Een CO2-vrije energievoorziening in 2050: implicaties voor het elektriciteitssysteem

Aanpak en enkele resultaten van FLEXNET

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KIVI symposium
Utrecht, 20 april 2017

Agenda

- Introduction of FLEXNET project
- Phase 1 (The demand for flexibility):
  - Summary of approach and main results (national level)
- Phase 2 (The supply of flexibility):
  - Approach and results COMPETES (ECN, national level)
  - Approach and main results OPERA (ECN, national level)
- Summary of major findings and conclusions

Disclaimers

- FLEXNET is an ongoing project (‘work- in-progress’). So, all the input and output data are semi-final, intermediate results that may be further updated during the progress of the project.

- This presentation is for internal purposes only – i.e. mainly to get feedback – and, therefore, it may not be quoted or distributed externally without permission of the author/project leader.

Introduction of the FLEXNET project

Project data

- Project title: Demand and supply of **FLEX**ibility in a more sustainable energy system of the **NET**herlands (FLEXNET)
- Project under TSE tender System Integration (EZ/RVO.nl)
- Objective: to analyse (quantitatively) demand and supply of flexibility of the energy (power) system in the Netherlands up to 2050 at the national and regional level
- Duration: April 2015 – June 2017
- Consortium:

ECN

netbeheer nederland
energie in beweging

GasTerra
Energizing the future

energie-nederland

Approach of phase 1: the demand for flexibility

Definition of flexibility

- Brief, simple definition:
  - "Flexibility is the ability of an energy system to respond to changes in residual power load."

- Characteristics of definition:
  - The problem (i.e. the demand for flexibility) is caused primarily by the power system;
  - The solution (i.e. the supply of flexibility) may come from the energy system as a whole;
  - Focus is on *changes* in *residual* power load, i.e. total power load minus power production from variable renewable energy (VRE).

Three perspectives ('causes') of the need for flexibility

1) *Expected* variation of the residual power load, in particular due to the *variability* of electricity generation from VRE sources such as sun/wind.
   - Positive/negative residual load
   - Positive/negative change in (hourly) residual load ('ramp up/down')

2) *Unexpected* variation of the residual power load, notably due to the *uncertainty* (less predictability) of electricity from VRE sources ('*forecast error*').

3) Network congestion (i.e. flexibility as a means of congestion management)

- Focus of today is on the first perspective

Scenarios & focal years

Two scenarios:

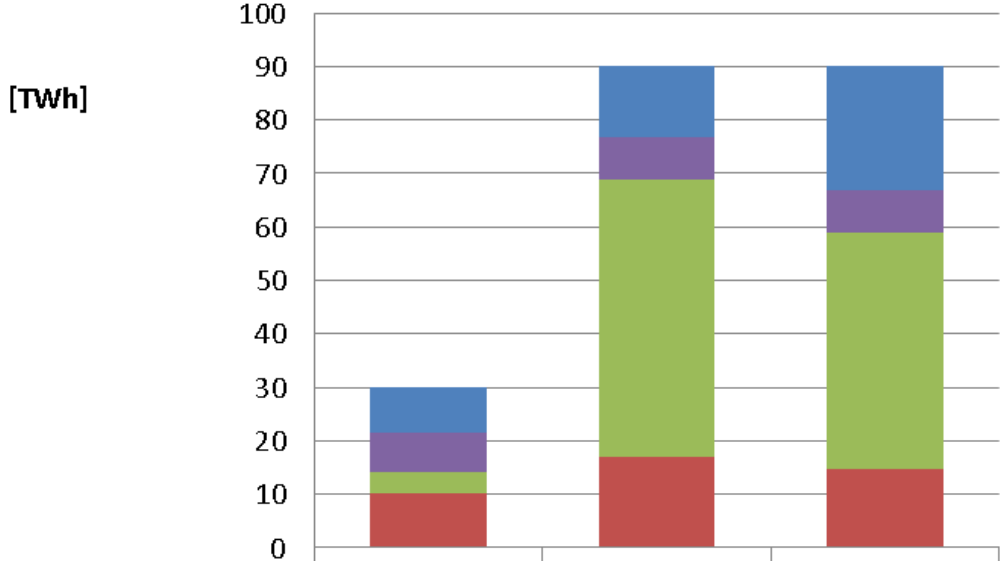
- Reference scenario:
  - Based on ‘accepted policy scenario’ of NEV 2015;
  - Major characteristics:
    - Strong growth of installed VRE capacity up to 2030;
    - Weak growth of additional electrification;
  - Focal years: ‘R2015’, ‘R2023’ and ‘R2030’.

- Alternative scenario:
  - Similar to the reference scenario with one major exception:
    - *Strong* growth of additional electrification;
  - Focal years: ‘A2023’, ‘A2030’ and ‘A2050’;
  - A2050: based on P2G-study (set of 85% GHG reduction scenarios)

Major scenario assumptions & input values (1): power load

		Reference scenario			Alternative scenario		
	Unit	2015	2023	2030	2023	2030	2050
Electrification/power load							
Share of EVs in total passenger cars	[%]	2.0%	4.7%	9.6%	12.0%	32.0%	74.0%
Share of HPs in total households	[%]	2.1%	6.5%	7.9%	8.0%	20.0%	69.0%
Conventional load	[TWh]	111.8	111.6	112.2	111.6	112.2	112.0
Additional load EVs	[TWh]	0.5	1.2	2.5	3.0	8.4	21.5
Additional load HPs	[TWh]	0.2	0.8	0.9	0.9	2.5	9.3
Add. load 'Other electrification'	[TWh]	0.0	0.0	0.0	10.0	30.0	90.0
Total final load	[TWh]	112.5	113.5	115.6	125.5	153.1	232.8

