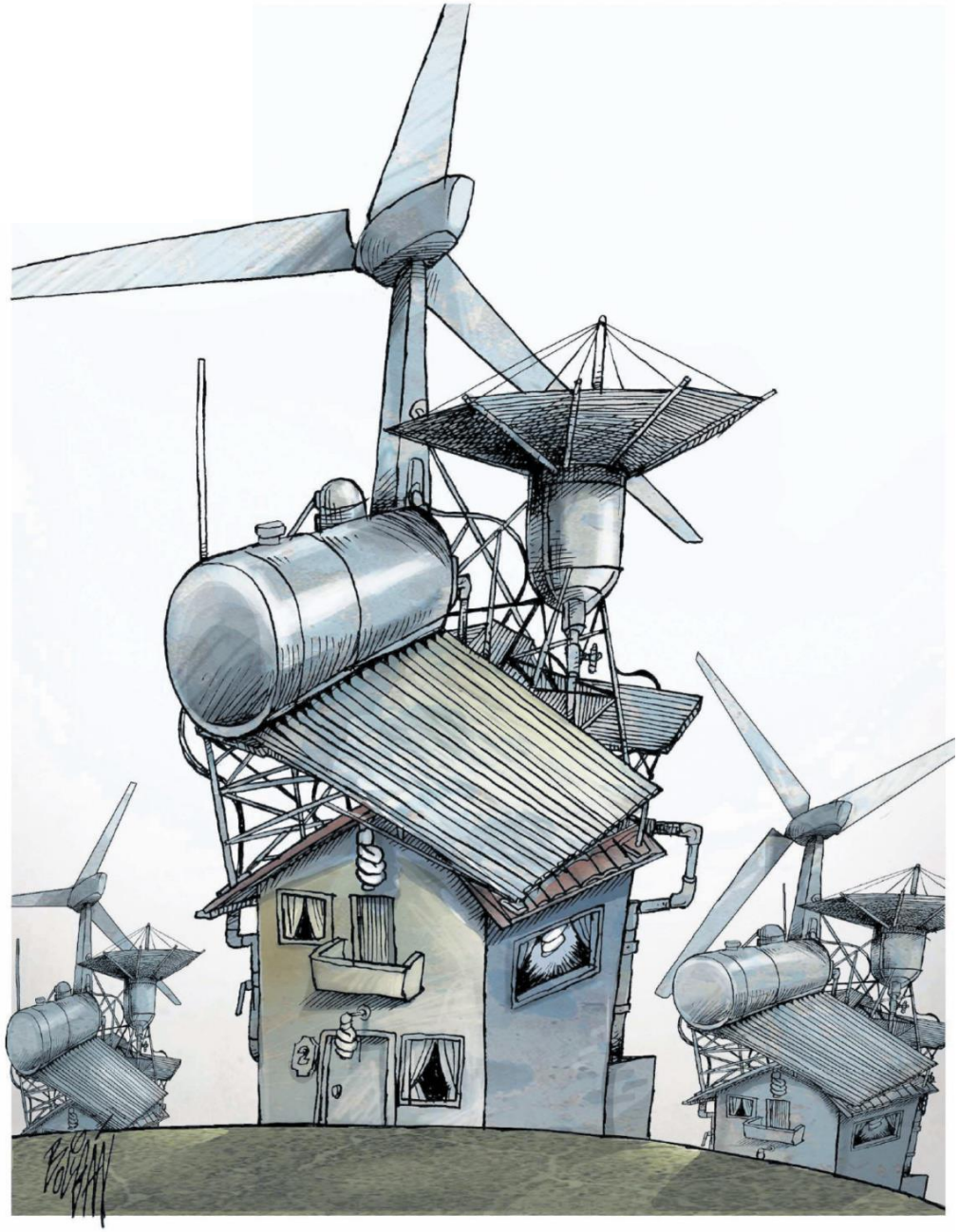

*Source drawing: NRC-HB, 19 August 2013*

*Some remarks on*

# Natural Gas Climate Change, and our Future Energy System


**Wim Turkenburg**

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*Utrecht University*
*&*
*Wim Turkenburg Energy and Environmental Consultancy, Amsterdam*


***KVGN***

***Soestduinen, 9 April 2015***

# Eurogas (incl. KVGN):
## *'A vision on the future of natural gas in the energy mix'*

**Our mission:**

**"To strengthen the role of gas in the energy mix by establishing an ongoing dialogue with European industry players, global producers of gas and relevant institutions such as the European Commission."**

**Our vision:**

**"A robust European gas market that encourages competitiveness, supports security of supply, delivers benefits to customers, stimulates energy efficiency and plays a significant role in reducing $CO_2$ emissions."**

*Source: Eurogas website, 8 April 2015*

eurogas
Fuelling the future

*"To achieve a secure and compatitive low-carbon energy system, the use of gas in electricity generation, heating, industrial processes and transport is indispensible"*

*Source: Eurogas, 'Response to the EC 2030 Energy and Climate Package', May 2014*

# GasTerra:

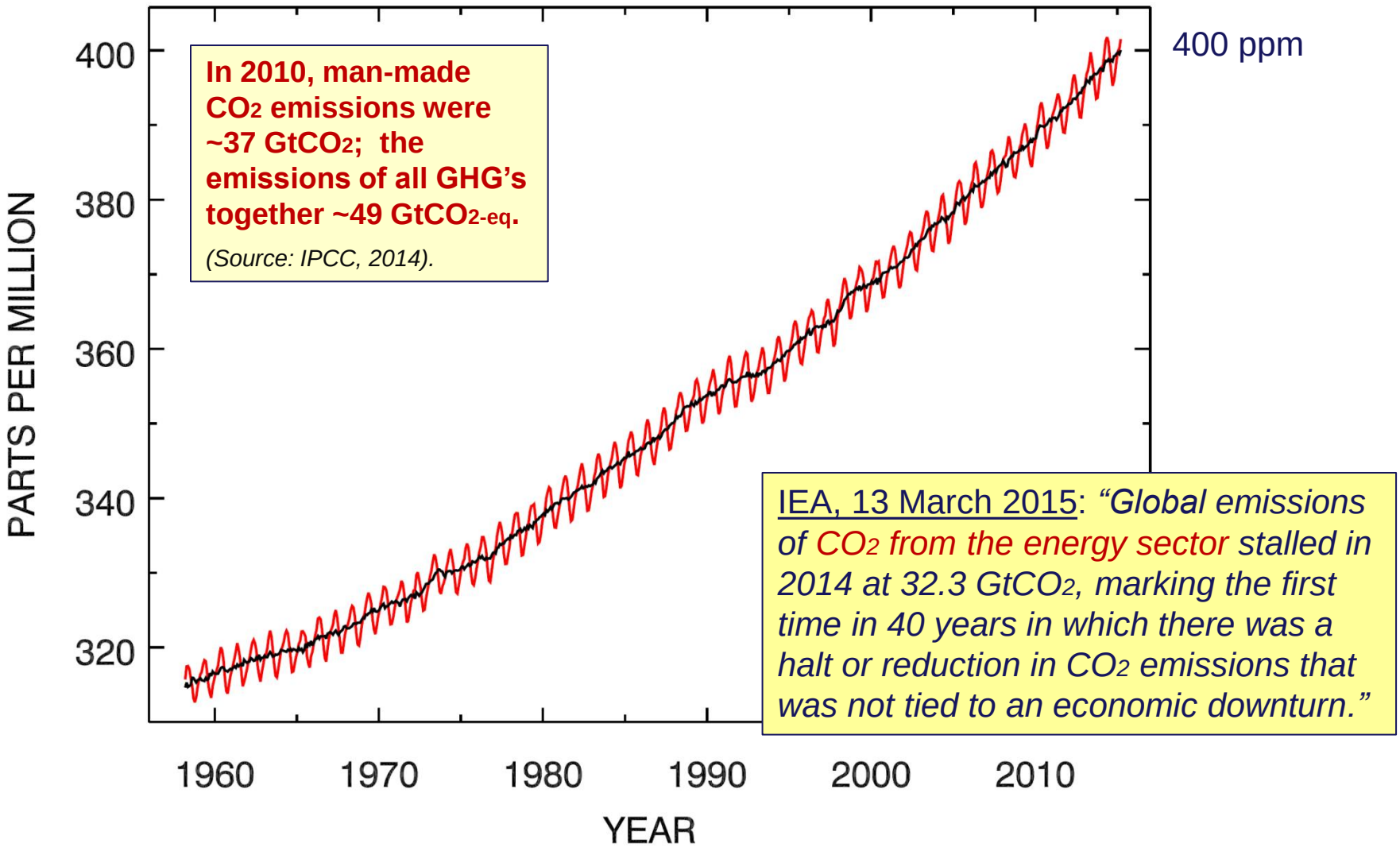
## *“We hechten groot belang aan verduurzaming van de energievoorziening”*

- **“We zoeken zoveel mogelijk dialoog en samenwerking met andere betrokken partijen, zoals de overheid, de politiek, wetenschap en onderwijs, denktanks, *NGO*’s en bedrijven, waarbij we benadrukken dat we het over de doelen eens zijn: *een $CO_2$-neutrale, zekere en betaalbare energievoorziening*.”**

- **“Uitgangspunt blijft onze overtuiging dat het efficiënte grootschalige gebruik van aardgas substantieel bijdraagt aan oplossing van het energie- en klimaatvraagstuk. De toekomst kan dus niet zonder gas.”**

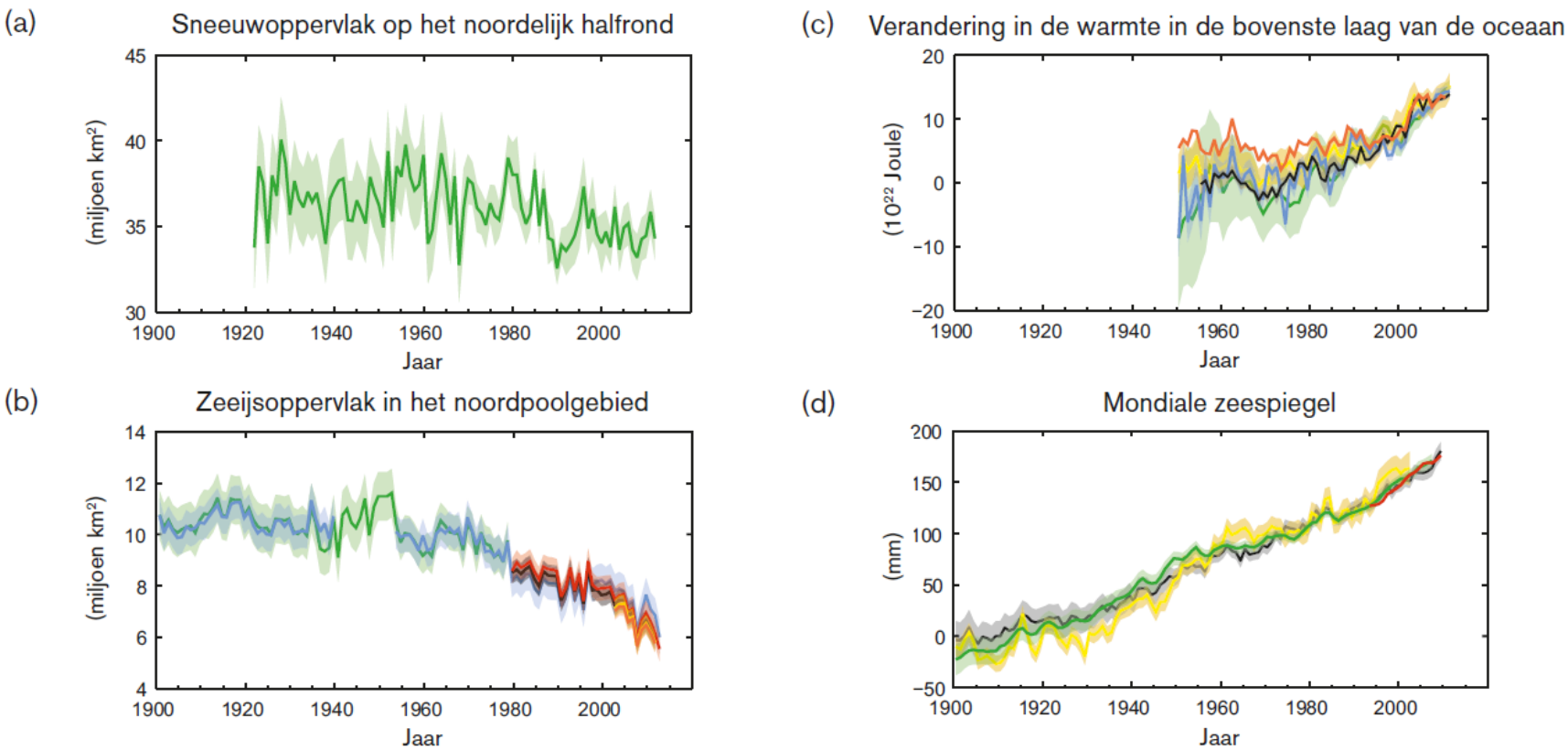
# Climate Change

# Monthly average $CO_2$ concentration in the atmosphere at Mauna Loa Observatory (1958 – April 2015)




*Source curve: http://www.esrl.noaa.gov/gmd/webdata/ccgg/trends/co2_data_mlo.pdf (visited: 8 April 2015)*

