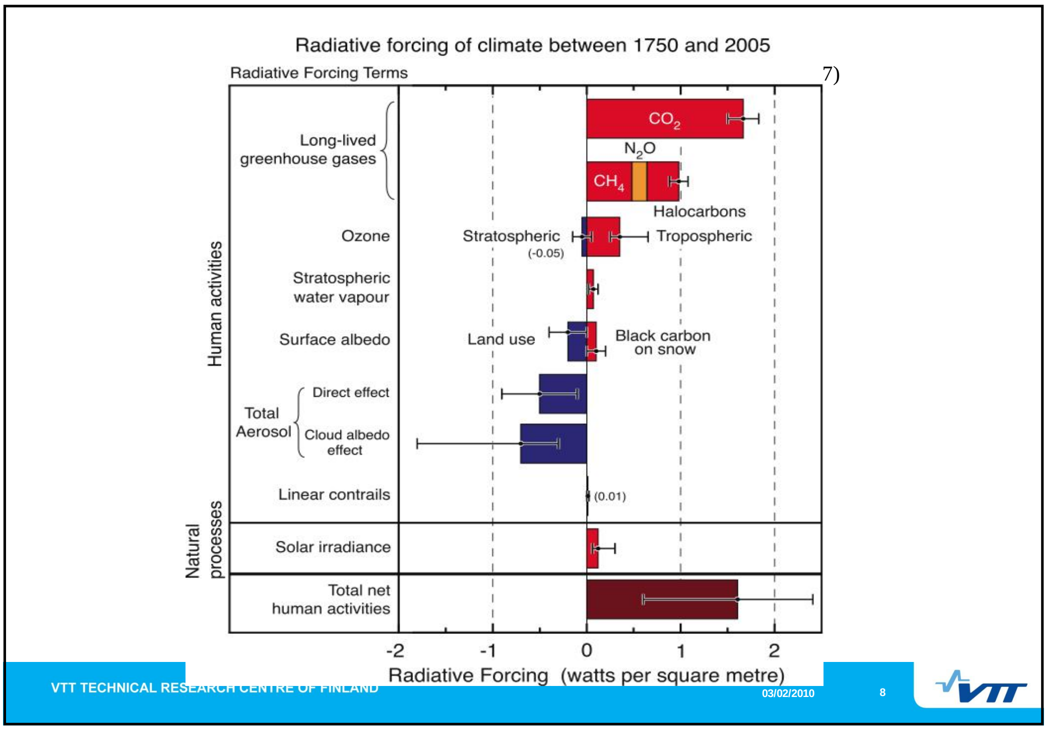
Natural systems (carbon cycle, heat capacity of oceans)
Anthropogenic systems (investments, infrastructure, governance, behaviour; growing population and economy)

Combined strategies could be beneficial?

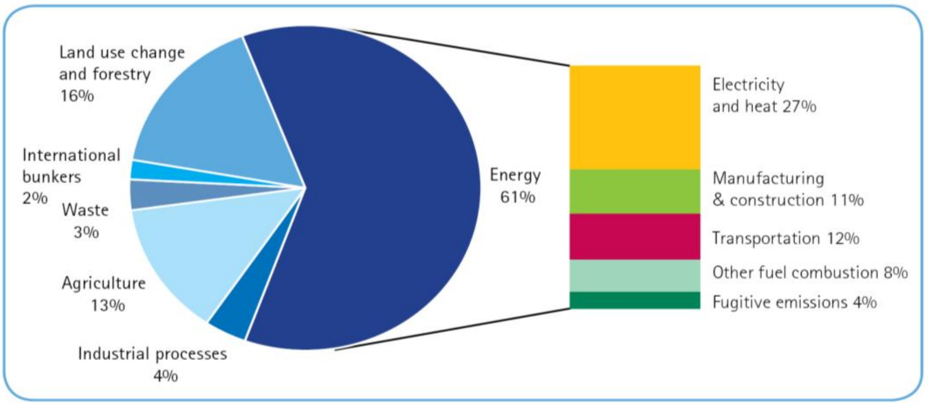


Illustrative map of future **climate change impacts related to freshwater** which threaten the sustainable development of the affected regions. Ensemble mean change in annual runoff (%) between present (1980–1999) and 2090–2099 for the SRES A1B emissions scenario. Areas with blue (red) colours indicate the increase (decrease) of annual runoff. (Bates et al. 2008.)


Carbon flows in nature vs. human intervention
Atmosphere
Respiration and decay
Photosynthesis
Deforestation
Net flow
Use of fossil fuels
Terrestrial
vegetation, detritus and soil
Ocean
Acidification
Biota
Fossil fuel reserves
Weathering of minerals
Sedimentation
Lithosphere (earth's crust)
VTT TECHNICAL RESEARCH CENTRE OF FINLAND

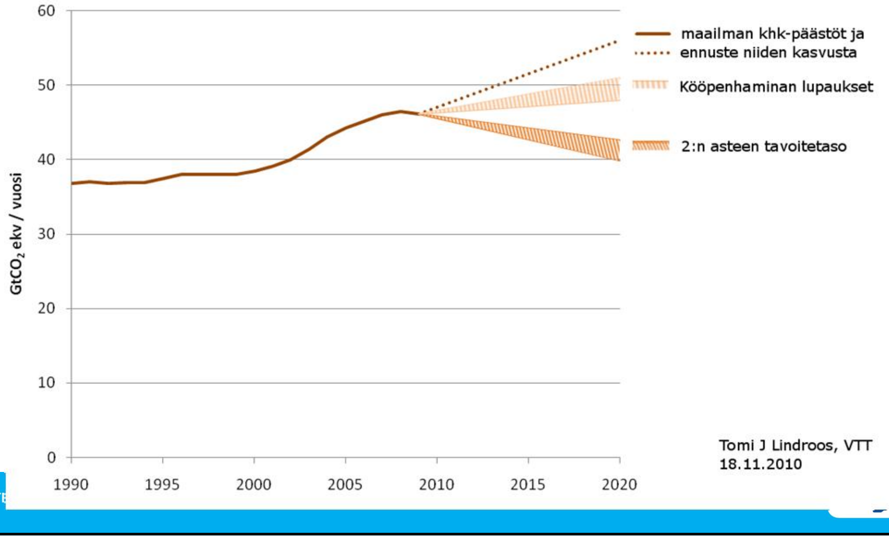

Radiative forcing of climate between 1750 and 2005
Radiative Forcing Terms
7)
Human activities
Long-lived greenhouse gases
CO_2
N_2O
CH_4
Halocarbons
Ozone
Stratospheric
(-0.05)
Tropospheric
Stratospheric water vapour
Surface albedo
Land use
Black carbon on snow
Total Aerosol
Direct effect
Cloud albedo effect
Linear contrails
(0.01)
Natural processes
Solar irradiance
Total net human activities
-2
-1
0
1
2
Radiative Forcing (watts per square metre)
VTT TECHNICAL RESEARCH CENTRE OF FINLAND
03/02/2010
8