Major scenario assumptions & input values (2): additional electrification

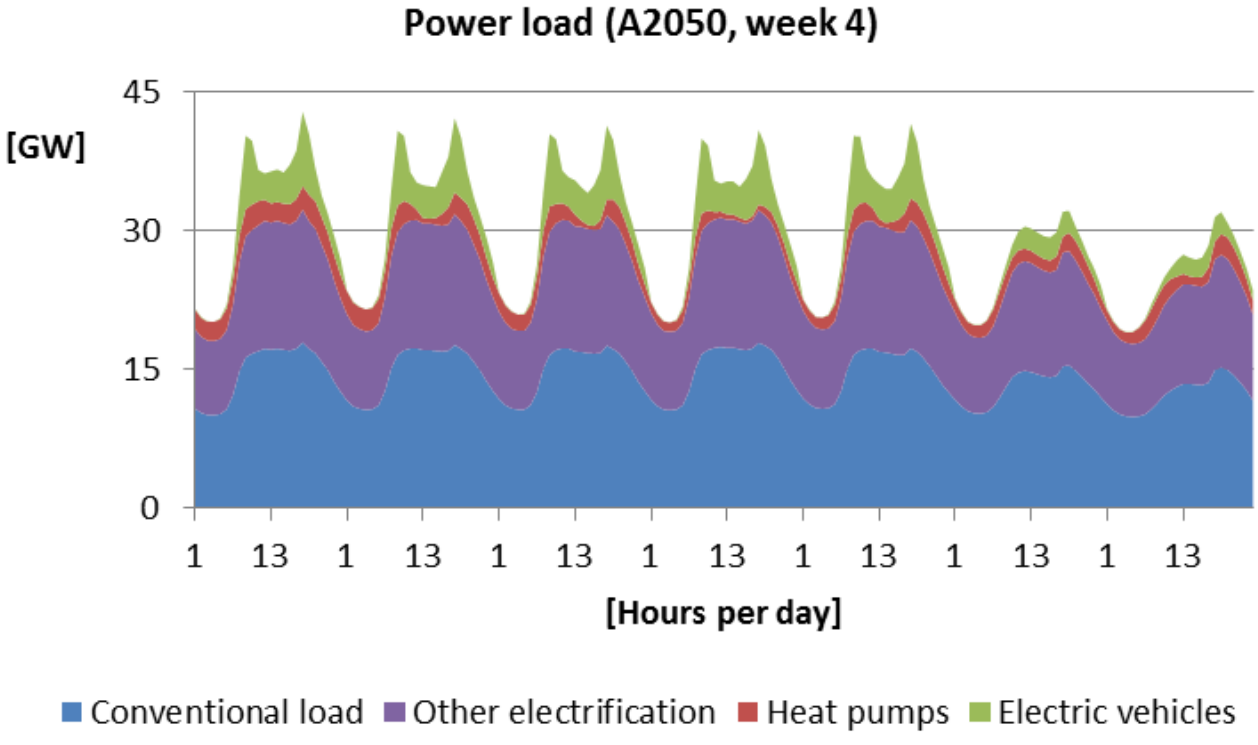


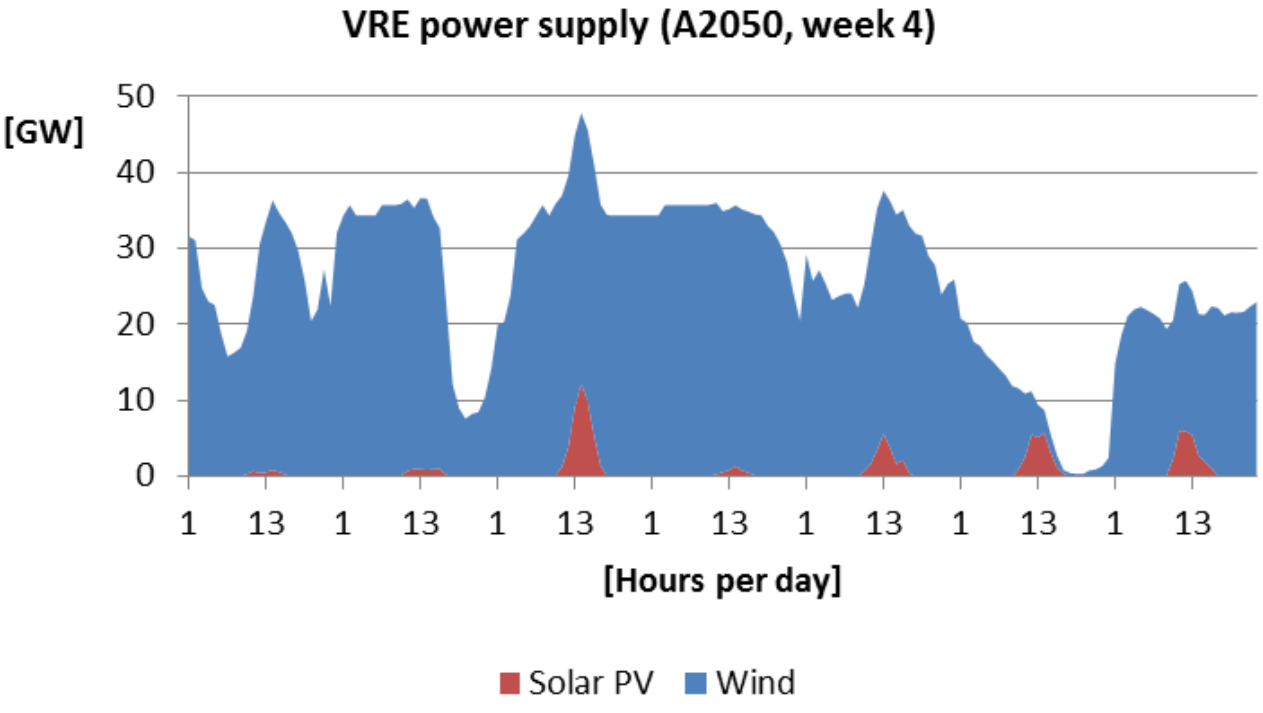
	A2030	A2050	C2050
Other electrification	8.5	13.2	23.1
Power to ammonia (P2A)	7.4	7.9	7.9
Power to gas (P2G)	3.9	51.8	44.2
Power to heat (P2H)	10.2	17.1	14.7

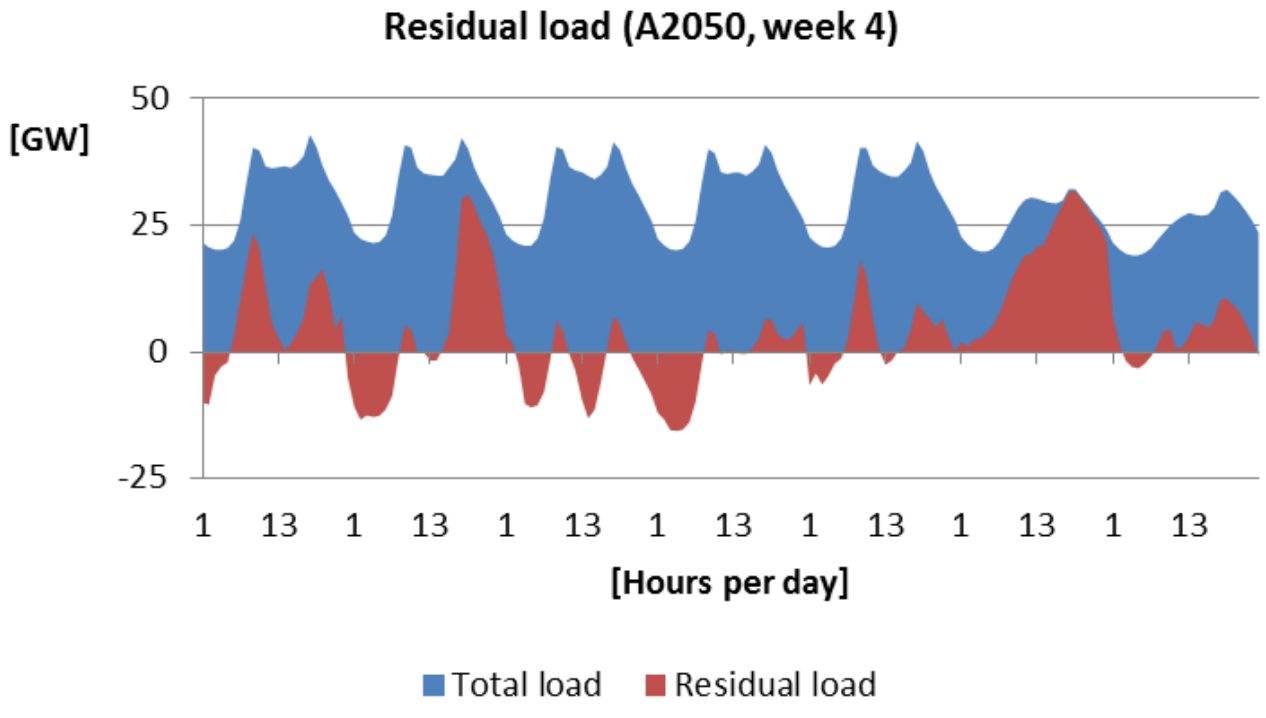
Major scenario assumptions & input values (3): VRE supply

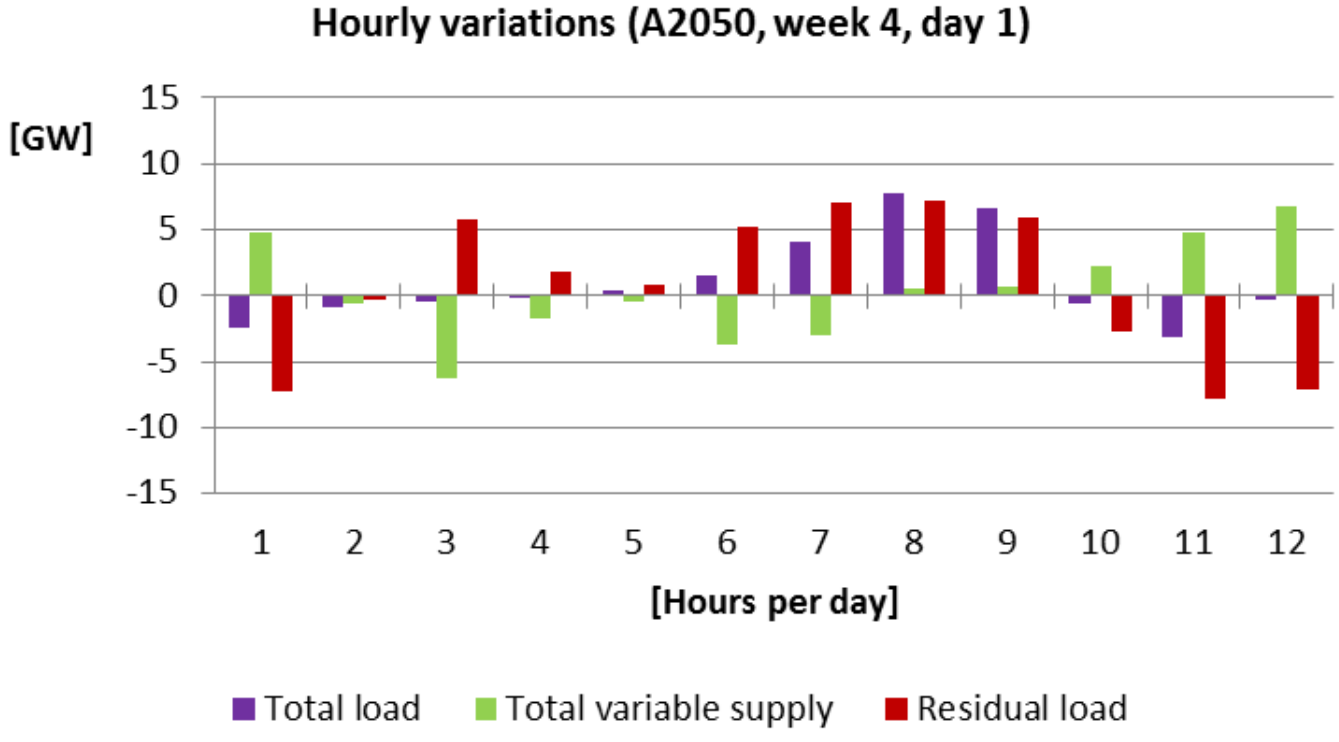
		Reference scenario			Alternative scenario		
	Unit	2015	2023	2030	2023	2030	2050
Power from variable renewable energy (VRE) sources							
VRE installed capacity:							
• Wind on land	[MWe]	2,630	6,020	6,330	6,020	6,330	6,800
• Wind on sea	[MWe]	360	4,120	6,060	4,120	6,060	28,900
• Sun PV	[MWe]	1,530	8,640	15,130	8,640	15,130	56,100
• Total VRE power capacity	[MWe]	4,520	18,780	27,520	18,780	27,520	91,800
VRE power generation:							
• Wind on land	[TWh]	6.1	16.1	18.1	16.1	18.1	19.7
• Wind on sea	[TWh]	1.3	16.8	25.0	16.8	25.0	120.2
• Sun PV	[TWh]	1.3	7.1	12.4	7.1	12.4	46.0
• Total VRE output	[TWh]	8.6	40.0	55.5	40.0	55.5	185.9
• Total VRE output as share of total final load	[%]	8	35	48	32	36	80