# Indicatoren van een veranderend klimaat *(IPCC, 2013)*

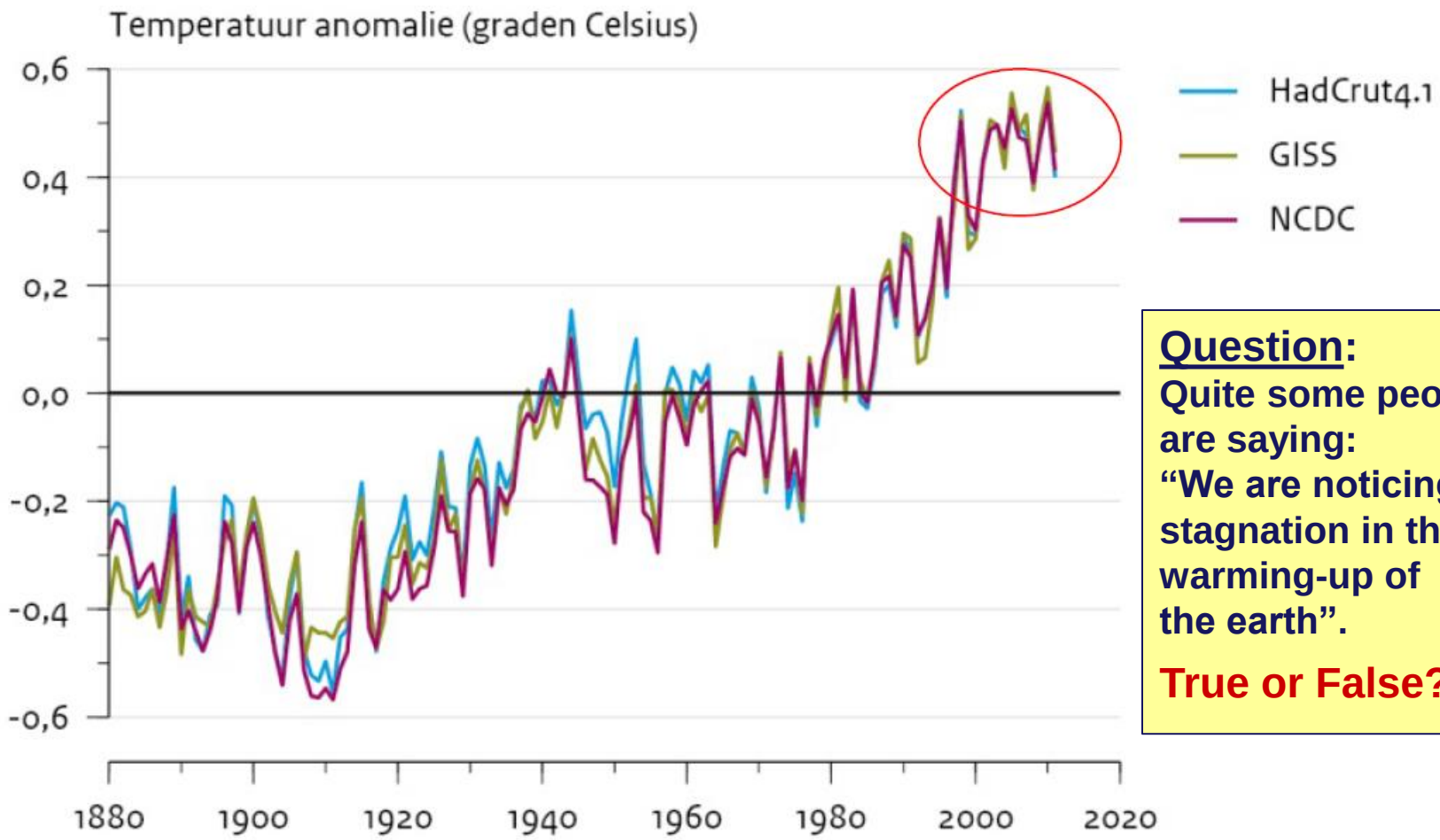



*<u>Toelichting 1</u>: (a) gemiddelde sneeuwoppervlak op het noordelijk halfrond in maart-april, (b) gemiddelde zeeijsoppervlak in het Noordpoolgebied in juli-augustus-september, (c) verandering in de mondiaal gemiddelde hoeveelheid warmte in de bovenste laag van de oceaan (0-700m), ten opzichte van het gemiddelde van alle datasets voor 1971, (d) mondiaal gemiddelde zeespiegel, afwijking ten opzichte van het 1900-1905 gemiddelde van de langstlopende dataset.*

*<u>Toelichting 2</u>: Alle tijdseries (gekleurde lijnen corresponderen met verschillende datasets) tonen jaarlijkse waarden. Waar beschikbaar zijn de onzekerheden aangegeven met gekleurde banden.*

*Bron: Rob van Dorland, in: 'De Staat van het Klimaat 2014', HIER Klimaatbureau, Utrecht, 2014, pp.10-14.*

# Average global temperature change
(relative to average value of 1961-1990)




**Question:**
**Quite some people are saying:**
**"We are noticing a stagnation in the warming-up of the earth".**

**True or False?**

*Source: KNMI, De Bilt, 2012*

**Which heating?**

**Elsevier – 02-10-2013**

# Welke opwarming?

**Klimaatpanel IPCC wordt met elk rapport ongeloofwaardiger. Zeker nu de temperatuur sinds 1998 niet meer stijgt.**

Door **Simon Rozendaal**

Er is weer een nieuw rapport van het VN-klimaatpanel IPCC. En opnieuw luidt de boodschap dat het zeer waarschijnlijk is dat de opwarming door de mens wordt veroorzaakt. Je moet maar durven.

**Trouw – 21 sept. 2013**

# Aarde warmt minder snel op dan gedacht

**Heating of the earth less than expected**

Door **Joep Engels**

De klimaatsceptici krijgen een beetje gelijk: de aarde warmt mogelijk iets minder snel op dan eerder voorspeld. Deze ontwikkeling is nieuwe brandstof voor de verhitte controverses over de noodzaak van urgente maatregelen om het klimaat te redden.

**The disaster that didn't come**

**NRC-HB – 21-09-2013**

# De ramp die niet kwam

Door **Karel Knip**

**De modellen die het broeikaseffect voorspellen, hadden niet voorzien dat het op aarde al twaalf jaar niet meer warmer wordt.**

Alle waarschuwingen voor de rampen die klimaatverandering zal veroorzaken, zijn nog veel dubieuzer.

(…) Klimaatverandering bestaat. Maar al die $CO_2$ veroorzaakt tot nu toe geen overstromingen. Geen cyclonen. Geen woestijnvorming. Geen malaria. Geen voedseltekorten. Geen waterschaarste. En geen oorlog.

**Heating is inevitable**

**De Volkskrant – 28 sept. 2013**

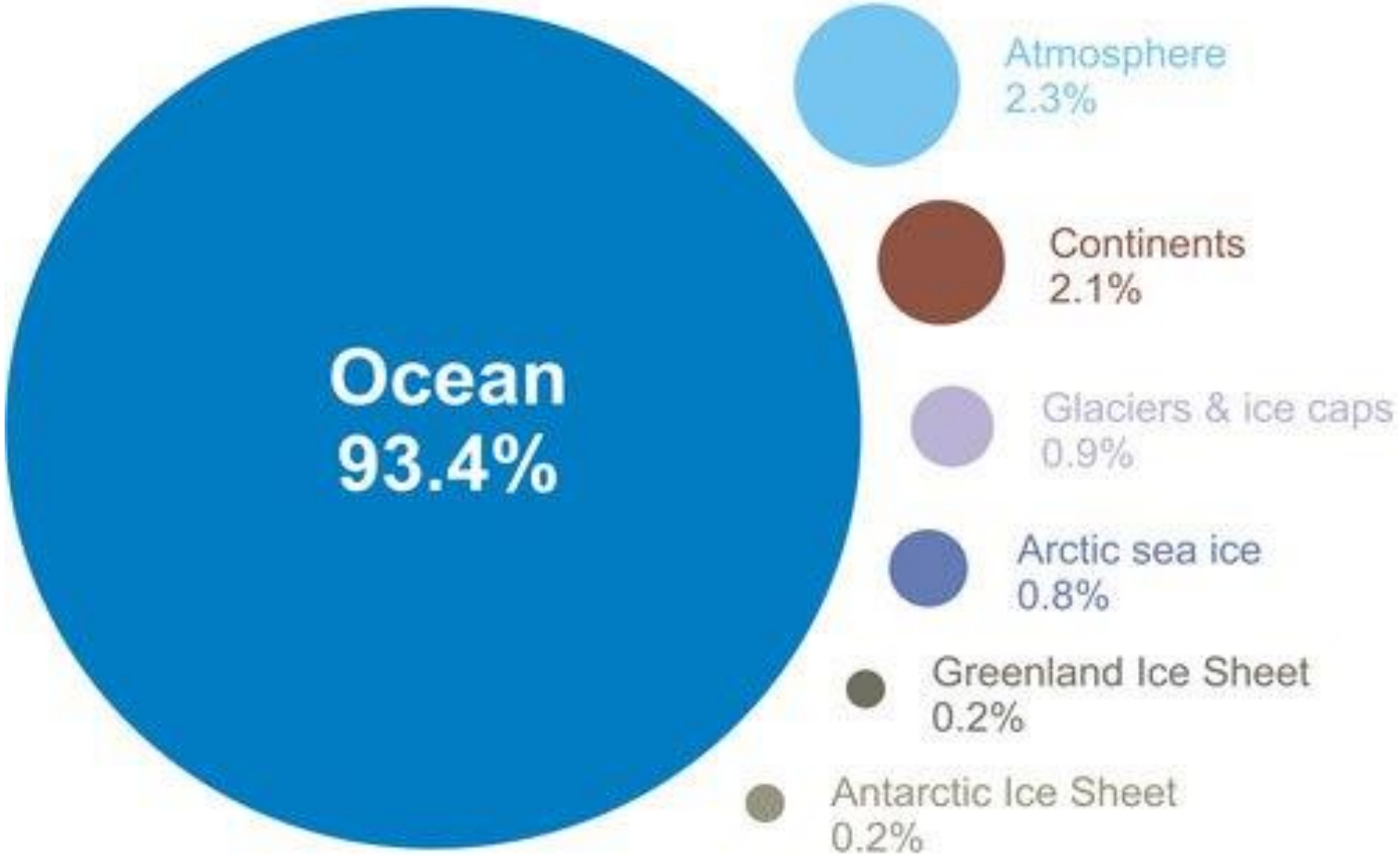
# Opwarming is onontkoombaar

**Het is nu vrijwel zeker: het komt door de mens. Die stoot zoveel broeikasgassen uit dat de aarde aan het opwarmen is. En die opwarming zet door, zelfs als vandaag alle uitstoot van $CO_2$ stopt.**

Door **Martijn van Calmthout** en **Maarten Keulemans**

De mens is de belangrijkste oorzaak van de opwarming van de aarde, zeker in de periode na 1950. Dit concludeert het VN panel IPCC met aan zekerheid grenzende waarschijnlijkheid in zijn 5$^{de}$ rapportage over klimaatverandering. Het rapport legt een vrijwel eenduidig verband tussen veranderingen in de atmosfeer, de oceanen en de ijsmassa's enerzijds en de toenemende concentratie van $CO_2$ en andere broeikasgassen in de lucht.