Global greenhouse gas emissions by sectors in 2005

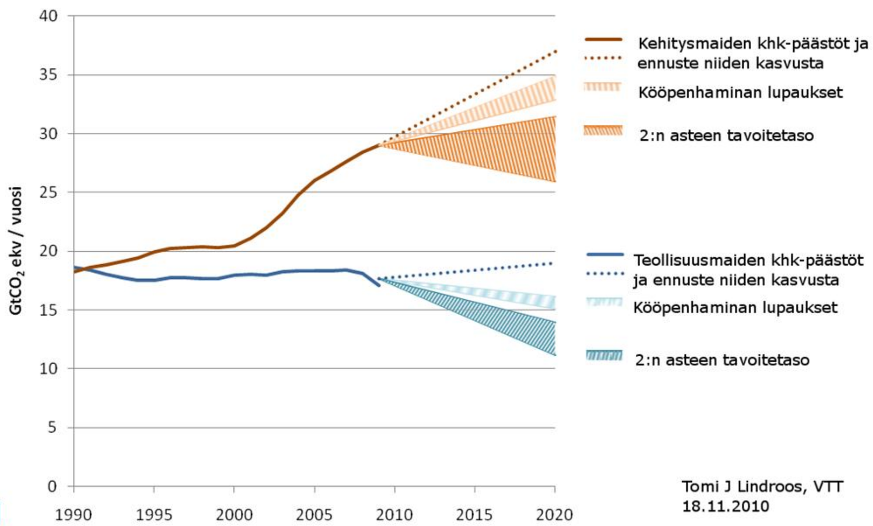


The emissions sum up to approximately 46,000 $MtCO_2eq$.
*Data source: CAIT, cait.wri.org. *) The estimated effect of land use change & forestry, 8,000 $MtCO_2$, is for the year 2000.*

Global GHG emissions, Pledges of the Copenhagen Accord, and the Path to 2 C warming until 2020

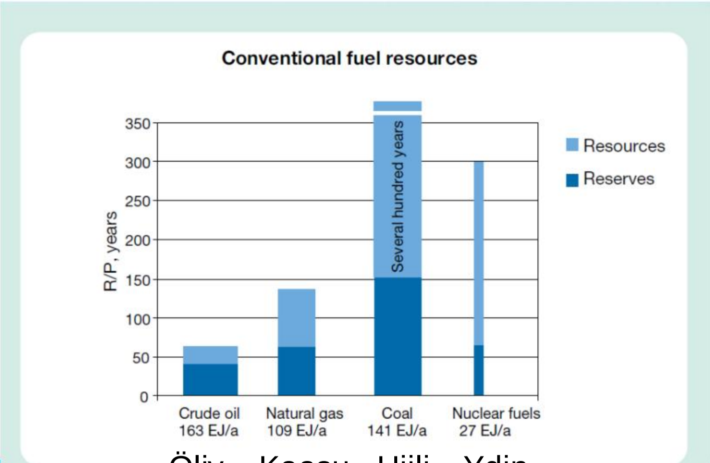


Previous figure but for Annex I ja non-Annex I country groups



Tomi J Lindroos, VTT
18.11.2010

Conventional oil and gas reserves are quite limited, coal and uranium resources are much larger



Öljy Kaasu Hiili Ydin

Polttoainevarojen riittävyys nykyisellä kulutuksella.

Pylvään leveys kuvaa nykyistä kulutusta ja pinta-ala varan suuruutta energiana.

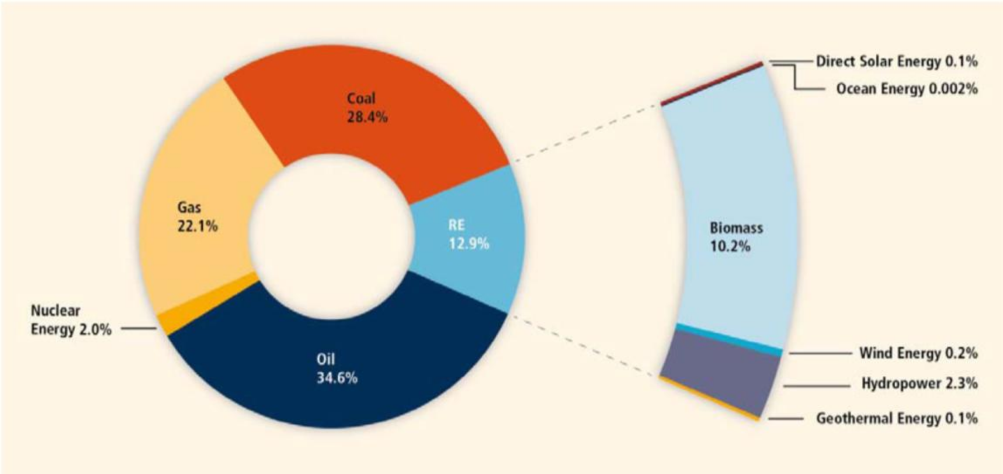
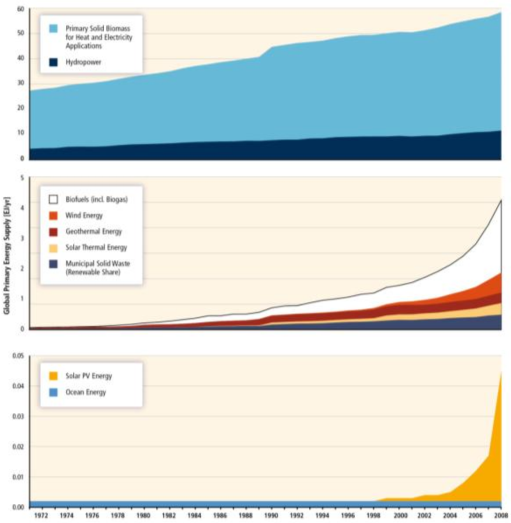


Figure SPM.2 | Shares of energy sources in total global primary energy supply in 2008 (492 EJ). Modern biomass contributes 38% of the total biomass share. [Figure 1.10, 1.1.5]

(IPCC SRREN 2011)

RE growth has been increasing rapidly in recent years.



140 GW of new RE power plant capacity was built in 2008-2009.

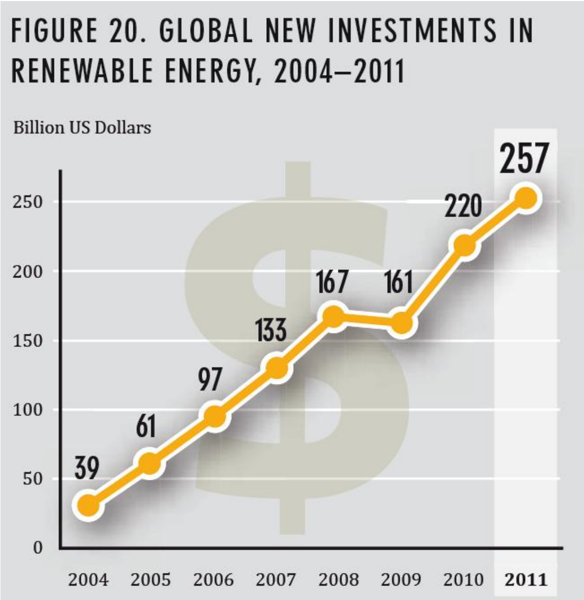
This equals 47% of all power plants built during that period.

(IPCC SRREN 2011)

REN21
Renewable Energy Policy Network for the 21th century

Rapid growth in investments to renewable energy
Total increase of the global new power capacity in 2011 was 208 GW, about half of it was renewable (100 GW)
share of wind was 40%
solar PV 30%
hydro 25

In 2011 renewable sources supplied 20.3% of global electricity.