Main results of phase 1

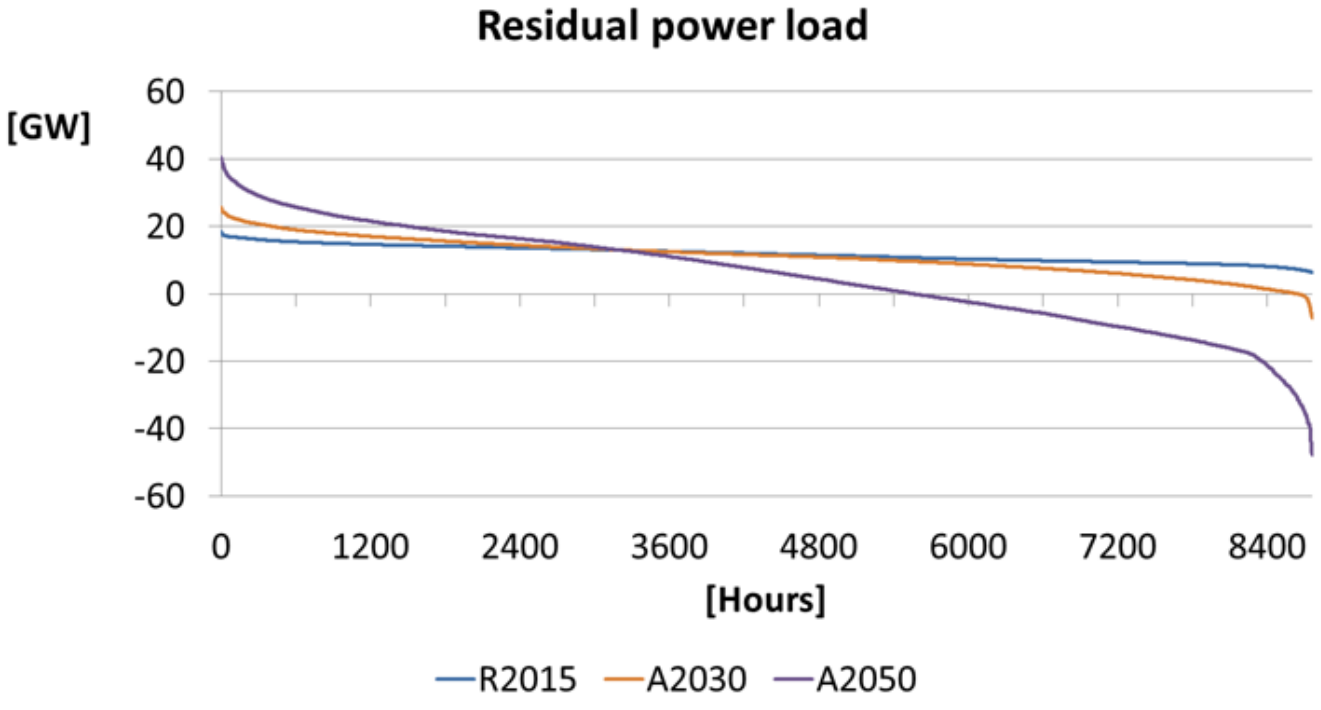

Power load (A2050, week 4)
[GW]
45
30
15
0
1
13
[Hours per day]
Conventional load
Other electrification
Heat pumps
Electric vehicles


VRE power supply (A2050, week 4)
[GW]
50
40
30
20
10
0
1
13
1
13
1
13
1
13
1
13
1
13
1
13
[Hours per day]
Solar PV
Wind

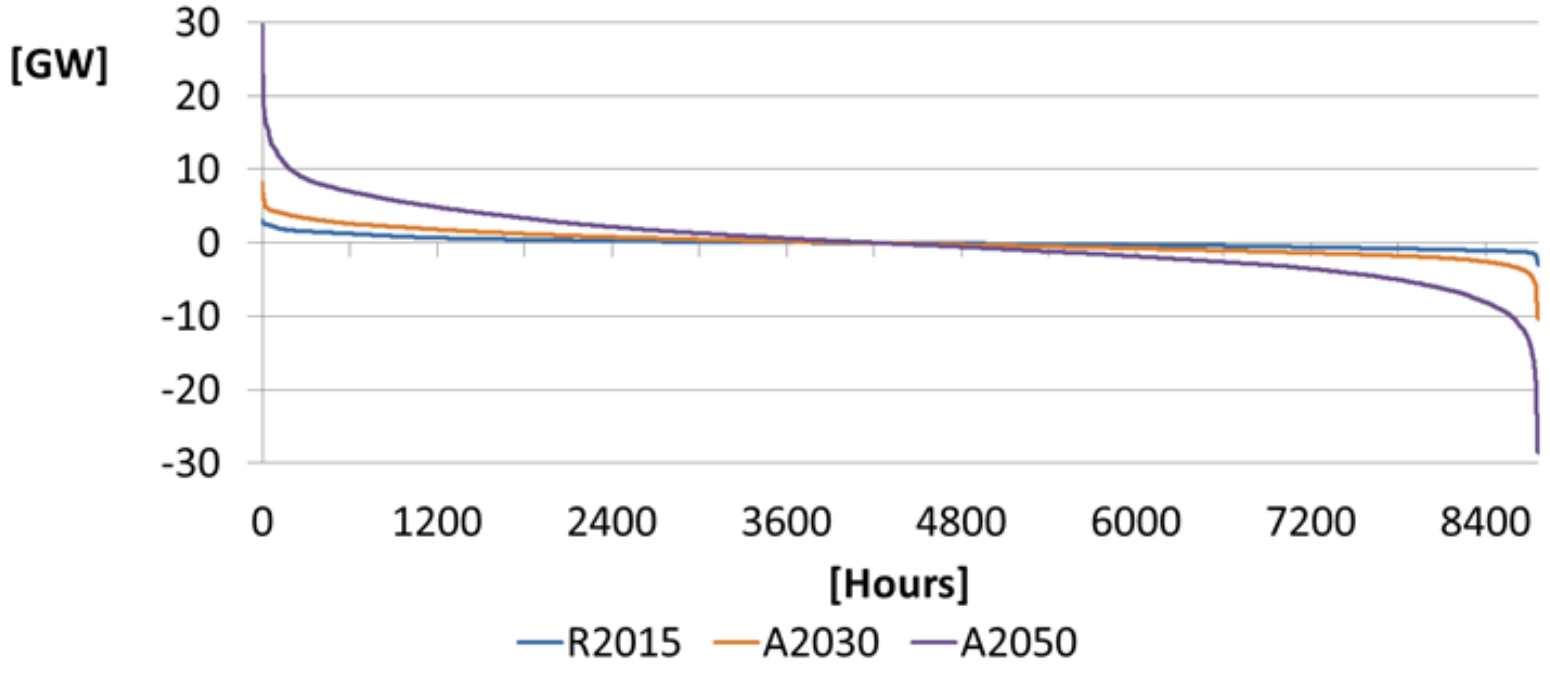

Residual load (A2050, week 4)
[GW]
50
25
0
-25
1
13
1
13
1
13
1
13
1
13
1
13
1
13
[Hours per day]
Total load
Residual load


Hourly variations (A2050, week 4, day 1)
[GW]
15
10
5
0
-5
-10
-15
1
2
3
4
5
6
7
8
9
10
11
12
[Hours per day]
Total load
Total variable supply
Residual load

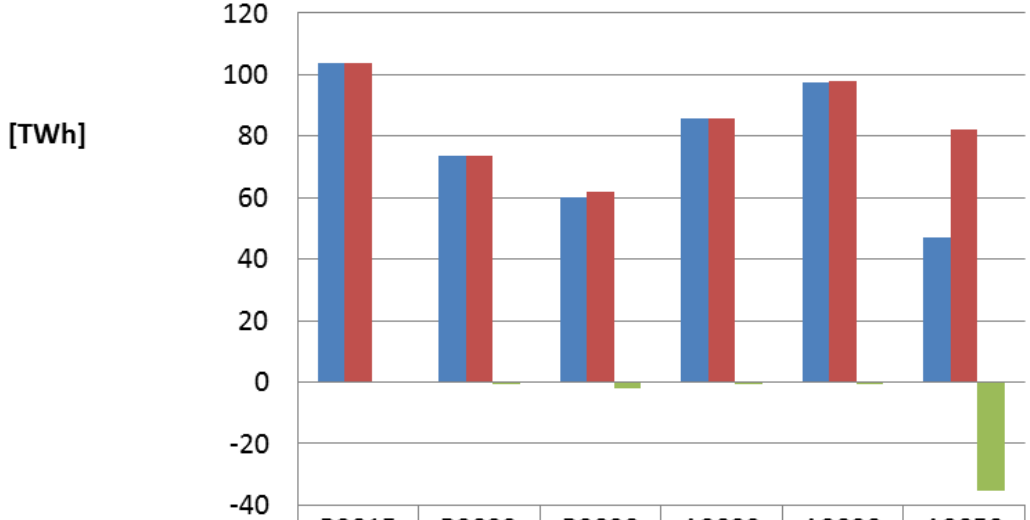
Duration curve



Duration curve of ‘ramps’ (hourly variations of residual power load)



Residual load
(‘VRE shortages/surpluses’)



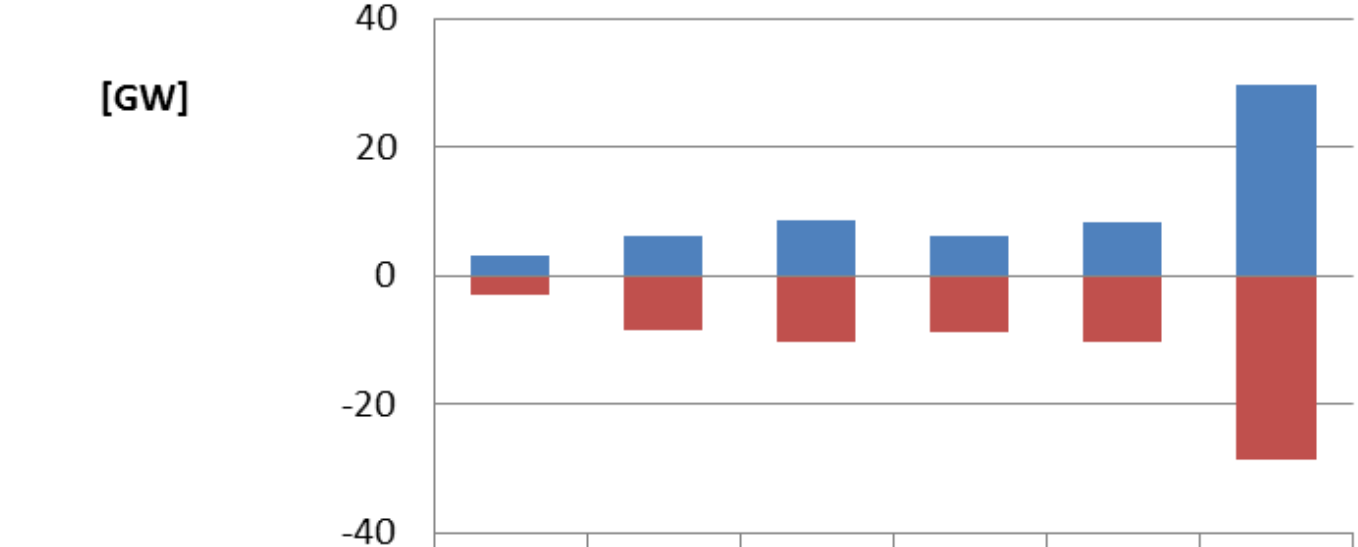
	R2015	R2023	R2030	A2023	A2030	A2050
Total residual load	103,8	73,6	60,2	85,6	97,6	46,8
Positive residual load (VRE shortage)	103,8	73,7	62,0	85,6	97,8	81,9
Negative residual load (VRE surplus)	0,0	-0,1	-1,8	0,0	-0,2	-35,1