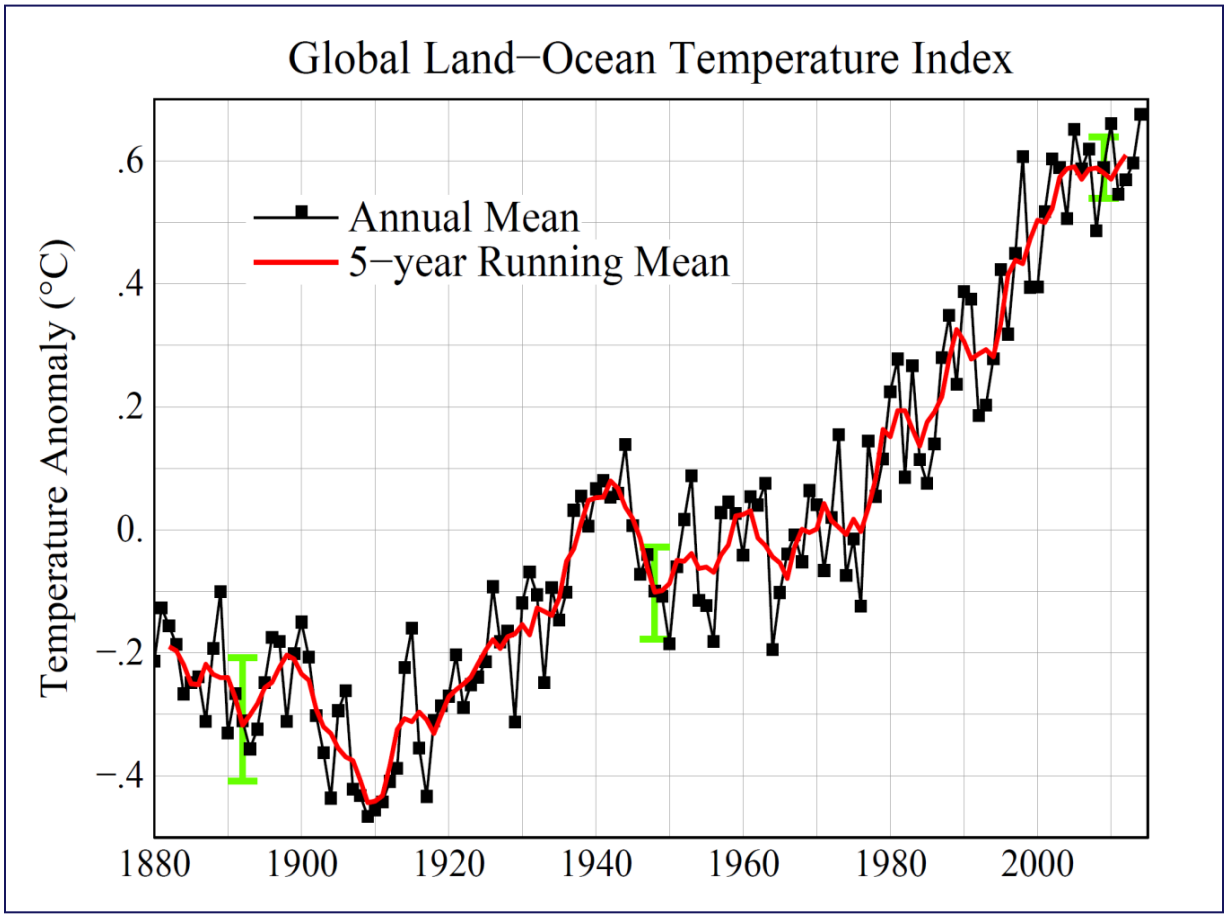
# Where is global warming going?




*Source: John Cook, 'Where is global warming going?', Skeptical Science, 20 April 2010.*
*(Calculated from IPCC-AR4; data from the period 1993-2003)*

*(16 January 2015)*

# NASA & NOAA Find 2014 Warmest Year in Modern Record




The year 2014 ranks as Earth's warmest since 1880, according to two separate analyses by NASA and National Oceanic and Atmospheric Administration (NOAA) scientists.

Since 1880, Earth's average surface temperature has warmed by about 0.8 ºC

*Source: http://www.giss.nasa.gov/research/news/20150116/*

# *The greenhouse effect* and *Global Warming*

## *- Three conclusions / remarks -*

1. ***'Global Warming'* is *not* equivalent to *'average temperature on earth (troposhere)'*!**

   because of mechanisms like (see next slide):

   - storage of heat into the (deep) ocean;
   - heat used to warm land, to melt ice, etcetera

2. **Temp. on earth also influenced by e.g. vulcanos.**

3. **The greenhouse effect of gases like $CO_2$, caused by *molecular absorption of heat radiation,* is a scientific fact – therefore it is not well understandable that quite some (sceptical) people are denying it.**

   For a demonstration of the absorption of heat radiation bij $CO_2$, see a 1-min. movie on YouTube:
   http://www.youtube.com/watch?v=Ot5n9m4whaw

# Carbon budget, *'stranded assets'* and CCS

# Austria's Pasterze Glacier has retreated hundreds of meters since nations began debating limiting warming to +2°C

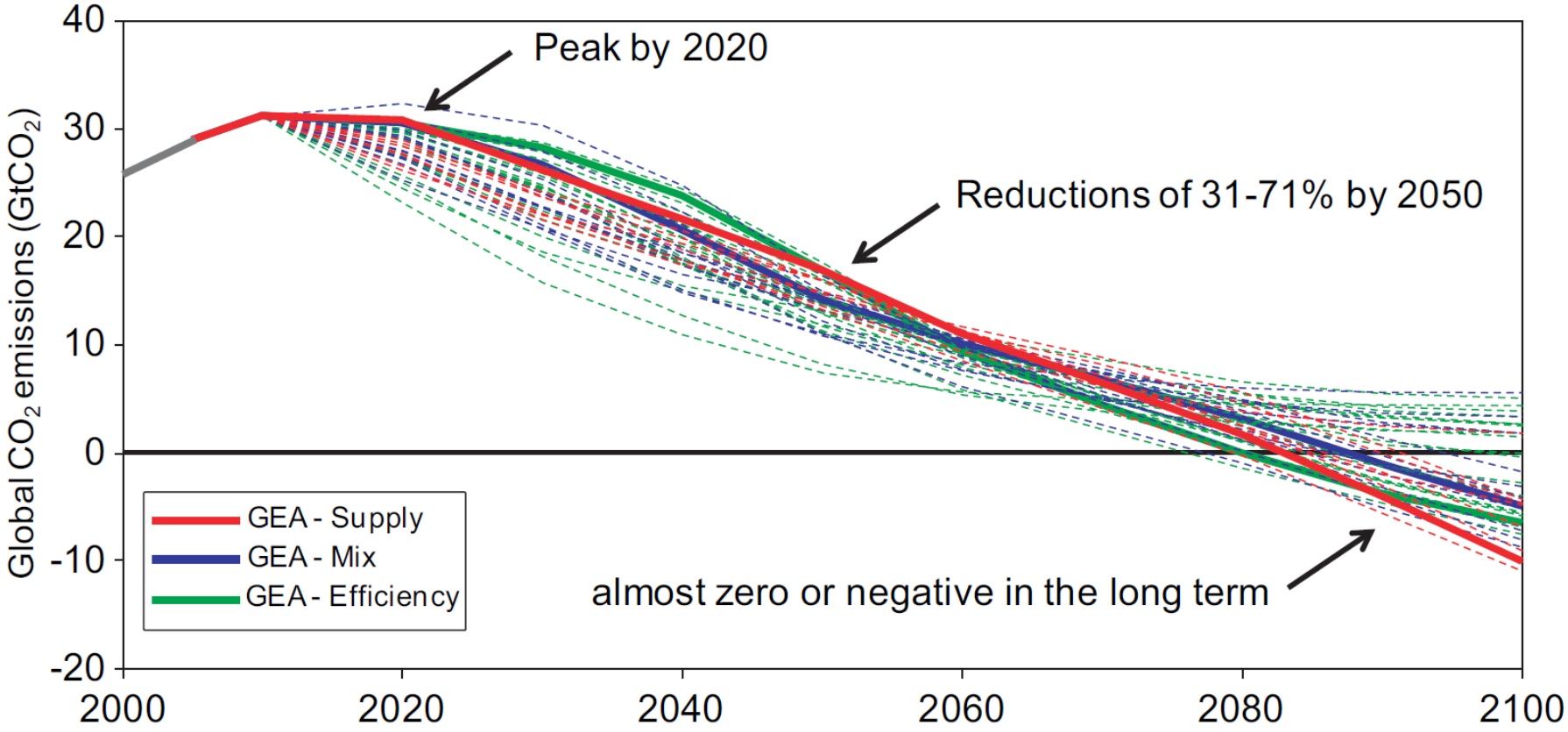
***"The science tells us that 1.5 °C might be considerably better."***

*Nature, 2 April 2015*

*Source: J. Tollefson, 'Global-warming limit of 2°C hangs in the balance', Nature, 2 April 2015, pp. 14-15.*

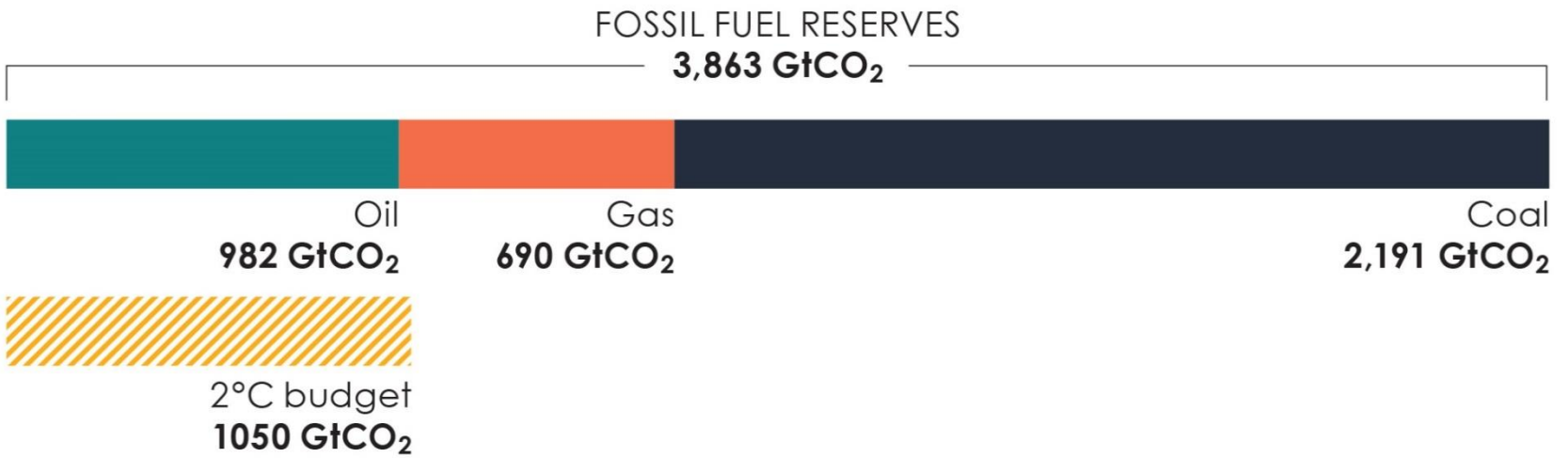
# Development of global $CO_2$ emissions from energy and industrial sources to limit temp. change to below 2°C (prob. > 50%)

*- GEA energy pathways toward a sustainable future -*




*Source: Global Energy Assessment, 2012*

# Global Carbon budget compatible with limiting global warming to +2°C *versus* fossil fuel reserves




**Conventional and unconventional fossil fuel reserves of coal, oil, and gas and the global carbon budget compatible with scenarios limiting global mean warming to 2°C above pre-industrial temperatures (with a 66% probability).**

*Source of Fossil Fuel reserves: IPCC, 2011 (figure 1.7).*
*Source of Carbon budget: IPCC, 2013 and IPCC erratum, November 2013.*

*Source figure: ECF, "Statement by leading climate and energy scientists", 2013*

# Unburnable Carbon and Stranded Assets

- Not the use of fossil fuels but **the emission of $CO_2$** (at present ~37 Gton/yr globally) is the problem!
- *Carbon Tracker,* and groups like *Urgenda* in NL, don't give enough attention to **the potential of CCS**.
- CCS can have a large impact (~***2,000 $GtCO_2$*** *till 2100*) on 'unburnable carbon'.
- But: within about 20 years we can't allow **any** new investments in **unabated use** of any fossil fuel (given 'max +2°C), having **huge consequences** for Shell, Exxon, BP, Gasunie, Gasterra, EBN, RWE, E.ON, Vattenfall, ENECO, KVGN, etc. Therefore a Roadmap CCS for the Netherlands is urgently needed!
- Note also the statement of the EC (Dec. 2011): *"No new investments in fossil fuel power plants after 2030 without CCS".*

# Removal of $CO_2$ from power plants

- **CCS is a proven technology that today securely stores 25 Mt $CO_2$ a year.**
- **There are 21 large-scale projects in operation or construction, all expected to be online by 2016.**
- **These will have the capacity to capture up to 40 Mt $CO_2$ per annum.**

- In Saskatchewan (Canada) the first commercial scale operation of CCS at a power plant started October 2014: the *Boundary Dam project* (Shell involved).
- It's a coal-burning plant that generates 110 MW and would emit more than 1 Mt of $CO_2$ per year. Its operators say, the project is "exceeding expectations."