(REN21, 2012)

TABLE 1. ESTIMATED JOBS IN RENEWABLE ENERGY WORLDWIDE, BY INDUSTRY

(REN21, 2012)

TECHNOLOGIES	Global	China	India	Brazil	USA	EU[7]	Germany	Spain	Others
	Thousand jobs								
Biomass[1]	750	266	58		152	273	51	14	2[8]
Biofuels	1,500			889[6]	47–160	151	23	2	194[9]
Biogas	230	90	85			53	51	1.4	
Geothermal[1]	90				10	53	14	0.6	
Hydropower (Small[2])	40		12		8	16	7	1.6	1[8]
Solar PV	820[4]	300[5]	112		82	268	111	28	60[10]
CSP	40				9		2	24	
Solar Heating/ Cooling	900	800	41		9	50	12	10	1[8]
Wind Power	670[4]	150	42	14	75	253	101	55	33[11]
Total[3]	**5,000**	**1,606**	**350**	**889**	**392-505**	**1,117**	**372**	**137**	**291**

VTT TECHNICAL RESEARCH CENTRE OF FINLAND 03/02/2010 17

(REN21; 2012)

Selected indicators

		2009	→	2010	→	2011
Investment in new renewable capacity (annual)[1]	billion USD	161	→	220	→	257
Renewable power capacity (total, not including hydro)	GW	250	→	315	→	390
Renewable power capacity (total, including hydro)[2]	GW	1,170	→	1,260	→	1,360
Hydropower capacity (total)[2]	GW	915	→	945	→	970
Solar PV capacity (total)	GW	23	→	40	→	70
Concentrating solar thermal power (total)	GW	0.7	→	1.3	→	1.8
Wind power capacity (total)	GW	159	→	198	→	238
Solar hot water/heat capacity (total)[3]	GW_{th}	153	→	182	→	232
Ethanol production (annual)	billion litres	73.1	→	86.5	→	86.1
Biodiesel production (annual)	billion litres	17.8	→	18.5	→	21.4
Countries with policy targets	#	89	→	109	→	118
States/provinces/countries with feed-in policies[4]	#	82	→	86	→	92
States/provinces/countries with RPS/quota policies[4]	#	66	→	69	→	71
States/provinces/countries with biofuels mandates[5]	#	57	→	71	→	72

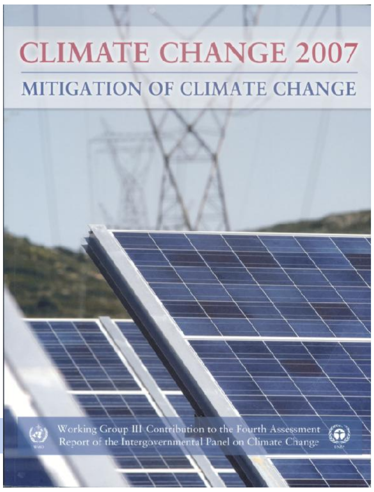
VTT TECHNICAL RESEARCH CENTRE OF FINLAND 03/02/2010 18

IPCC report (2007)

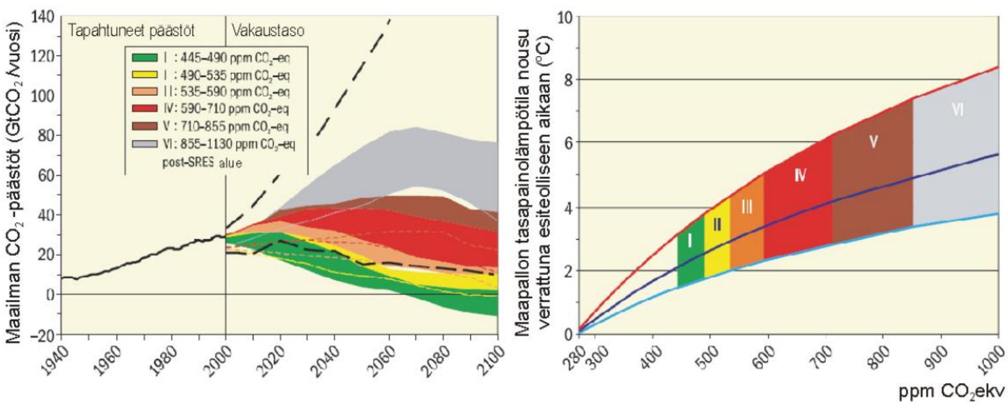
If the objective is to limit the temperature rise to 2ºC

- Global emissions should peak within ten years,
- Global emissions should be 50-85% lower than 2000 by 2050,
- Emissions from the developed countries should be 25-40% lower by 2020, 80-95% lower by 2050.

www.ipcc.ch



IPCC (2007) Stabilization Scenarios



Green area: In equilibrium a warming of about 2.0-2.4 C if the best estimate of climate sensitivity is used. Negative emission in the second half of the century.

Emission reduction options (1)

Energy efficiency improvements
Renewable energy
Carbon capture and storage (CCS)
Nuclear power
Increase of biospheric carbon sinks
Emission reduction concerning other sectors (waste, agriculture, industry) and other greenhouse gases (CH4, N2O and F-gases)
Changes in consumption behaviour

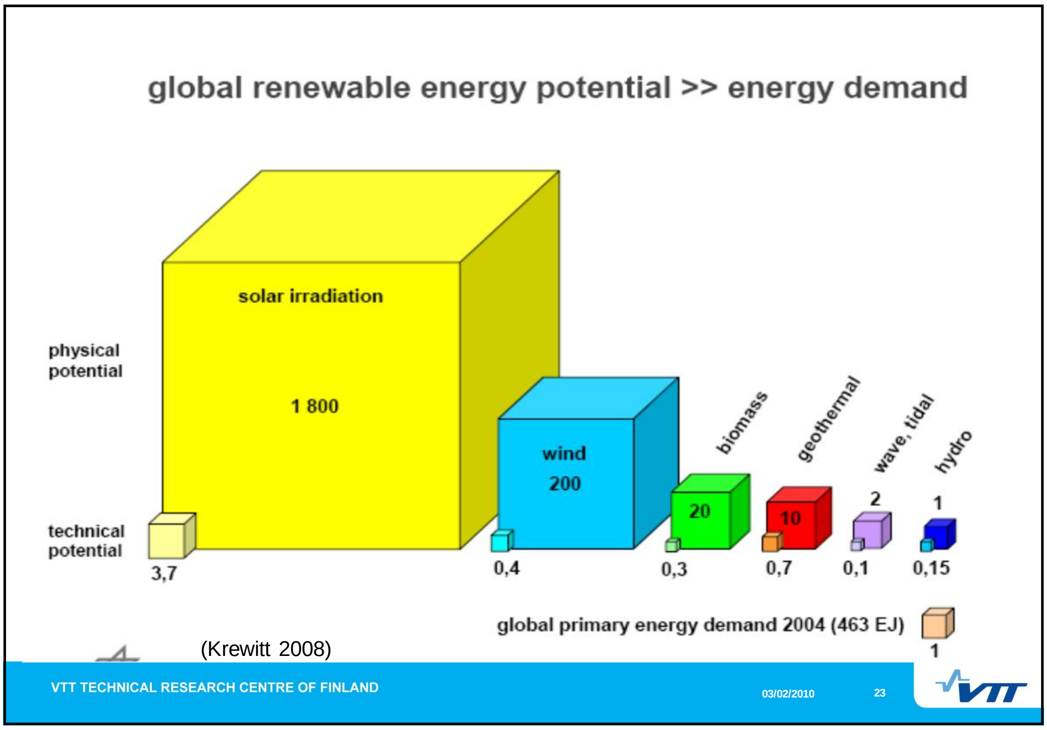
A wide palette of measures needed in order to reach deep enough emission reductions

Emission reduction options (2)

Negative emissions required after 2050?