Demand for flexibility due to the incidence of hourly VRE surplus

		Reference scenario			Alternative scenario		
	Unit	2015	2023	2030	2023	2030	2050
Total hourly VRE surplus (per annum)[a]	[TWh]	0	0.1	1.8	0.0	0.2	35.1
Total number of surplus hours (p.a.)	[hrs]	0	145	873	29	120	3217
Number of consecutive surplus hours	[hrs]	0	10	21	8	10	61
Maximum VRE surplus (per hour)	[GW]	0	4.7	10.6	3.6	7.2	47.9

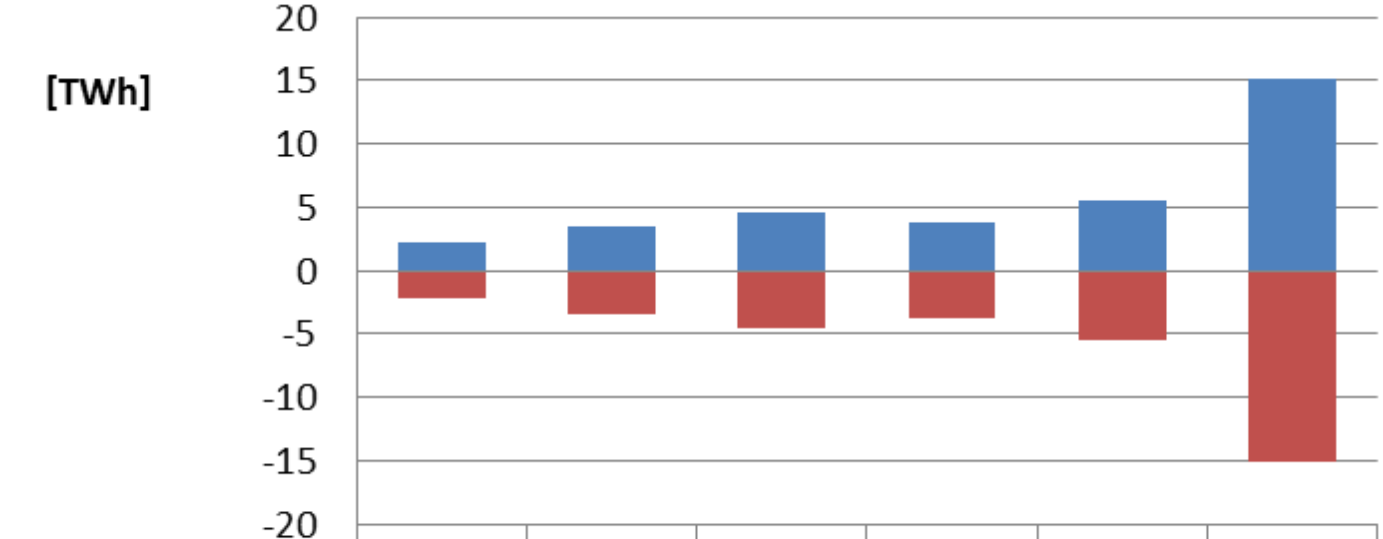
a) Total hourly VRE surplus refers to those hours that show a surplus of power generation from VRE resources compared to hourly load ('negative residual load') but does not include those hours in which there is an actual 'positive residual load'.

Need for maximum hourly ramps ('flexibility')



	Reference scenario			Alternative scenario		
	2015	2023	2030	2023	2030	2050
Maximum ramp-up	3.0	6.3	8.5	6.2	8.2	29.6
Maximum ramp-down	-3.1	-8.6	-10.2	-8.7	-10.4	-28.6

Need for total annual hourly ramps (‘flexibility’)



	2015	2023	2030	2023	2030	2050
	Reference scenario			Alternative scenario		
Total ramp-up	2.2	3.5	4.6	3.8	5.5	15.2
Total ramp-down	-2.2	-3.5	-4.6	-3.8	-5.5	-15.2

Phase 2, the supply of flexibility: approach

Aanpak fase 2: doel & middelen

- **Doel**: het bepalen, kwantificeren en optimaliseren van de aanbodmix van flexibiliteitsopties ten behoeve van de elektriciteitssector
- **Middelen**:
  - **COMPETES** (EU elektriciteitsmodel):
    - Voordeel:
      - Bevat gedetailleerde informatie over (flexibele) opwekopties
      - Bevat relaties (interconnecties) tussen EU landen (‘handelsoptie’)
    - Nadeel:
      - Bevat weinig of geen overige flexopties (opslag; vraagreactie)
  - **OPERA** (NL energiemodel):
    - Voordeel:
      - Bevat gedetailleerde informatie over alle sectoren en (flexibele) technologieopties
      - Geïntegreerde analyse (optimalisatie; systeemintegratie)
    - Nadeel:
      - Bevat geen externe (handels)relaties met het buitenland

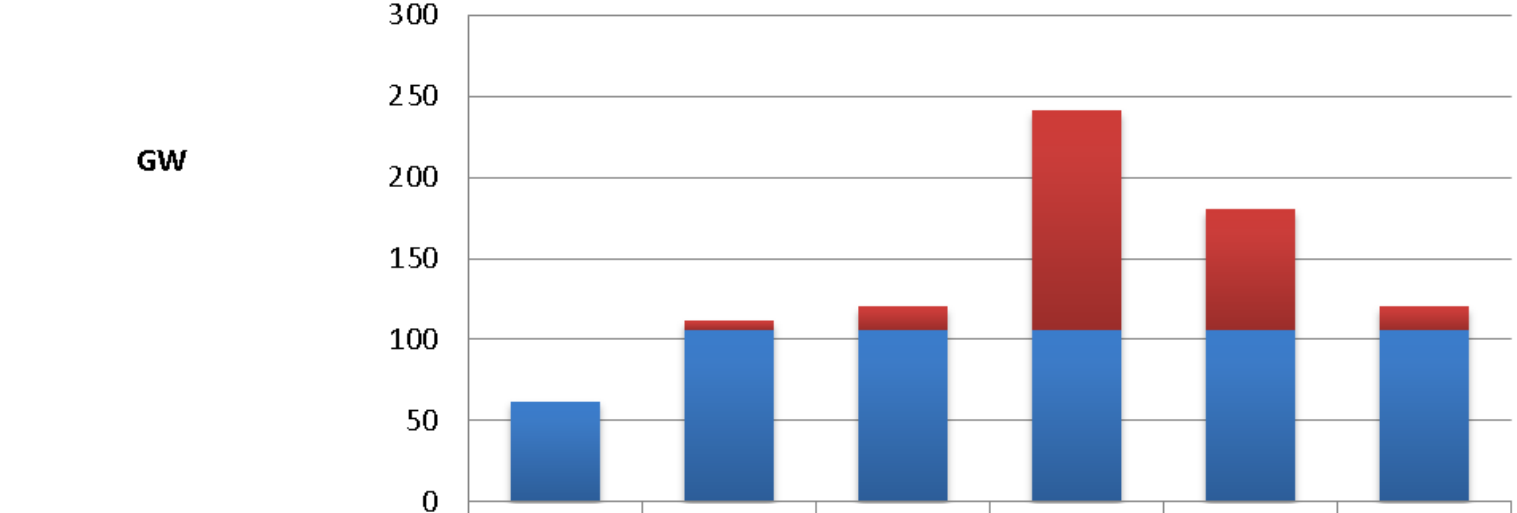
Aanpak fase 2: stappen

- **COMPETES**:
  - Output fase 1 (vraag- en aanbodprofielen) is input voor fase 2.1 (COMPETES);
  - Opschalen van NL scenario's naar EU scenario's;
  - Runnen van geïntegreerde investeringsmodule voor het bepalen van het geïnstalleerde vermogen in opwekkings- en interconnectiecapaciteit per EU land;
  - Runnen van geïntegreerde productie- en handelsmodule voor het bepalen van de opwekking en invoer/uitvoer van elektriciteit op uurbasis (inclusief e-prijzen);
  - Bepalen van aanbodmix van flexopties, in het bijzonder van (i) buitenlandse handel, (ii) flexibele centrales, en (iii) zon/wind curtailment.

- **OPERA:**
  - Output fase 1 + output COMPETES (handelsprofielen) is input voor fase 2.2 (OPERA);
  - Runnen van modelscenario's voor het bepalen en nader differentiëren van het binnenlandse aanbod van elektriciteit en flexopties, inclusief opslag, vraagresponse, P2X, etc.