- Shell/Cansolv and SSE are looking to develop the world's first full-scale gas CCS project – the *Peterhead Project* (Scotland), with support of the UK Gov't

*Sources: GCCSI, 2014 // SaskPower, 2015 // Shell UK, 2015*

# Energy scenarios
# &
# Renewables

# World Primary Energy Supply in 2009

*(using GEA substitution method to calculate contribution from renewables)*

| | | | |
|---|---|---|---|
| **Fossil fuels:** | | **412 EJ** | **( 78 % )** |
| - oil | 167 EJ | | |
| - gas | 106 EJ | | |
| - coal | 139 EJ | | |
| **Renewables:** | | **89 EJ** | **( 17 % )** |
| - large hydro | 30 EJ *) | | |
| - traditional biomass | 39 EJ | | |
| **- 'new' renewables** | **20 EJ *)** | | **(~ 4%)** |
| **Nuclear:** | | **27 EJ** | **( 5 % )** |
| **Total:** | | **528 EJ** | **( 100 % )** |

Figure NL: also ~ 4%

**) Assuming for hydro, wind, solar and geothermal electricity: 1 EJ(el) = 2.85 EJ savings on fossil fuels, and for solar and geothermal heat: 1 EJ(th) = 1.17 EJ savings on fossil fuels.*

*Source: W.C. Turkenburg et al., 'Renewable Energy'. In: Global Energy Assessment, 2012, chapter 11*

# Contribution renewables to gross *energy* consumption in NL and EU-28 in 2012

Contribution RE in NL (2012):

**about 4.5% to energy cons.**

- mostly from biomass (86.9%) and wind (11.3%)
- from solar 1.3%, geoth. 0.3% and hydro 0.2%

Contribution RE in EU-28 (2012):

**about 14.1% to energy cons.**

- 65.4% from biomass energy
- 16.2% from hydro power
- 10.0% from wind energy
- 5.2% from solar energy
- 3.2% from geothermal energy
- 0.02% from tide, wave, and ocean power

**Ranking NL on renew. energy: nr. 25**

**Note:**

- NL has limited resources:
  - small country (in $km^2$);
  - hardly any hydro power resources;
  - limited availability of land for biomass energy cultures.
- Also: high ranking NL on population density: nr. 2

**Nevertheless, within EU-28 (2012):**

- Ranking NL on biopower use: nr. 6
- Ranking NL on wind electricity: nr. 13
- Ranking NL on solar PV: nr. 13

*Source: Eurostat, 2014*

# Renewable Energy in 2011 in EU countries (EU-27) *and* potential of renewable sources in EU countries

| Country | Renew. In 2011 (PJ/yr) | Share RE in 2011 | RE/cap (GJ/cap) | RE/GDP (kJ/USD) | RE/km$^2$ (GJ/km$^2$) | Wind | Solar | Hydro | Biom. | Geoth. | Ocean |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | |
| Austria | 367.3 | 26.5% | 43.7 | 879 | 4,379 | | | | | | |
| Belgium | 119.7 | 4.9% | 10.9 | 233 | 3,944 | | | | | | |
| Bulgaria | 56.6 | 7.1% | 7.8 | 1,058 | 510 | | | | | | |
| Cyprus | 5.1 | 5.1% | 4.6 | 206 | 551 | | | | | | |
| Czech Rep. | 125.2 | 6.9% | 11.9 | 577 | 1,616 | | | | | | |
| Denmark | 170.7 | 22.4% | 30.5 | 512 | 3,961 | | | | | | |
| Estonia | 34.8 | 15.0% | 26.8 | 1,568 | 770 | | | | | | |
| Finland | 379.9 | 25.8% | 70.4 | 1,444 | 1,128 | | | | | | |
| France | 765.0 | 7.2% | 11.7 | 276 | 1,188 | | | | | | |
| Germany | 1,307.7 | 10.1% | 16.0 | 363 | 3,660 | | | | | | |
| Greece | 89.3 | 7.8% | 7.9 | 308 | 677 | | | | | | |
| Hungary | 79.0 | 7.5% | 7.9 | 564 | 849 | | | | | | |
| Ireland | 34.3 | 6.2% | 7.5 | 158 | 491 | | | | | | |
| Italy | 834,9 | 11.7% | 13.7 | 381 | 2,771 | | | | | | |
| Latvia | 60.1 | 34.7% | 28.6 | 2,124 | 931 | | | | | | |
| Lithuania | 44.2 | 15.1% | 14.7 | 1,035 | 677 | | | | | | |
| Luxembourg | 5.1 | 2.9% | 9.8 | 86 | 1,977 | | | | | | |
| Malta | 0.1 | 0.1% | 0.24 | 11 | 323 | | | | | | |
| Netherlands | 138.1 (13) | 4.2% (24/25) | 8.3 (20) | 165 (23) | 3,697 (4) | | | | | | |
| Poland | 332.9 | 7.8% | 8.6 | 647 | 1,067 | | | | | | |
| Portugal | 215.3 | 22.4% | 20.3 | 907 | 2,335 | | | | | | |
| Romania | 212.2 | 14.0% | 9.9 | 1,180 | 890 | | | | | | |
| Slovakia | 57.2 | 7.8% | 10.6 | 596 | 1,167 | | | | | | |
| Slovenia | 39.7 | 13.1% | 18.9 | 802 | 1,949 | | | | | | |
| Spain | 612.9 | 11.7% | 13.3 | 415 | 1,211 | | | | | | |
| Sweden | 659.4 | 32.1% | 70.1 | 1,222 | 1,464 | | | | | | |
| Un. Kingdom | 326.6 | 4.2% | 5.2 | 134 | 1,347 | | | | | | |

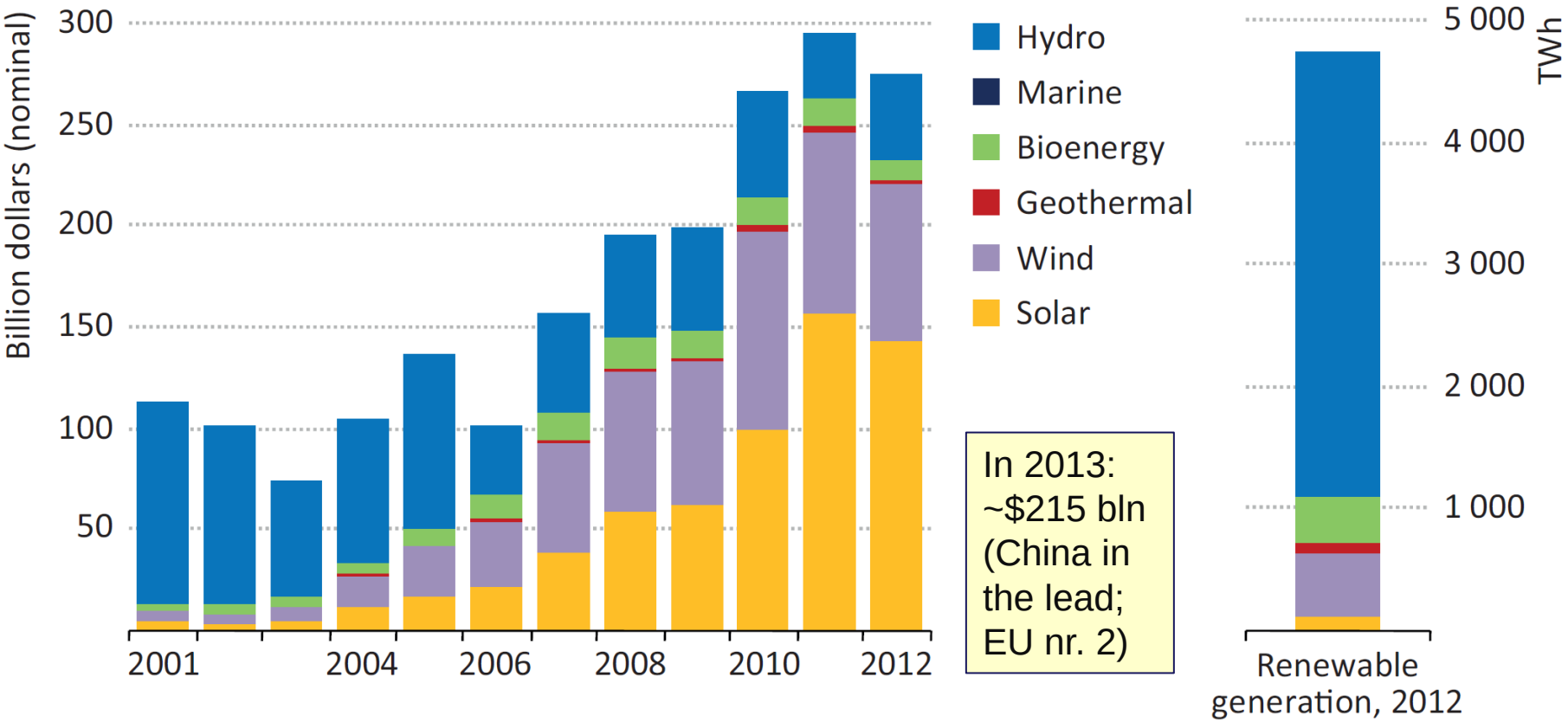
| *high* | *High/medium* | *medium* | *medium/low* | *low* | *unknown* | *Not-applicable* |
|---|---|---|---|---|---|---|
| | | | | | | |

**- The colour table shows that, within the EU, NL is not a favourable country for developing renewable en. sources, apart from wind energy.**

**- Therefore alternatives like Gas+CCS also important for especially NL.**

*Source: Wim Turkenburg Consultancy, 2013 (based on data from IRENA, 2013).*

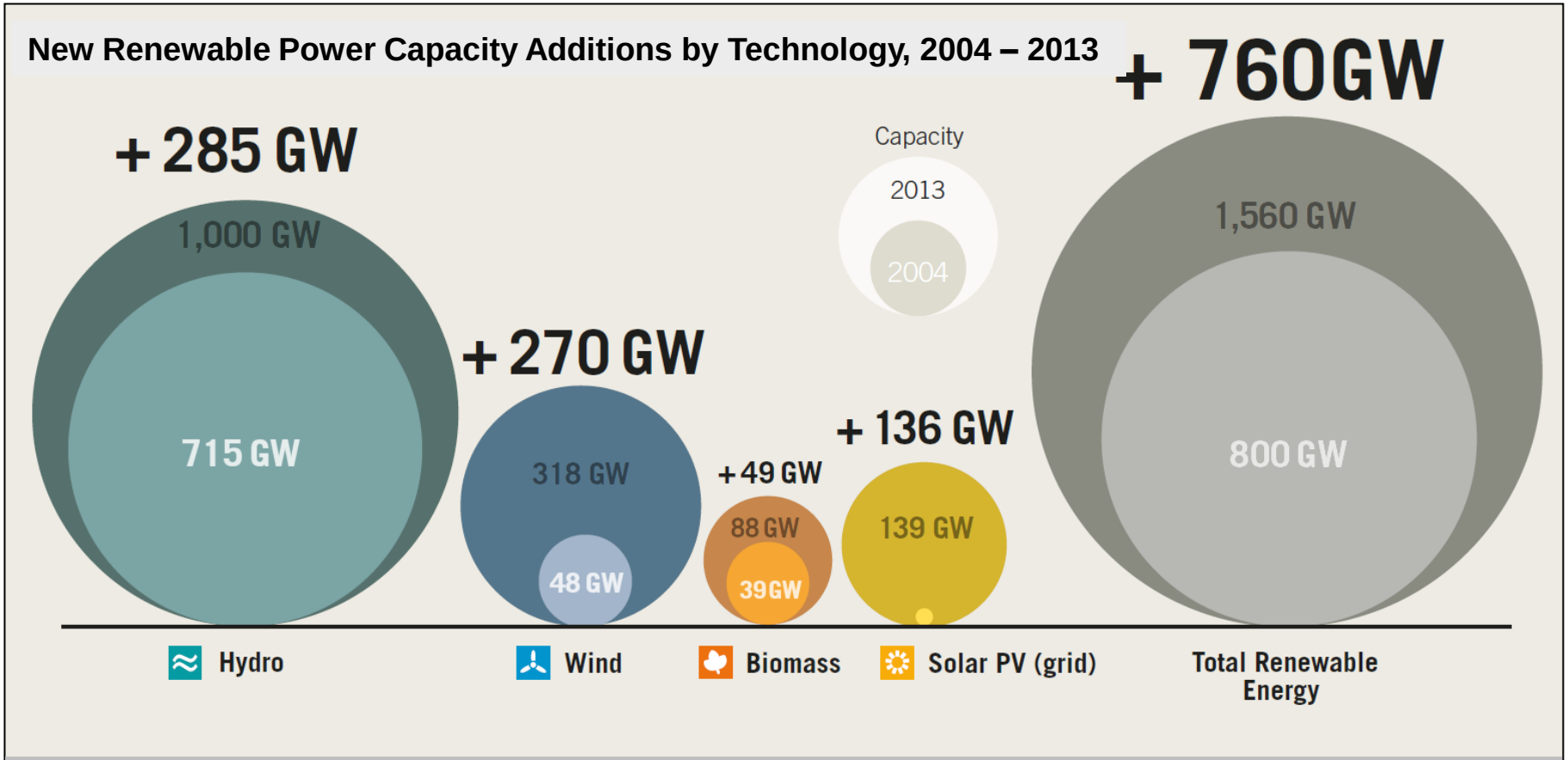
# World renewables-based power sector investments by type (2001-2012) and total generation by type (2012)