Carbon sinks,
Biomass CCS,
others?

Should geoengineering belong to the selected palette of measures?
- Side effects of geoengineering alternatives?
- Governance?



Special Report on Renewable Energy Sources and Climate Change Mitigation

Introductory Chapter

1. Renewable Energy and Climate Change

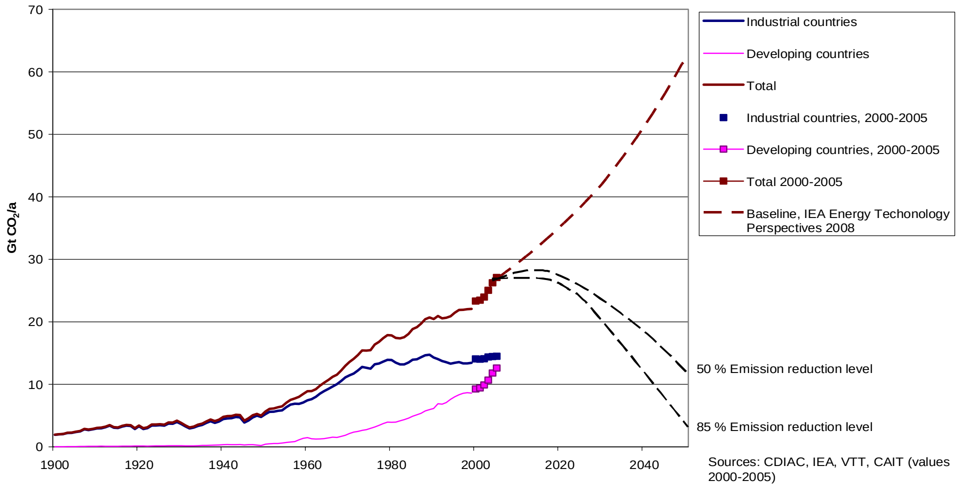
Technology Chapters

2. Bioenergy
3. Direct Solar Energy
4. Geothermal Energy
5. Hydropower
6. Ocean Energy
7. Wind Energy

Integrative Chapters

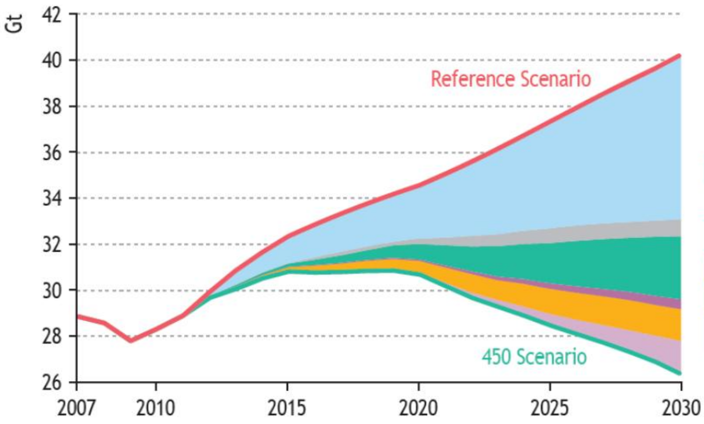
8. Integration of Renewable Energy into Present and Future Energy Systems
9. Renewable Energy in the Context of Sustainable Development
10. Mitigation Potential and Costs
11. Policy, Financing and Implementation

(IPCC SRREN 2011)



CO2-päästöt fossiilisista polttoaineista. Käyrät 50 ja 85 % vastaavat 2 asteen lämpötilan nousutavoitteen päästöjen ylä- ja alarajaa (IPCC 2007). EU:n uusin teollisuusmaita koskeva indikatiivinen tavoite on 80-95 % vähennys vuoteen 2050 mennessä.

Figure 5.8 ● World energy-related CO_2 emission savings by policy measure in the 450 Scenario



	Abatement ($Mt\ CO_2$) 2020	2030
Efficiency	2 517	7 880
End-use	2 284	7 145
Power plants	233	735
Renewables	680	2 741
Biofuels	57	429
Nuclear	493	1 380
CCS	102	1 410

WEO 2009

Binding targets 2020 for EU and Finland

- opens market for new technology investments ,
EU SET-Plan propose up to 60 B€ demonstration investments-

Low Carbon Europe:
- GHG reduction 20% by 2020
- Energy end use reduction 20%
- Share of renewable energy 7 => 20%
- Renewable energy in transport 10%
- (GHG reduction over 80% by 2050)

Low Carbon Finland by 2020
- GHG reduction 16% in the non-ETS sector by 2020
- Share of renewables 28,5 => 38%
- Renewable energy in transport 20%
- (GHG reduction 80 % by 2050)

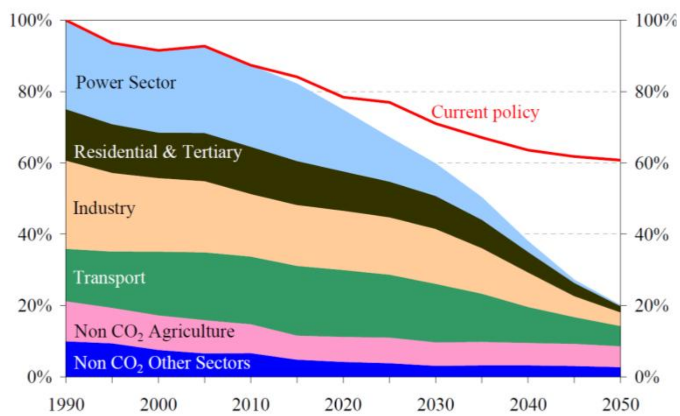
EU is considering to tighten the emission reductions to 30% by 2020

Structural change in energy system:
-Low carbon energy production
-Efficient use of energy industry, transport, and buildings
-Smart integration of production, use, and consumers

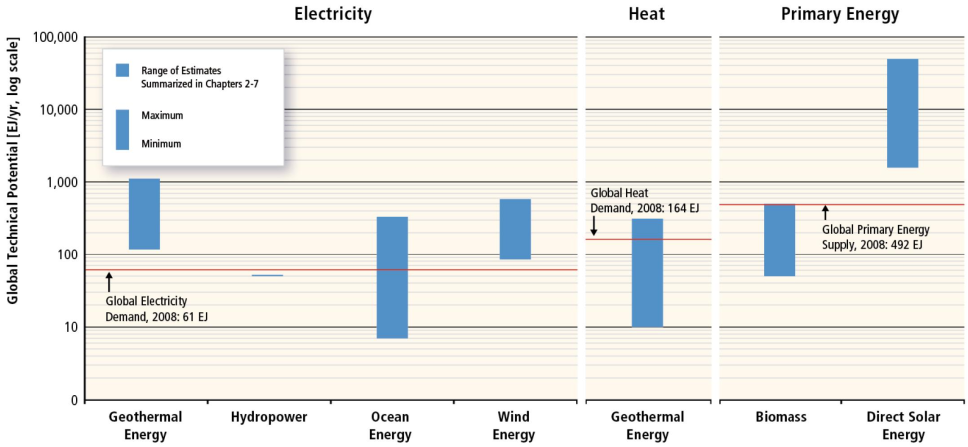
EU:n päästönvähennysten ”tiekartta”
EU Roadmap for ghg emissions reduction