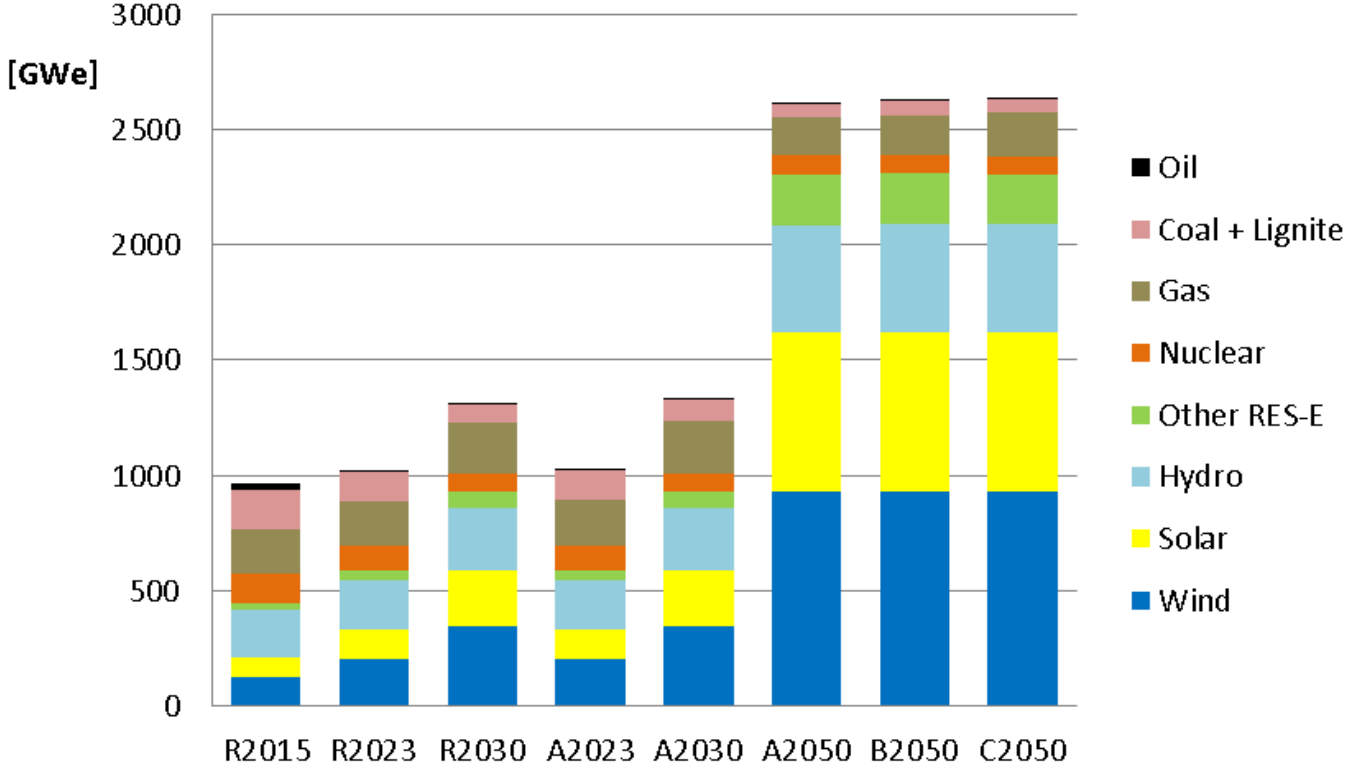
Phase 2:
COMPETES results

Total interconnection capacity EU

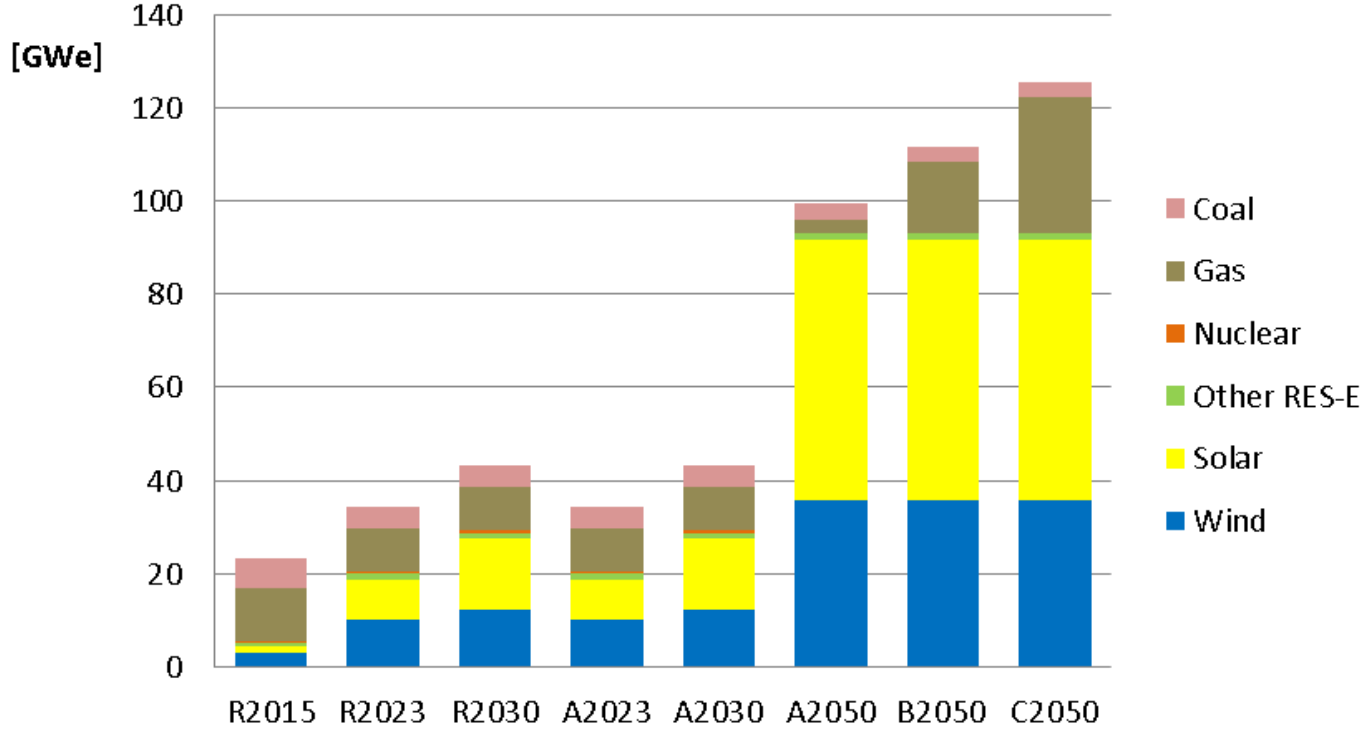


	R2015	R2030	A2030	A2050 (100%)	B2050 (50%)	C2050 (0%)
New transmission capacity	0	6	15	135	75	15
Baseline capacity (TYNDP2016)	62	106	106	106	106	106

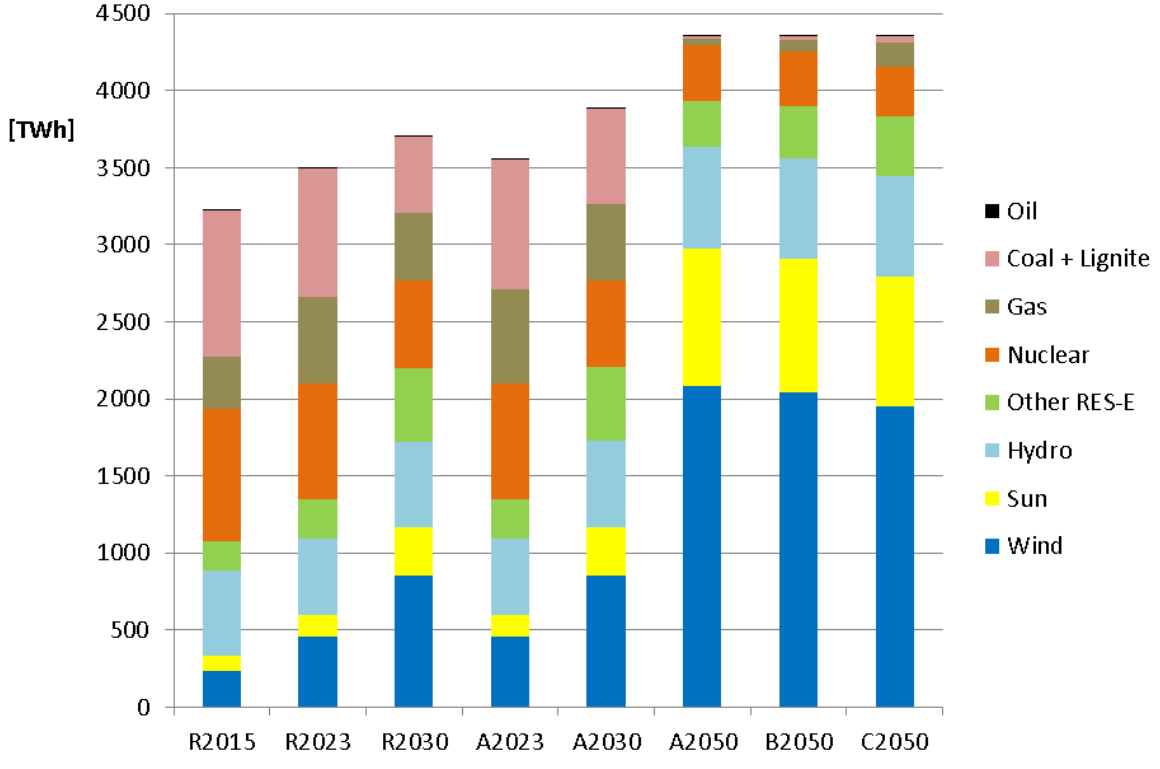
Total installed power generation capacity EU



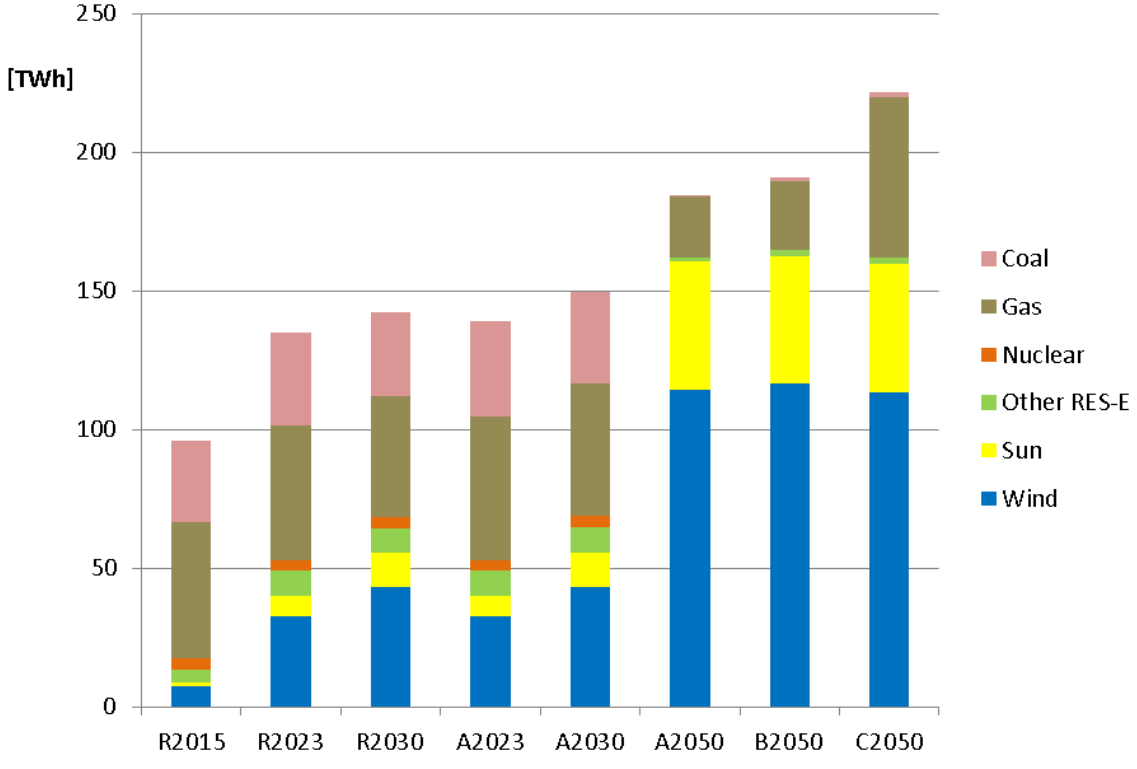
Total installed power generation capacity NL