**Increase of investments in *new* renewables by a factor 100 within about 20 years)!**

*Source: IEA, 2013 (based on: BNEF, 2013) // REN21, Nov. 2014*

# Ten years of renewable energy progress (2004-2013)




Geothermal figures for 2004 and 2013 were 9 and 12 GW respectively. For CSP, capacity was 0.4 GW in 2004 and 3.4 GW in 2013. These amounts have been included in the Total Renewable Energy calculation.

*Source: REN21, Nov. 2014*

# Global Market Overview – Power Markets

- **Renewable energy comprises more than 26% of global power generation capacity in 2012.**

- **Almost 22% of global electricity was produced from renewable energy (with 16.5% from hydro).**

- **Renewables accounted globally for *just over half (51%)* of the estimated 280 GW of new installed electric capacity in 2012 (and in Europe even *70%).***

- **We are witnessing a revolution in the energy field!**

*Source: REN21, 'Renewables 2013 Global Status Report', June 2013*

# Some recent energy scenario studies

***- Can we achieve a sustainable future? -***

- **Shell, 2013: 'New LENS scenarios'** (*Mountains* and *Oceans*)
  - Global warming will continue up to at least +4°C.
  - Increase energy efficiency: 1.4% per year.
  - Contribution from renewables in 2050: 22%-31%.

  **NO !**

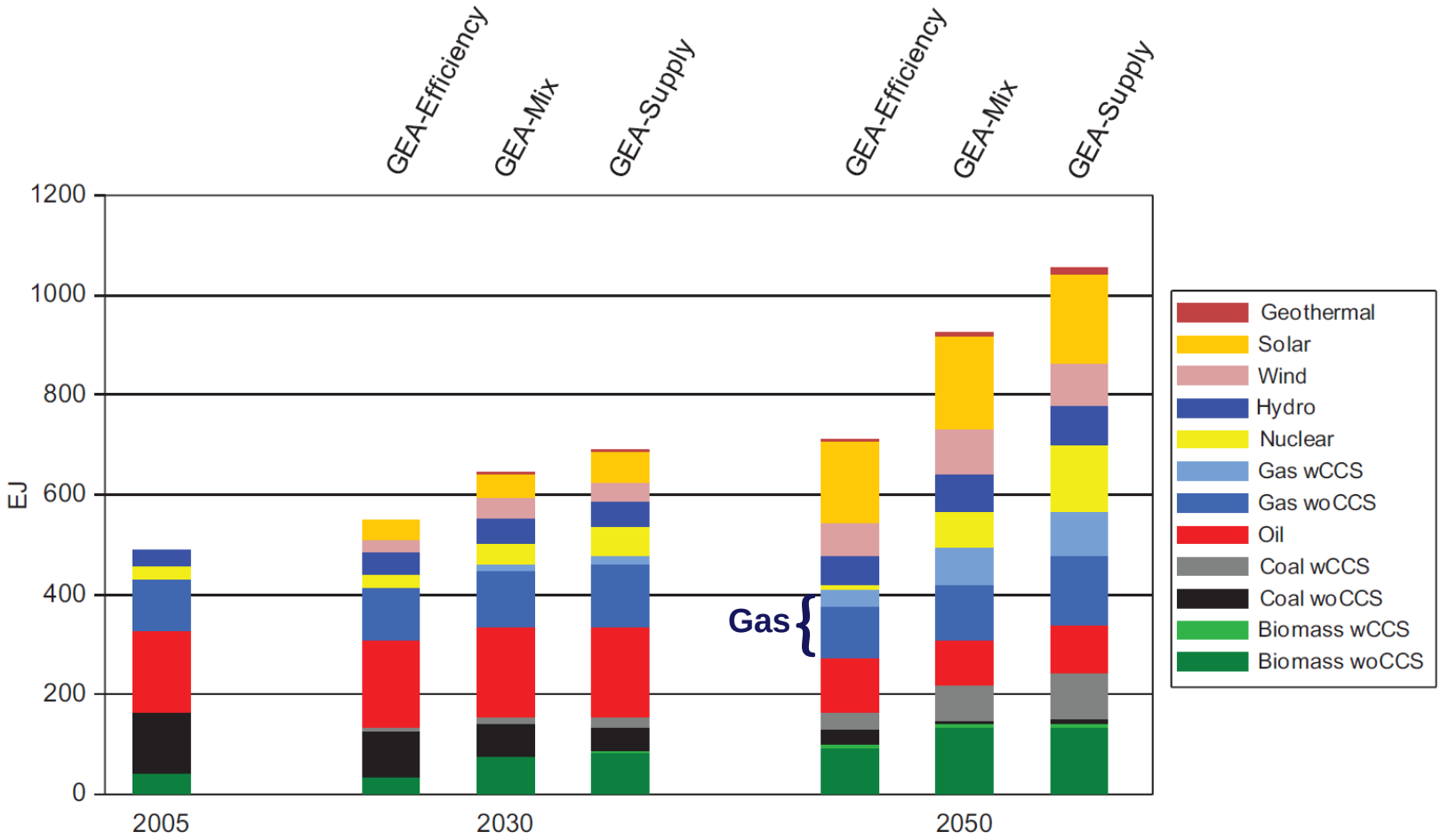
- **GEA, 2012: 'Toward a Sustainable Future'**
  - Many combinations of energy resources, end-use, and supply technologies that can simultaneously address the multiple sustainability challenges.
  - Increase energy efficiency: 1.5% up to 2.2% per year.
  - Contribution from renewables in 2050: 30%-75%.
  - Cumulative storage of $CO_2$ in 2050: up to 250 $GtCO_2$.

  **YES !**

- **Ecofys and WWF, 2011: 'The Energy Report'**
  - A fully sustainable system is possible by 2050.
  - Increase energy efficiency: 3%-4% per year.
  - Almost 100% of all energy carriers, all regions and all sectors of the global energy system can be renewable, by 2050.

  **YES !**

# GEA Energy pathways for Sustainable development



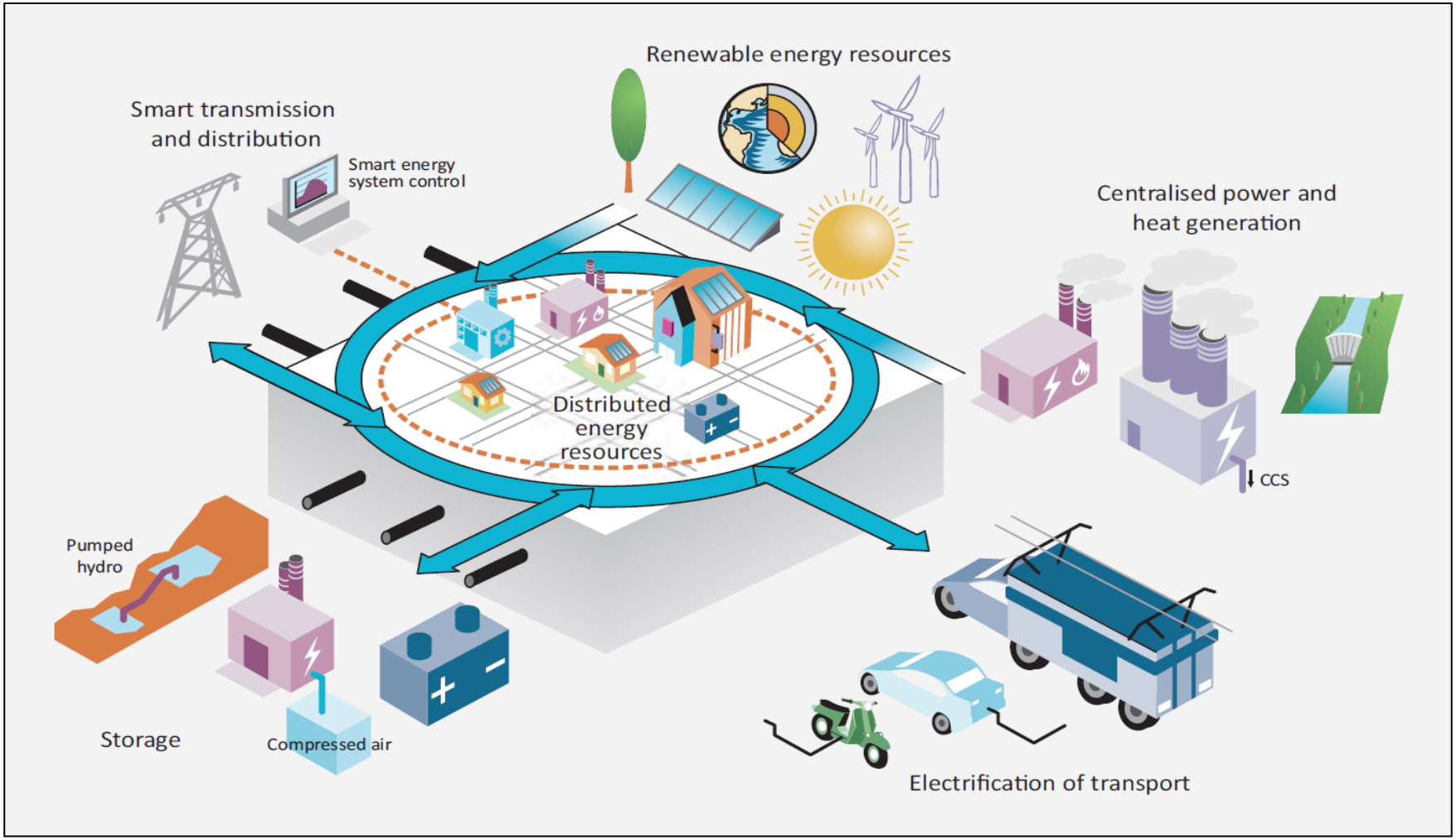

Composition of global primary energy supply in 2005, 2030 and 2050. Here three pathways are presented under an 'unrestricted supply' portfolio and 'conventional transportation' setup.