Figure 1: EU GHG emissions towards an 80% domestic reduction (100% =1990)

Sähköntuotanto
Rakennukset ja palvelut
Teollisuus
Liikenne
Maatalous
Muut

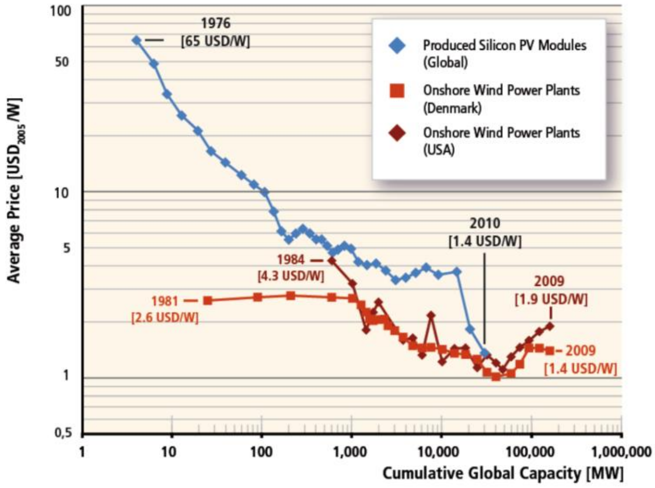


The technical potential of renewable energy technologies to supply energy services exceeds current demands.



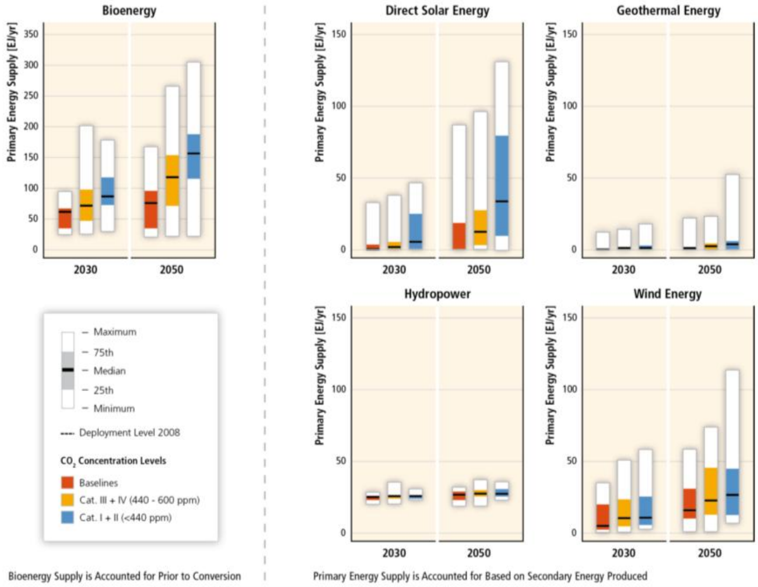
(IPCC 2011)

RE costs have declined in the past and further de can be expected in the future.

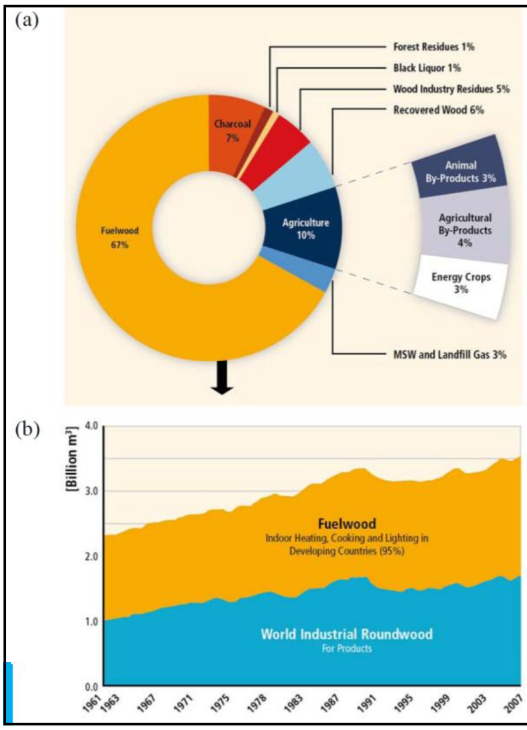


IPCC 2011

RE deployment increases in scenarios with lower greenhouse gas concentration stabilization levels.



IPCC 2011

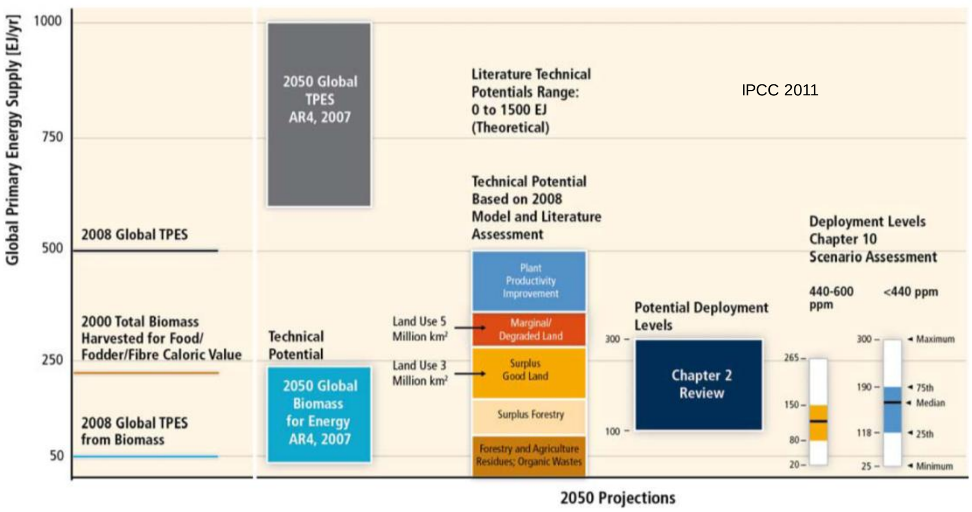


IPCC 2011

Table TS.2.1 | Examples of traditional and select modern biomass energy flows in 2008; see Table 2.1 for notes on specific flows and accounting challenges. [Table 2.1]

IPCC 2011

Type	Approximate Primary Energy (EJ/yr)	Approximate Average Efficiency (%)	Approximate Secondary Energy (EJ/yr)
Traditional Biomass			
Accounted for in IEA energy balance statistics	30.7	10–20	3–6
Estimated for informal sectors (e.g., charcoal) [2.1]	6–12		0.6–2.4
Total Traditional Biomass	***37–43***		***3.6–8.4***
Modern Bioenergy			
Electricity and CHP from biomass, MSW, and biogas	4.0	32	1.3
Heat in residential, public/commercial buildings from solid biomass and biogas	4.2	80	3.4
Road Transport Fuels (ethanol and biodiesel)	3.1	60	1.9
Total Modern Bioenergy	***11.3***	***58***	***6.6***



IPCC 2011

Figure TS.2.2 | A summary of major 2050 projections of global terrestrial biomass technical potential for energy and possible deployment levels compared to 2008 global total primary energy and biomass supply as well as the equivalent energy of world total biomass harvest. [Figure 2.25]