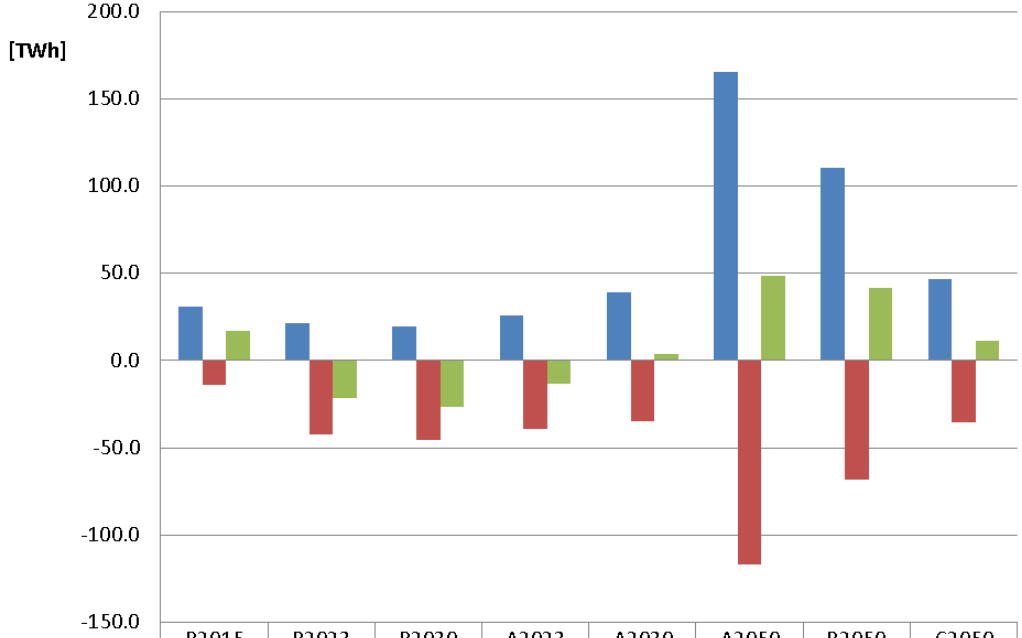
Power generation mix EU



Power generation mix NL

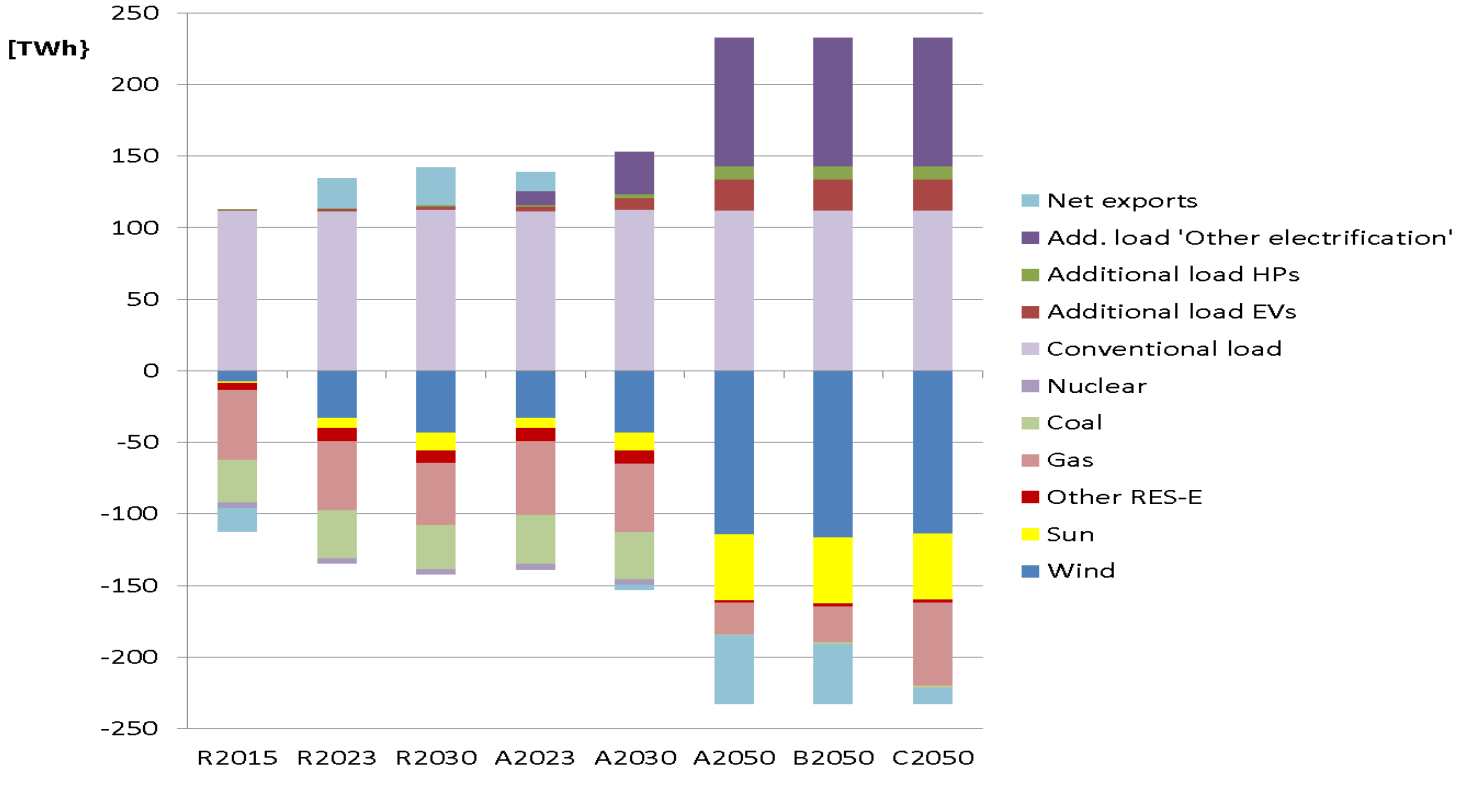


Power trade NL

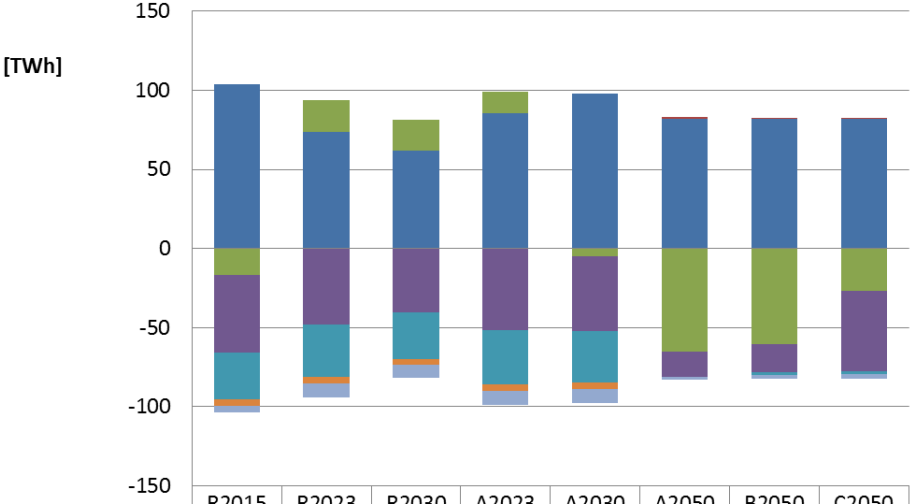


	R2015	R2023	R2030	A2023	A2030	A2050	B2050	C2050
Imports	30.5	21.2	19.2	25.5	38.8	165.0	110.4	46.6
Exports	-13.8	-42.5	-45.9	-38.9	-35.1	-116.8	-68.6	-35.6
Net imports	16.7	-21.3	-26.7	-13.5	3.6	48.2	41.7	11.0

Power balance NL

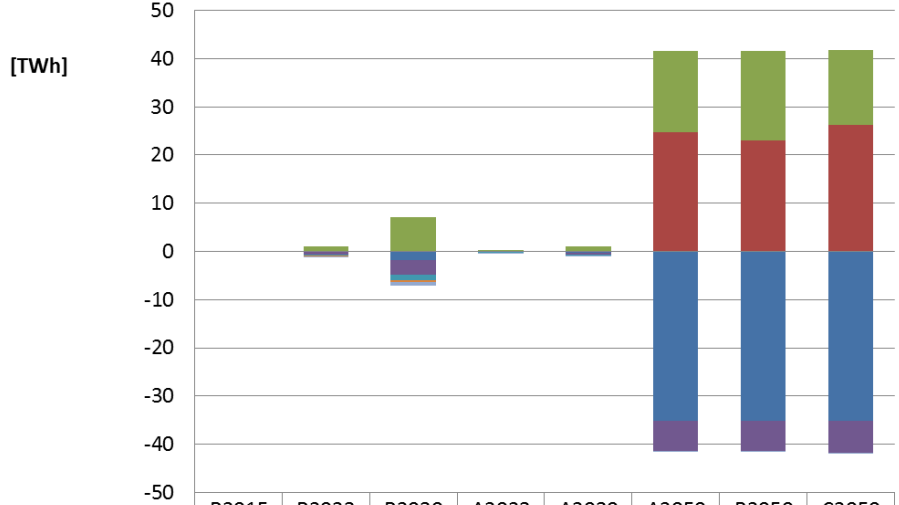


Positive residual demand/supply ('VRE shortage')