*Source: GEA (2012), chapter 17, page 1231.*

# How to deal with intermittent renewables (wind / solar-PV)?

… and misunderstandings about P2G and re-utilization of $CO_2$

# The integrated and intelligent electricity system of the future

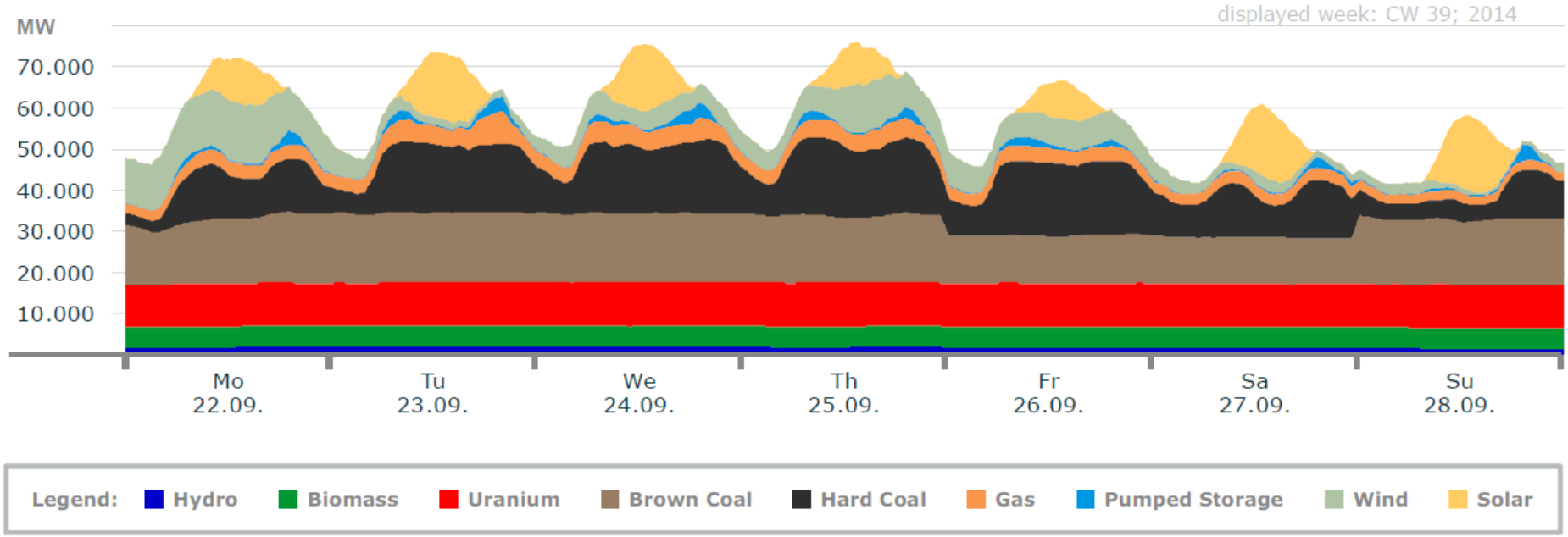



To better integrate all elements of electricity systems will increase complexity, but improve operations, efficiency and resilience while optimising energy resources and investments.

*Source: IEA, 'Energy Technology Perspectives 2014', May 2014*

# *Integrating renewables:*
# Electricity production in Germany
## 2014, Week 39 (22-28 Sept.)

- by solar PV, wind, pumped storage, conventional capacity, biomass and hydropower -

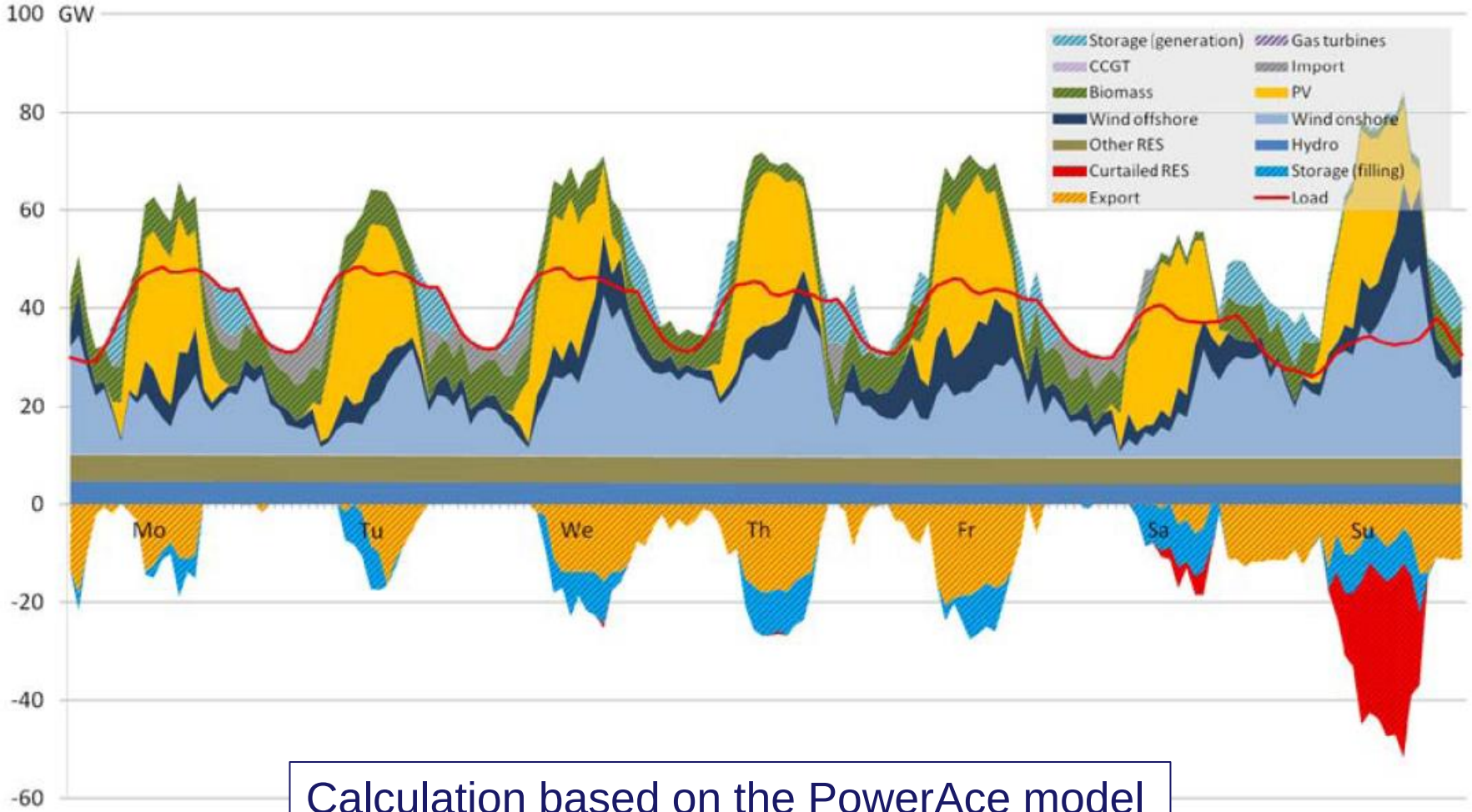



*Source:* Bruno Burger, Fraunhofer ISE, *2014*

# *Integrating renewables:*

## Spain's (possible) load curve and supply in 2050, Week 27

**(on an hourly basis; weather data from 2008)**



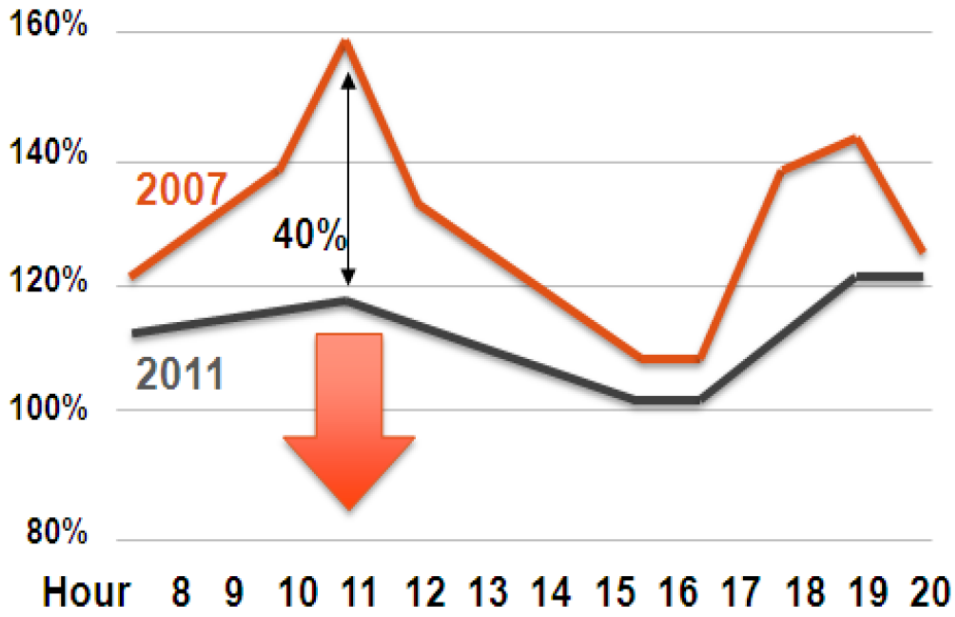

Calculation based on the PowerAce model

*Source: W. Eichhammer, June 2013 / Fraunhofer ISI, 2012*

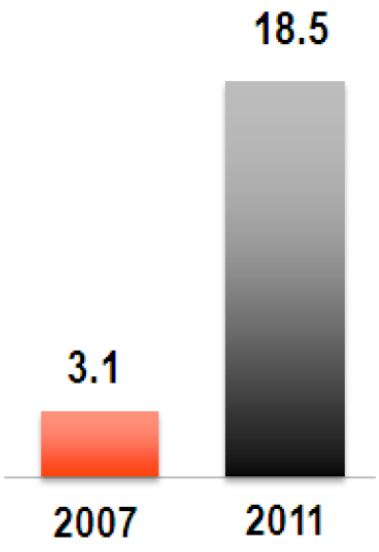
## *Integrating renewables:*

# Effect on peak electricity prices in Germany

**Electricity price index on EPEX in 2007 and 2011 (average peak to base price ratio in %)**



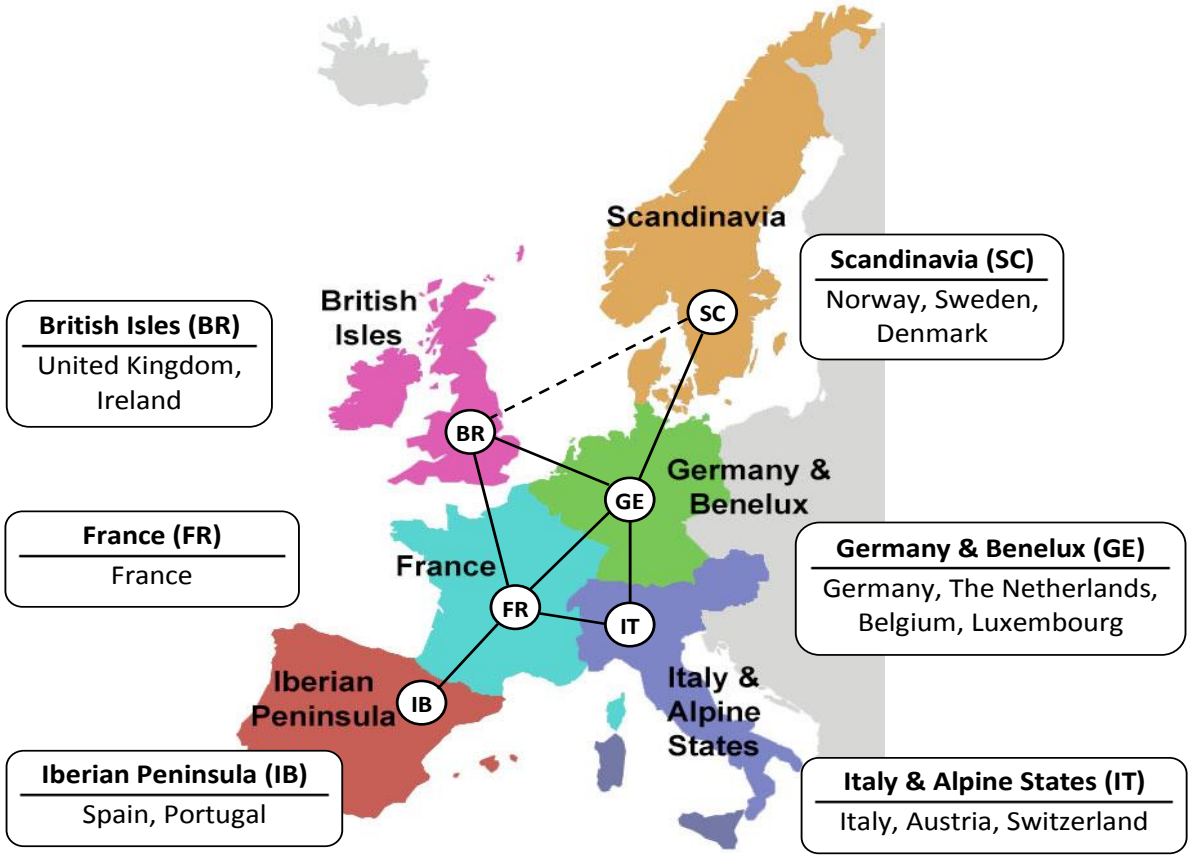

**PV production (TWh)**




**Solar power reduces average trading prices on liquid wholesale markets (Merit Order Effect)**

*Source: Wim Sinke, ECN, 2013 (based on EU PVTP GA 2012 and IZES, Germany, 2012)*

# UU-study: Integration of renewables in low-carbon power systems in Western Europe




Boundary conditions:

- 95% reduction of power sector $CO_2$ emissions in 2050 compared to 1990.
- Maintaining reliability of supply (LoL<2h/yr).
- Increase RE in 2050 up to 40%, 60%, 80%.