Table TS.2.2 | Experience curves for major components of bioenergy systems and final energy carriers expressed as reduction (%) in cost (or price) per doubling of cumulative production, the Learning Rate (LR); N: number of doublings of cumulative production; R^2 is the correlation coefficient of the statistical data; O&M: Operations and Maintenance. [Table 2.17]

Learning system	LR (%)	Time frame	Region	N	R^2
Feedstock production					
Sugarcane (tonnes sugarcane)	32±1	1975–2005	Brazil	2.9	0.81
Corn (tonnes corn)	45±1.6	1975–2005	USA	1.6	0.87
Logistic chains					
Forest wood chips (Sweden)	15–12	1975–2003	Sweden/Finland	9	0.87–0.93
Investment and O&M costs					
CHP plants	19-25	1983–2002	Sweden	2.3	0.17–0.18
Biogas plants	12	1984–1998		6	0.69
Ethanol production from sugarcane	19±0.5	1975–2003	Brazil	4.6	0.80
Ethanol production from corn (only O&M costs)	13±0.15	1983–2005	USA	6.4	0.88
Final energy carriers					
Ethanol from sugarcane	7	1970–1985	Brazil		
	29	1985–2002		~6.1	n.a.
Ethanol from sugarcane	20±0.5	1975–2003	Brazil	4.6	0.84
Ethanol from corn	18±0.2	1983–2005	USA	6.4	0.96
Electricity from biomass CHP	9-8	1990–2002	Sweden	~9	0.85–0.88
Electricity from biomass	15	Unknown	OECD	n.a.	n.a.
Biogas	0–15	1984–2001	Denmark	~10	0.97

IPCC 2011

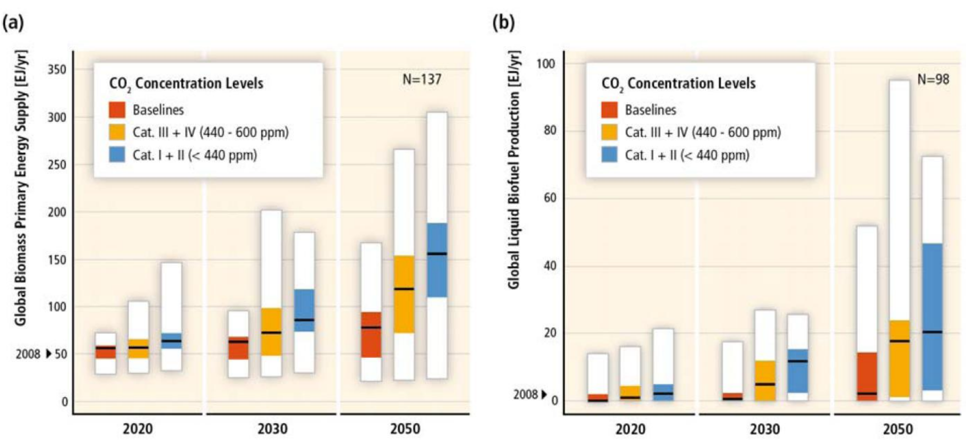


Figure TS.2.7 | (a) The global primary energy supply from biomass in long-term scenarios for electricity, heat and biofuels, all accounted for as primary energy; and (b) global biofuels production in long-term scenarios reported in secondary energy terms. For comparison, the historical levels in 2008 are indicated in the small black arrows on the left axis. [Figure 2.23]

IPCC 2011

Summary concerning scenarios

Estimated bioenergy use varies considerably between scenarios, also in the case of given atmospheric concentration target

The average over scenarios increases as a function of time even in baselines

Many scenarios show very strong increase in bioenergy use (and strongly expanding bioenergy technology markets)

The great variability depends mainly on the assumptions concerning bioenergy and other technologies (efficiency, other renewables, nuclear etc.) and energy demand, economy

Also consideration of other impacts can influence (competition on land, land use impacts on ghgs, carbon dynamics, albedo effects, particulate emissions from combustion etc.)

Environmental and social concerns related to energy sources - all sources have some concerns in some cases (1)

Fossil fuels

- **Greenhouse gases, particulate emissions etc.**
- **Fluctuating oil and gas prices, security of supply**
- **Limited and concentrated oil reserves**

Nuclear

- Radioactive wastes, risks of proliferation and accidents
- Fuel reserves relatively limited if breeder reactors not used

Bioenergy

- **Ghg balances of bioenergy vary by chains, balances are not very favourable in some bioenergy chains**
- **Land use changes causing ghg emissions,**
- **Competition on water and land with food and fiber supply, biodiversity and carbon sinks;**
- **Health and climate impacts of particulate emissions from small scale combustion**

Environmental and social concerns related to energy sources - all sources have some concerns in some cases (2)

Hydro
- Harm to fish migration, loss of biodiversity, human population displacement
- Limited resources in developed countries

Wind
- Bird fatalities, visibility of wind turbines, noise
- (Relatively unexploited resource)

Direct solar
- Water usage by CSP plants in arid areas, waste created in PV manufacture and disposal
- (Very unexploited resource)

Global CO2 emissions and concentrations
- Biomass is a part of the global carbon cycle

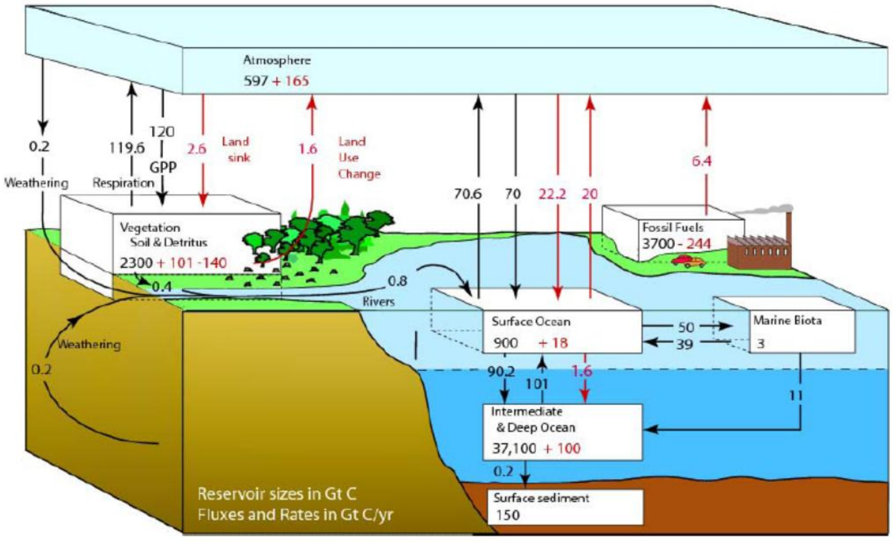
Sources
- Fossil fuels
- Cement and lime production
- Release of carbon storages in the biosphere

Carbon Cycle consists of two main cycles:
- Atmosphere - Ocean
- Atmosphere - Terrestrial Biosphere

Inertial features
- An emission pulse is diluted by the atmosphere and by the surface layers of the ocean, dilution to deeper waters takes hundreds of years

Preindustrial concentration in the atmosphere war 275-280 ppm, now about 390

(IPCC carbon cycle for 1990’s, 2007)



Assumption on the zero C emissions of biomass combustion

It is an estimate for real emissions

- Best valid when the biomass grows back rapidly and binds C released in combustion
- Fits best to agriculture which supplies a great share of global bioenergy
- In case of forest biomass the processes are much lower and a potential C deficit can durate a relatively long time. (In plantation forestry the impact can be opposite.)