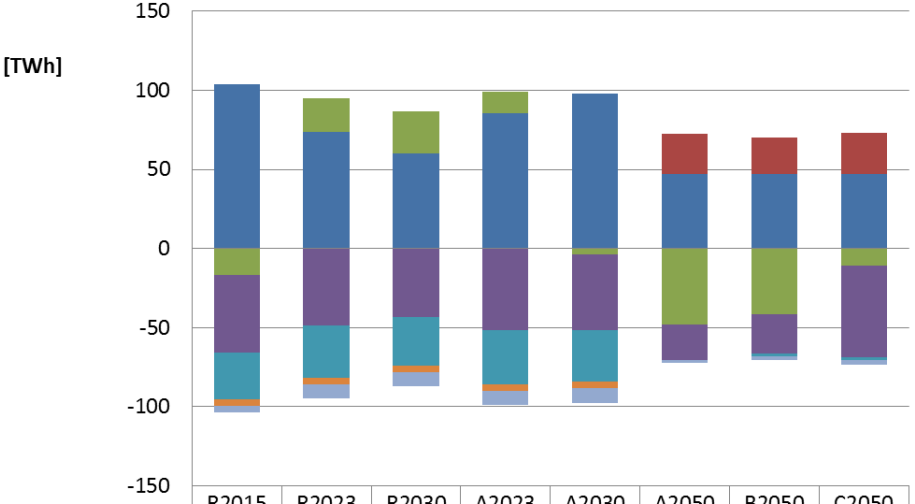
	R2015	R2023	R2030	A2023	A2030	A2050	B2050	C2050
Other RES-E	-4,6	-8,9	-8,3	-9,0	-9,1	-1,6	-2,1	-2,4
Nuclear	-4,1	-4,0	-3,6	-4,0	-4,0	0,0	0,0	0,0
Coal	-29,4	-33,2	-29,2	-34,1	-32,7	-0,4	-1,7	-1,9
Gas	-49,0	-47,8	-40,5	-51,7	-47,4	-15,8	-18,2	-51,0
Net exports	-16,7	20,2	19,6	13,2	-4,6	-65,0	-60,2	-26,6
VRE curtailment	0,0	0,0	0,0	0,0	0,0	0,9	0,3	0,1
Residual load (uncurtailed)	103,8	73,7	62,0	85,6	97,8	81,9	81,9	81,9

Negative residual demand/supply ('VRE surplus')



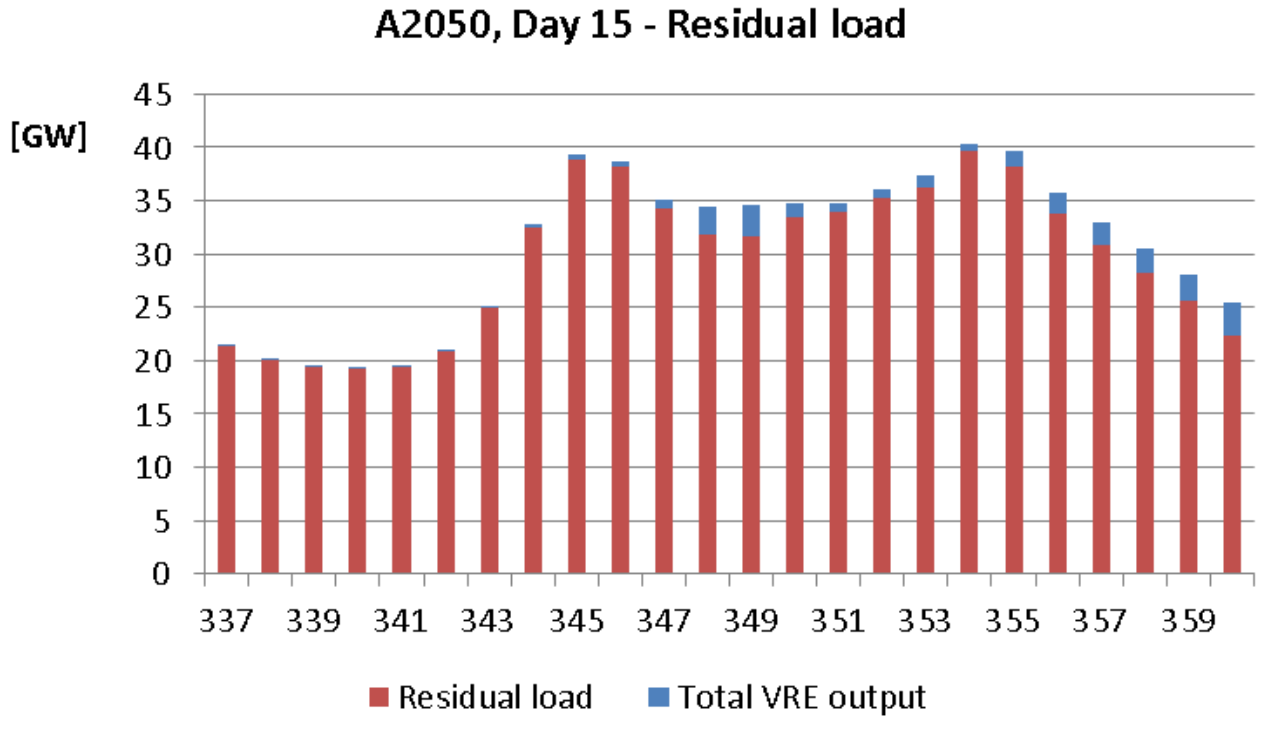
	R2015	R2023	R2030	A2023	A2030	A2050	B2050	C2050
Other RES-E	0,0	-0,1	-0,7	0,0	-0,1	-0,1	-0,2	-0,2
Nuclear	0,0	-0,1	-0,4	0,0	-0,1	0,0	0,0	0,0
Coal	0,0	-0,3	-1,2	0,0	-0,2	0,0	0,0	0,0
Gas	0,0	-0,5	-3,0	-0,1	-0,4	-6,3	-6,3	-6,6
Net exports	0,0	1,1	7,1	0,2	1,0	16,8	18,5	15,6
VRE curtailment	0,0	0,0	0,0	0,0	0,0	24,7	23,1	26,2
Residual load (uncurtailed)	0,0	-0,1	-1,8	0,0	-0,2	-35,1	-35,1	-35,1

Total residual demand/supply ('VRE shortage')

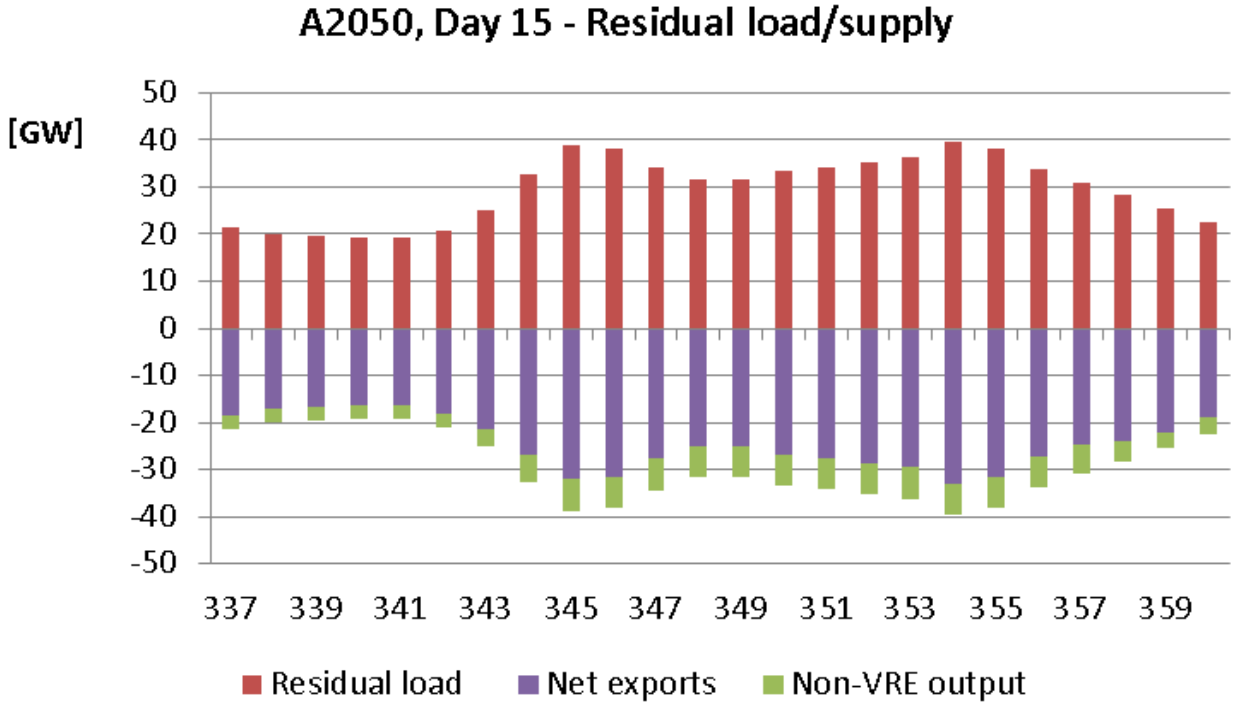


	R2015	R2023	R2030	A2023	A2030	A2050	B2050	C2050
Other RES-E	-4,6	-9,0	-9,0	-9,0	-9,2	-1,7	-2,3	-2,6
Nuclear	-4,1	-4,0	-4,0	-4,0	-4,0	0,0	0,0	0,0
Coal	-29,4	-33,4	-30,4	-34,2	-32,9	-0,4	-1,7	-1,9
Gas	-49,0	-48,4	-43,5	-51,8	-47,8	-22,1	-24,5	-57,7
Net exports	-16,7	21,3	26,7	13,5	-3,6	-48,2	-41,7	-11,0
VRE curtailment	0,0	0,0	0,0	0,0	0,0	25,5	23,5	26,4
Residual load (uncurtailed)	103,8	73,6	60,2	85,6	97,6	46,8	46,8	46,9