***Figure**:* The six regions considered in the UU study using the PLEXOS model to simulate the hourly electricity production in the year 2050.

*Source: Anne Sjoerd Brouwer et al., Utrecht University, March 2015 (to be published)*

# UU-study: Integration of renewables in low-carbon power systems in Western Europe

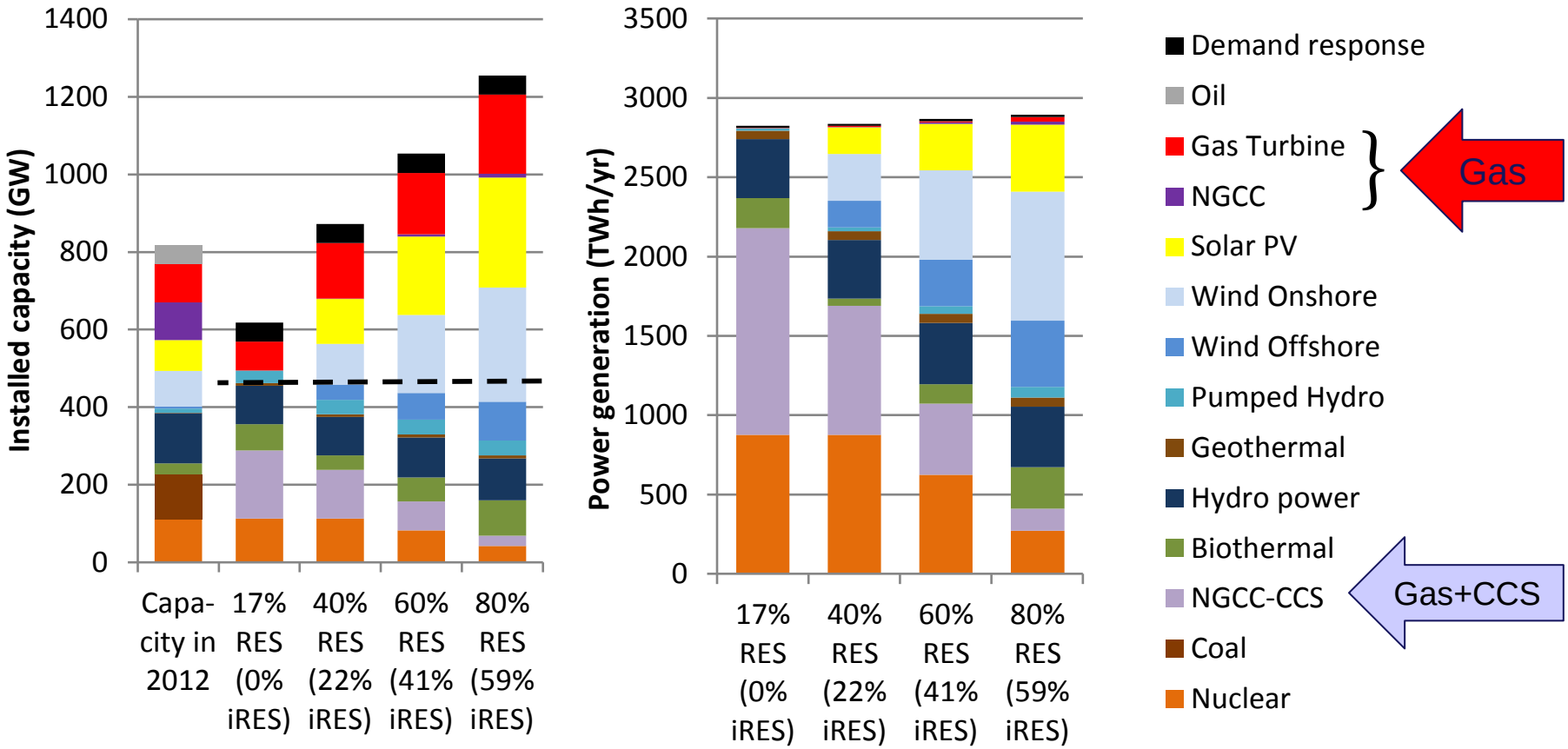



***Figure**: Installed capacities and power generation in the core scenarios in the year 2050. The dashed line depicts the peak load in 2050.*

*Source: Anne Sjoerd Brouwer et al., Utrecht University, March 2015 (to be published)*

# UU-study: Integration of renewables in low-carbon power systems in Western Europe

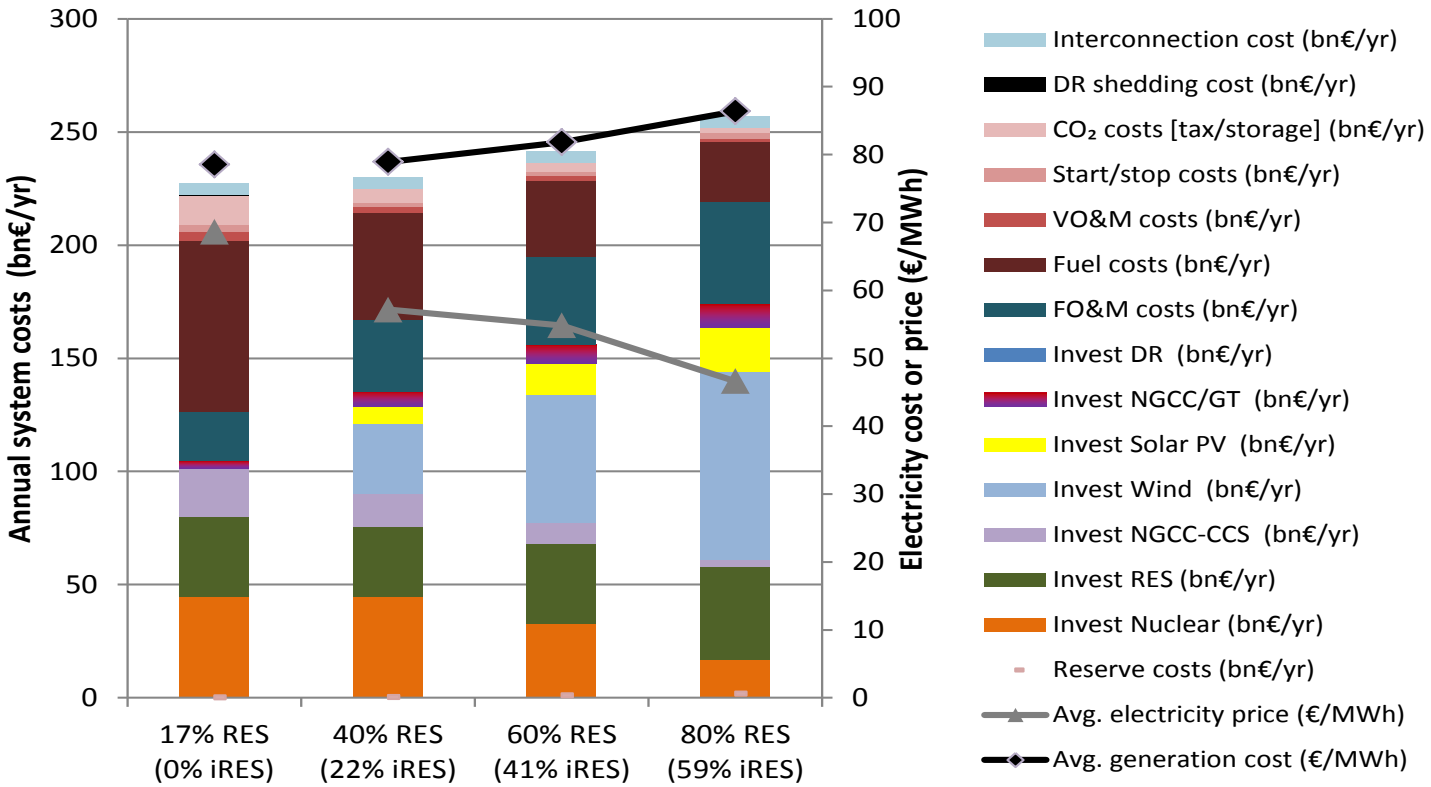



***Figure**: Total annual system costs in the core scenarios in Western Europe in 2050. Also: electricity production costs vs. electricity market price (€/MWh), showing a huge problem that must be solved!!*

*Source: Anne Sjoerd Brouwer et al., Utrecht University, March 2015 (to be published)*

# Interaction between renewable energy supply, conventional energy supply, and the demand side

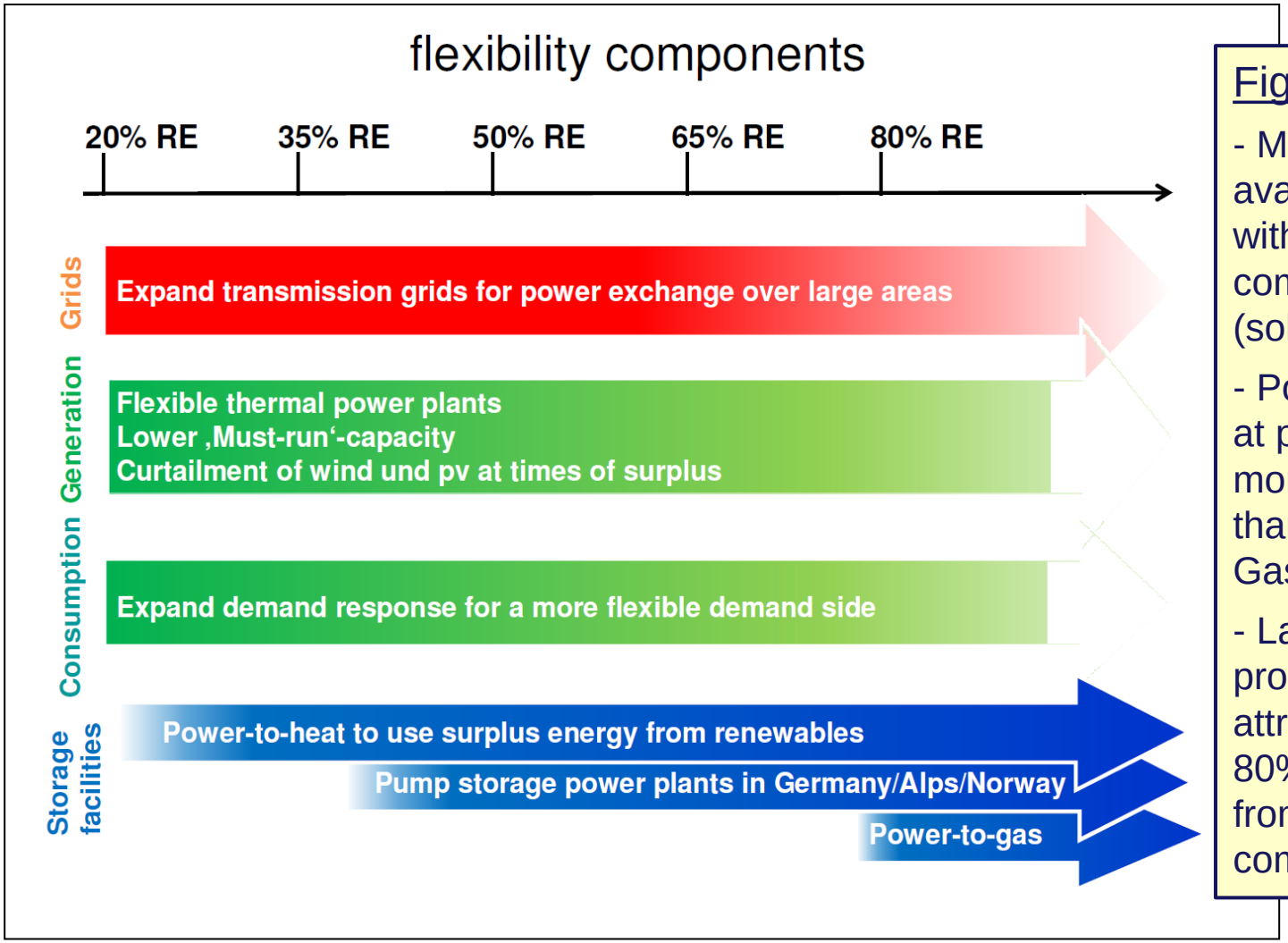



Figure shows:

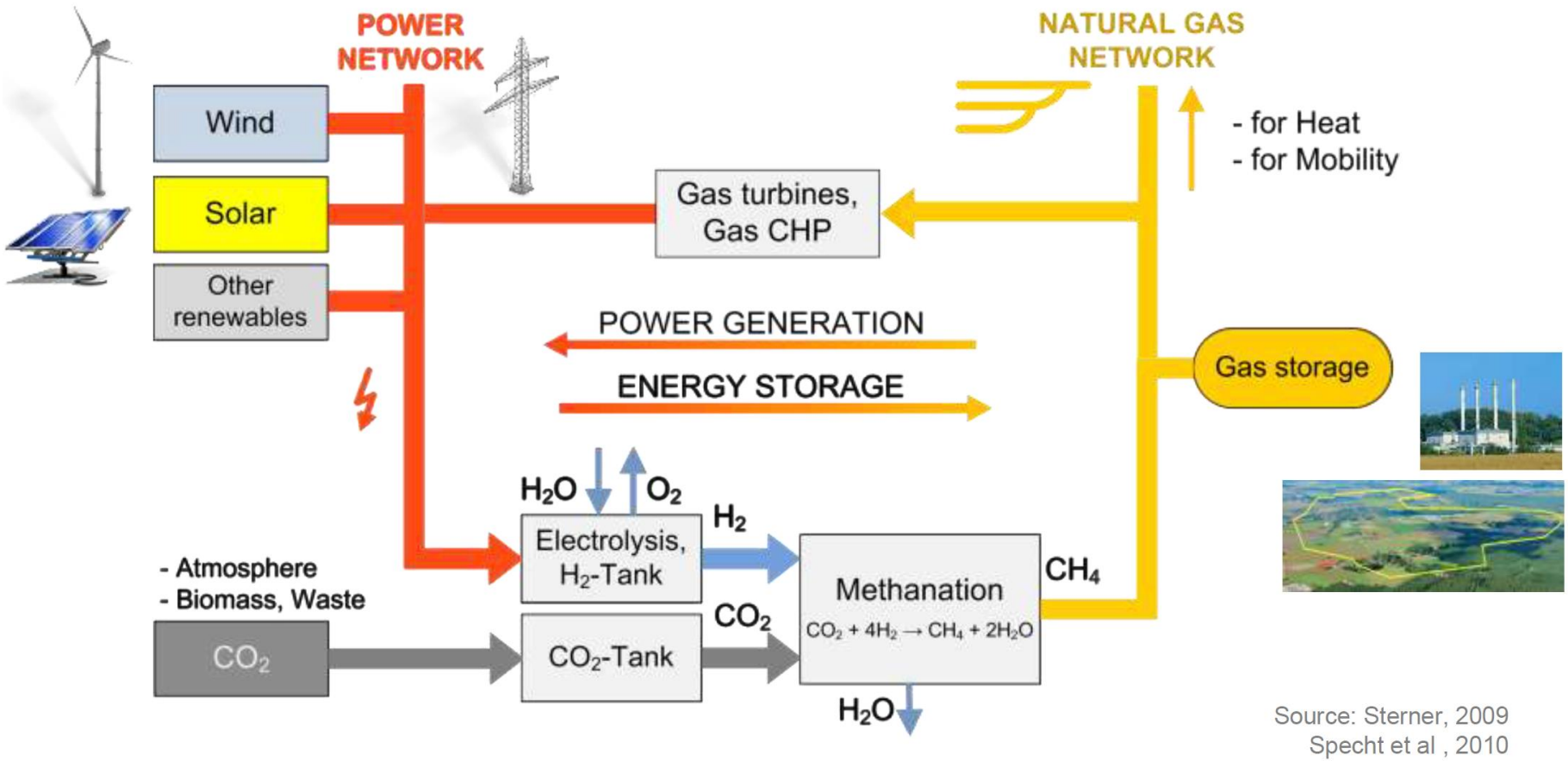
- Many options available to deal with flexibility components (solar-PV & wind).
- Power-to-Heat at present far more attractive than Power-to-Gas (P2G).
- Large scale P2G probably not attractive below 80% contribution from flexibility components!

*Source: Steering Committee of the Renewable Energy Platforms, Germany, 15 Oct. 2012*

# Misunderstandings about Power-to-Gas (P2G) and about re-utilization of $CO_2$

# Power-to-Gas ($H_2$ and/or $CH_4$)

## *Energy storage by coupling electricity and gas networks*




*Source: Michael Sterner, 'The impact of the next big thing: (Solar) energy storage', OTH Regensburg, 2014*

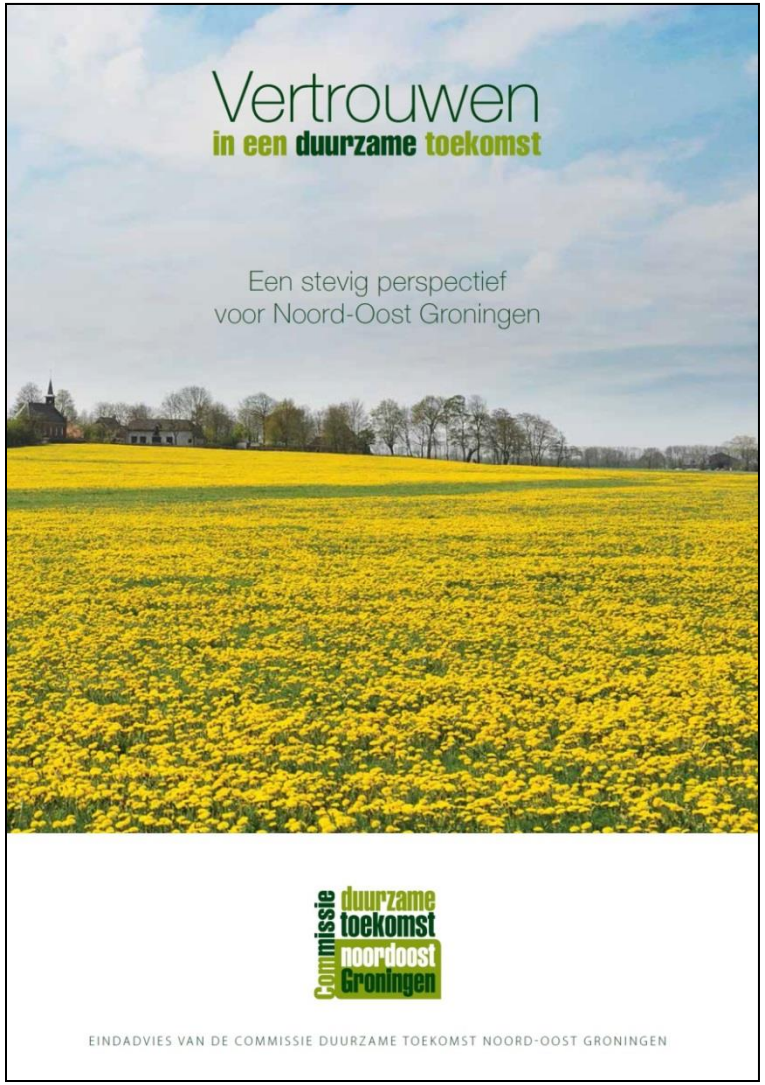
# TKI-Gas:

# Industrieel onderzoek 'Power2Gas and the power of methane'

Projectpartners:

- *DNV GL*
- *Stedin Netbeheer*

*Bron:*
*TKI-Gas (website, oktober 2014)*
*http://www.tki-gas.nl/projecten/tkig01015*




*Bron: Commissie Wim Meijer et al., 2013*

# Advies Commissie 'Duurzame Toekomst Noord-Oost Groningen'

Maatregel 11 (330 mln Euro):

***Ambitieus innovatieprogramma 'Gas 2.0'***

*"De aanwezigheid van de gassector en bijbehorende transportinfrastructuur bieden Power2Gas geweldige mogelijkheden:*

*1. De omzetting van overschotten (duurzame) elektriciteit in gasvormige energiedragers als waterstof en synthetisch aardgas.*

*2. $CO_2$ dat vrijkomt bij verbranding van fossiele brandstoffen kan benut worden door er, met behulp van goedkope duurzame elektriciteit, methaan van te maken.*

*3. Het gassysteem, inclusief de 'nieuwe gassen' als waterstof en synthetisch methaan, kan worden gebruikt om energie op te slaan en het wisselende aanbod van zon- en windenergie in te passen (balanceren)."*

# VNCI over hergebruik $CO_2$ *(CCU / Circulaire Economie)*

## *$CO_2$: grondstof voor methanol*

*"Een mooi voorbeeld van Carbon Capture and Usage is het gebruik van $CO_2$ als grondstof voor methanol, een van de grondstoffen voor onder andere benzine."*

*"Methanol in brandstoffen bijmengen kan een grote impact hebben en niet alleen door een iconische waarde van de oplossing. Bestaande installaties in Japan en Korea hebben een capaciteit van respectievelijk 100 ton per jaar en 3.000 ton per dag."*

## *$CO_2$: grondstof voor polymeren*

*"Het doel is $CO_2$ te gebruiken als grondstof voor polymeren. Bij veel processen komt $CO_2$ vrij als bijproduct."*

*"Bayer en RWE onderzoeken de mogelijkheden om $CO_2$ af te vangen en te gebruiken voor de productie van PU (Polyurethaan). Novomer en DSM hebben een systeem commercieel beschikbaar om $CO_2$ te gebruiken als grondstof voor polymeren."*

*Source: VNCI, 'Road Map Chemistry', 2013*

# Power-to-Gas ($H_2$ and/or $CH_4$)

- From the perspective of climate change, the production of $CH_4$ using $H_2$ from solar/wind and captured $CO_2$ from fossil fuel power plants can only be an option if it doesn't result into an increase of $CO_2$ concentration in the atmosphere.
- Electrochemical production of $H_2$ is very expensive: About 5-10€/kg$H_2$. Also ~25% of the kWh-energy will be lost (but in practice at present ~50%).
- Note: Captured $CO_2$ from a coal plant would cost at present about 80$/t$CO_2$.
- There is a need to develop a $H_2$ production technology with (much) lower energy losses and production costs.
- An interesting approach might be: plasmolytic $H_2$ production:

  *step 1*: CO from $CO_2$ ($CO_2 \rightarrow CO + ½ O_2$)
  *step 2*: water-gas shift reaction ($CO + H_2O \rightarrow CO_2 + H_2$)
  *step 3*: Separating $H_2$ from $CO_2$ and re-use $CO_2$ in step 1

*Source: Partly based on a discussion with Richard van de Sanden, DIFFER, NL, 7 January 2014.*

# Misunderstandings about re-utilization of $CO_2$

- Re-utilization of captured $CO_2$ from fossil fuel power plants is more and more promoted [see e.g.: Chemical Magazine; VNCI; TV program 'Labyrint'; Report Cie Meijer (Noord-Groningen); NWO and FOM research progr.; EDGaR progr., TKI-Gas, URGENDA, etc.].
- **But: From the perspective of climate change it can only be an option if the emission of $CO_2$ to the air is reduced, and about 25-30 years from now completely avoided. (Thereafter $CO_2$ emissions should become even negative!)**

<u>Consequently</u>:

- Re-utilization of fossil $CO_2$ in horticultures: not a permanent solution when striving for zero GHG emissions.
- Re-utilization of $CO_2$: no problem when $CO_2$ from biomass.
- Re-utilization of fossil $CO_2$: only in a really circular approach!
- Massive application of methanation of $H_2$ only with air capture of $CO_2$. Cost $CO_2$ ~$600/tonne *(Source: Am. Phys. Soc., 2011).*

# Thanks!

**Wim Turkenburg**

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