Currently, a vivid scientific debate both in Europe and in USA is going on how biomass carbon emissions should be accounted.

Carbon dynamics accounting

IPCC guidelines for national annual emission inventories reported to FCCC:

C emissions from combustion of renewable biomass is zero,
but C balance change of ecosystem is reported in land use category.

C balance of the ecosystem is assessed on the basis of growth, cuttings and other losses including soil C.

In many practical considerations, the C balance change of the ecosystem is not considered which can lead to the omission of considerable emissions in some cases. E.g. in many scenario studies or LCAs the increase of the use of forest biomass is assumed to be of net zero emissions which do not account the lowering the ecosystem carbon amount from the level it would have without increased biomass use. The inaccuracy / error is greatest in the case of long rotation biomass. In short rotation case, practically no error is made.

Repo et al. 2011

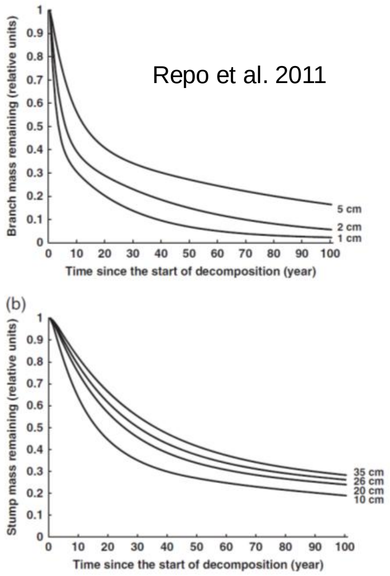


Fig. 1 Mass remaining of decomposing Norway spruce branches (diameter 1–5 cm) and stumps (diameter 10–35 cm) over a 100-year period after the start of decomposition in southern boreal conditions as simulated using the Yasso07 model (model input values in Table 1).

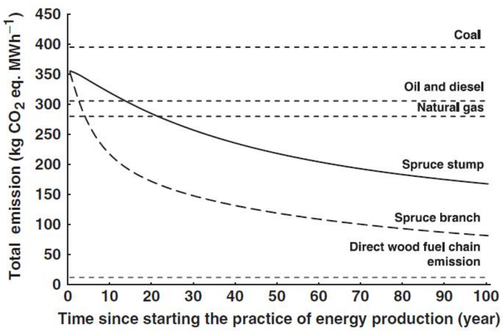
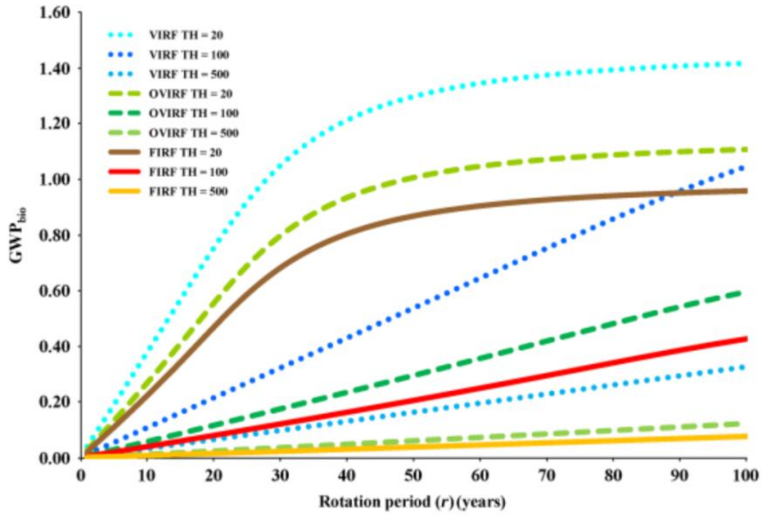


Fig. 3 The total greenhouse gas emission per unit of energy produced from using Norway spruce branches (diameter 2 cm) or stumps (diameter 26 cm) for bioenergy over a 100-year period after starting this practice and the total emissions from various fossil fuels. The emission estimates of bioenergy production include both an indirect (see Fig. 2) emission resulting from decreasing carbon stock and a direct wood fuel chain emission (equal to 12 kg CO_2 eq. MW h^{-1}) resulting from collecting, chipping and transporting the harvest residues, CH_4 and N_2O emissions from combusting the residues, fertilizing the forest to compensate for nutrient loss, and recycling of ash. The estimates of the fossil fuels represent entire fuel cycle emissions (Statistics Finland, 2006; Ecoinvent Centre, 2007).

GWPbio for TH equal to 20, 100 and 500 years as a function of the biomass rotation period. GWP, global warming potential; TH, time horizon. (Cherubini et al. 2011)

(IS: the figure shows the sensitivity to various assumptions, the red line can be seen as basis alternative)



VTT TECHNICAL RESEARCH CENTRE OF FINLAND 03/02/2010 45

Optimal accounting of bioenergy C

Effective emission factor depends on the time horizon of the consideration

Short time horizons can give relatively high weight to emissions from slow rotation bioenergy

Long time horizons favor bioenergy

Choice of the time horizon is ”political”

Effective lifetime of CO2 in the atmosphere, about 100 a

Forest rotation (boreal)	60 -100 a
Industrial investments	20 a –
Use of building investments	50 – 100 a

Emission reduction target horizons 10 a (2020), 40 a (2050)

Most commonly used time horizon in GWPs 100 a

VTT TECHNICAL RESEARCH CENTRE OF FINLAND 03/02/2010 46

Other climate impacts of biomass use

Impact of land use change on

- Carbon storage (e.g. forest clearing for plantations)
- Local surface albedo
- Air humidity, cloudiness and albedo

Impact of combustion on

- Particulate emissions and albedo (black and white particles, brown cloud)

VTT TECHNICAL RESEARCH CENTRE OF FINLAND 03/02/2010 47

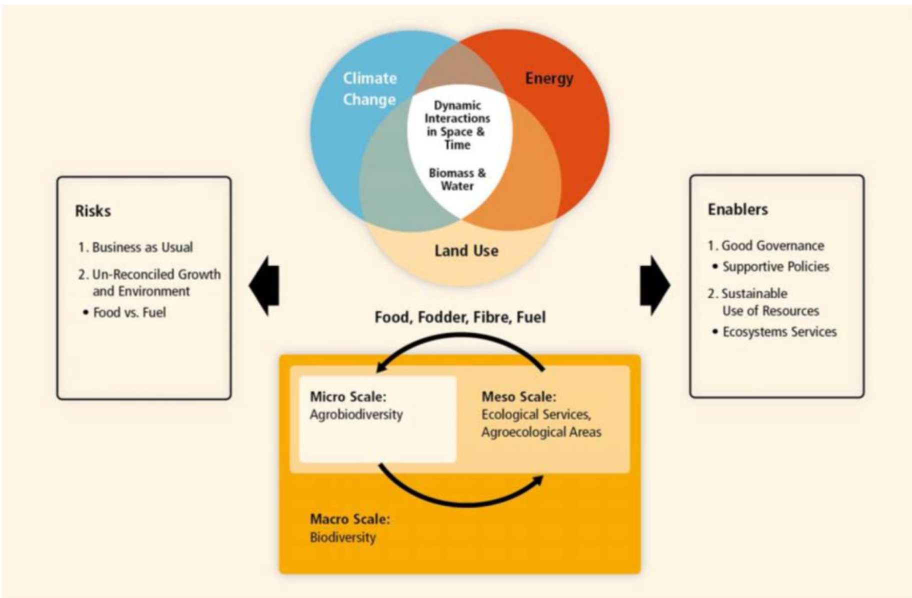


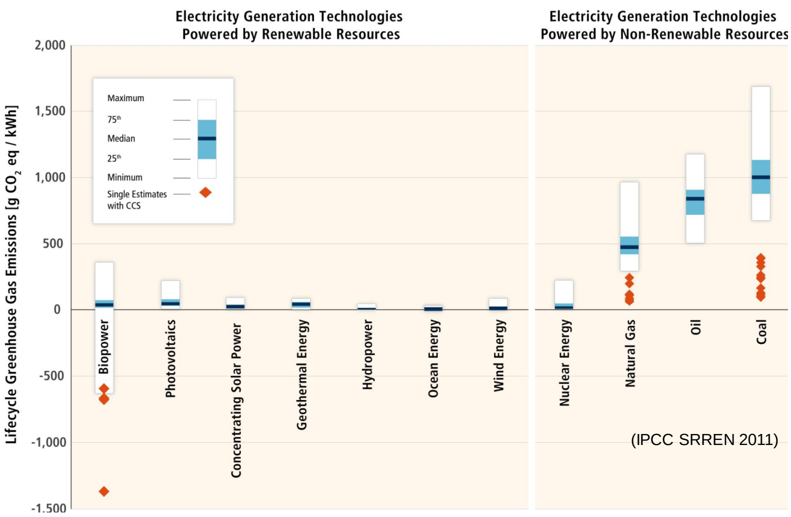
Figure TS.2.4 | The complex dynamic interactions among society, energy and the environment associated with bioenergy. Approaches of uncoordinated production of food and fuel that emerge in poor governance of land use are examples of business as usual practices. [Figure 2.15]

Direct and indirect land use changes cause risks of increasing the total life cycle emissions

Direct land use change (dLUC) occurs when bioenergy feedstock production modifies an existing land use, resulting in a change in above- and below-ground carbon stocks. Indirect LUC (iLUC) occurs when a change in production level of an agricultural product (i.e., a reduction in food or feed production induced by agricultural land conversion to produce a bioenergy feedstock) leads to a market-mediated shift in land management activities (i.e., dLUC) outside the region of primary production expansion. iLUC is not directly observable and is complex to model and difficult to attribute to a single cause as multiple actors, industry, countries, policies and markets dynamically interact. [2.5.3, 9.3.4.1]

(IPCC SRREN 2011)

Lifecycle GHG emissions of RE technologies are, in ge considerably lower than those of fossil fuel options.



(IPCC SRREN 2011)

BioCCS (Biomass fuel and Carbon Capture and Storage)

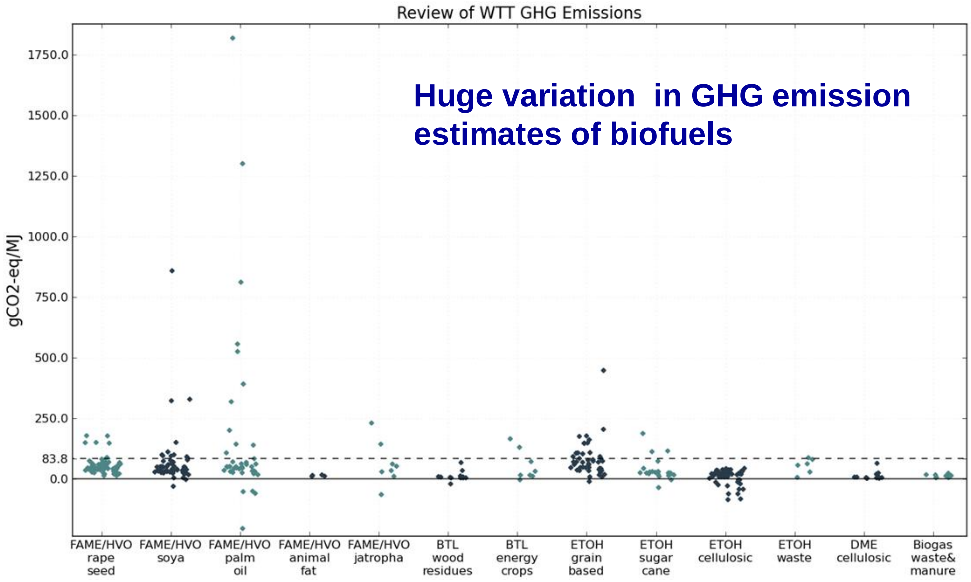
Clearly negative ghg emissions can be reached if the CO2 from renewable biomass combustion is stored

- If fuel contains order of 20% biomass, the zero net emission level can be reached

CCS requires typically large units, mixed fuel base might be more practical than pure biomass fuel

Some processes like Fischer-Tropsch liquid biofuel production have CO2 output in so clean form that it can be directly compressed for transport and storage

BioCCS could be profitable if the carbon price is very high



Source: Soimakallio & Koponen 2011

The EU Renewable Energy Directive (RED)

- Mandatory targets to increase the use of renewable energy and transportation biofuels within the Member States in 2020
- Mandatory sustainability criteria for transportation biofuels and other bioliquids
  - Including GHG performance criteria (35-60% reduction in GHG emissions compared to fossil reference fuels)
    - LCA based framework applied
    - Certain rules fixed (e.g. allocation) but still a lot of open issues

……………………………………………………………………………

→ Extension of the criteria to other bioenergy applications?
→ Introduction of similar criteria for other (biomass-based) products?
→ LCA as a decision-making tool?

Technological challenges

- Improve biomass supply chains to limit costs
  - E.g. use existing logistics systems of the forest industry
- Extend resource base in order to lessen competition between other biomass users and competition on land and water
- Improve efficiencies and lower costs of energy and fuel production
- Lower ghg balances

Challengies in research on energy systems and economies

Combined strategies for climate change mitigation, reduction of health effects, reduction of energy poverty and improvement of energy security? Synergies and trade-offs?

Energy efficiency improvements

Negative ghg emissions required after 2050?

Should geoengineering belong to the selected palette of measures?

Side effects of geoengineering alternatives? Governance?

Role of bioenergy? Land use changes causing ghg emissions, competition on water and land with food and fiber supply, biodiversity and carbon sinks; control of particulate emissions

Strategy and management of energy system transition, change to low carbon society

Financing of investments in new energy systems?

Handling of **uncertainties**

Challenges

- Energy efficiengy improvement and increase of the share of renewable energy have central role in the reduction of emissions (Both measures also improve energy security and contribute to sustainable development)
- Renewable energy potentials have great regional differences, regional information needed.
- Different renewable energy sources are in different state of technological maturity (Best deployment potential have hydro and wind, breakthrough of solar is coming. Biomass covers many technologies the status of which varies from laboratory to mature markets. Geothermal and ocean energy are in developmental state.)
- Integration of renewable energy in existing and future energy systems is a central challenge (all renewable energy sources have their own characters).
- In the assessment of changes, several viewpoints are needed, e.g.: life-cycle, cost-efficiency and systems approach (Ghg emission reduction depends on the whole (energy) system, not only on the increase of renewables)
- Well designed policy measures are needed in the deployment of renewable energy sources