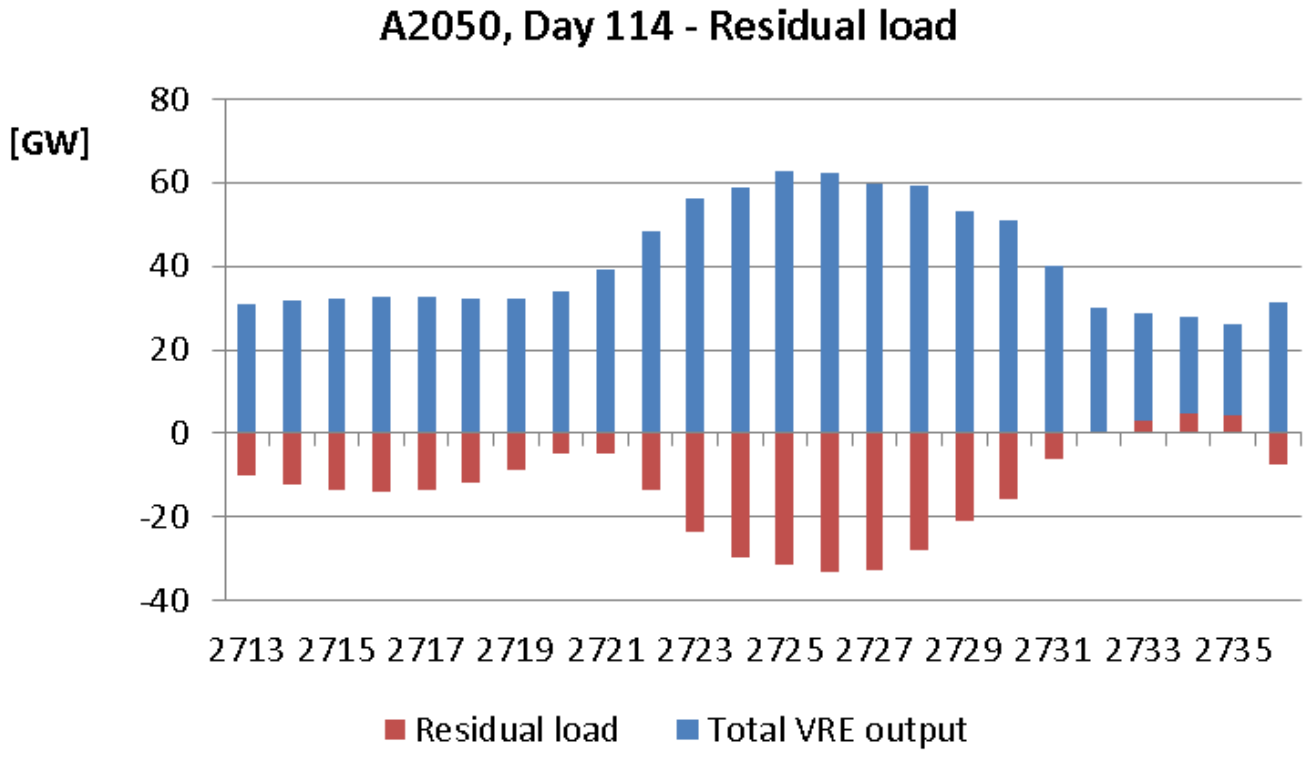
VRE shortage



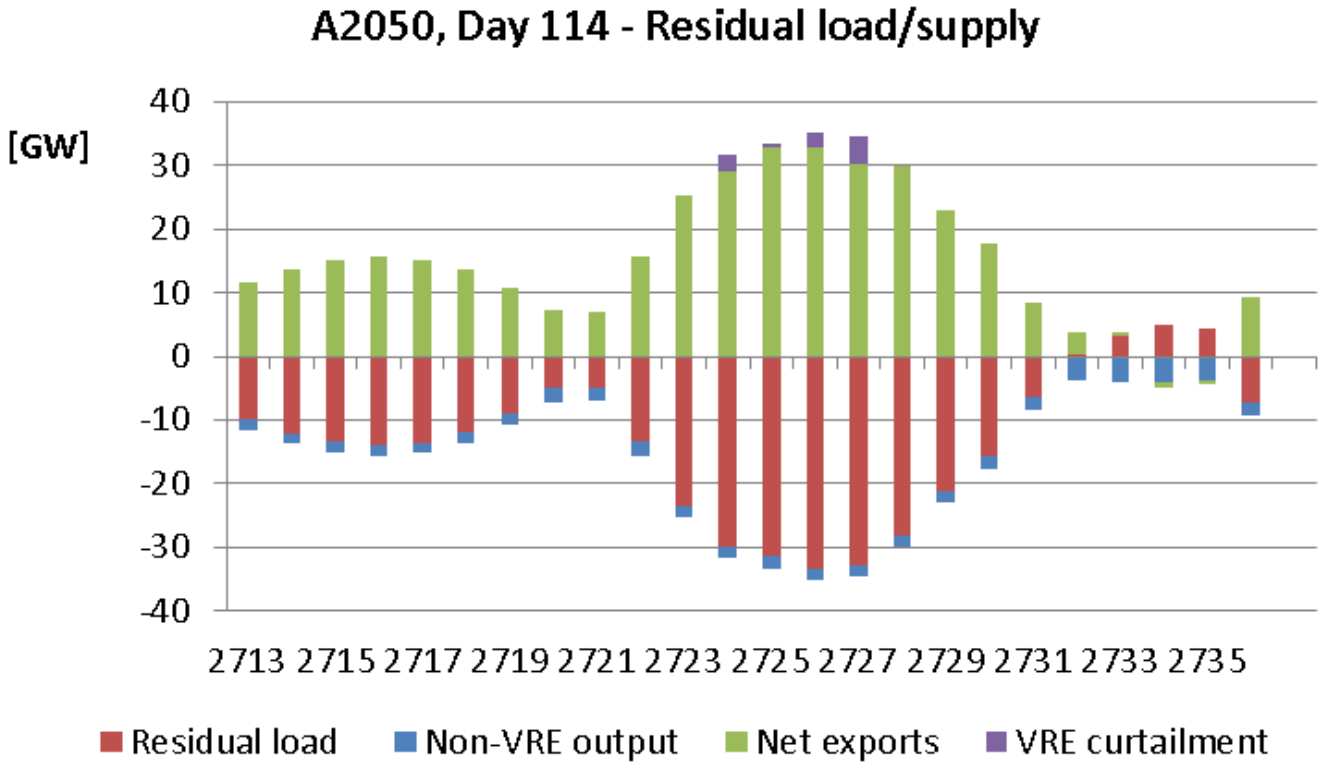
VRE shortage



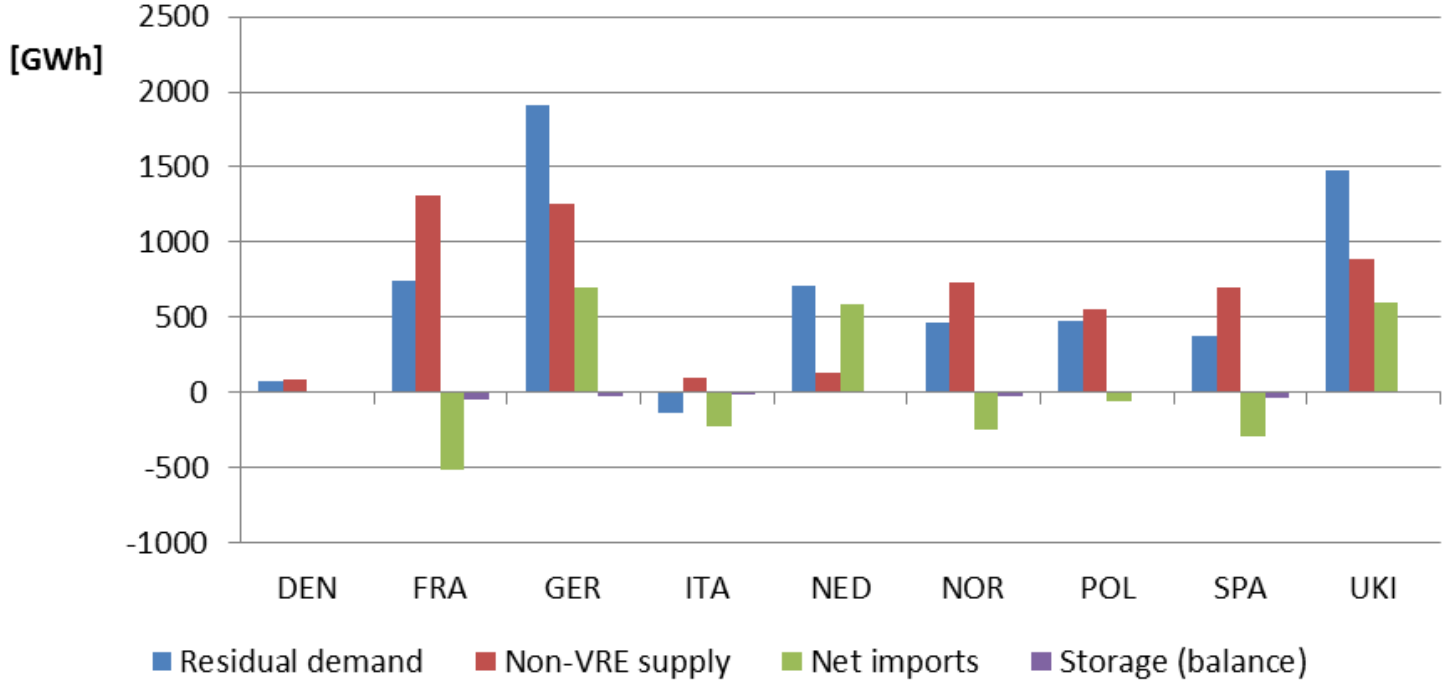
VRE surplus


A2050, Day 114 - Residual load
[GW]
80
60
40
20
0
-20
-40
2713 2715 2717 2719 2721 2723 2725 2727 2729 2731 2733 2735
Residual load
Total VRE output

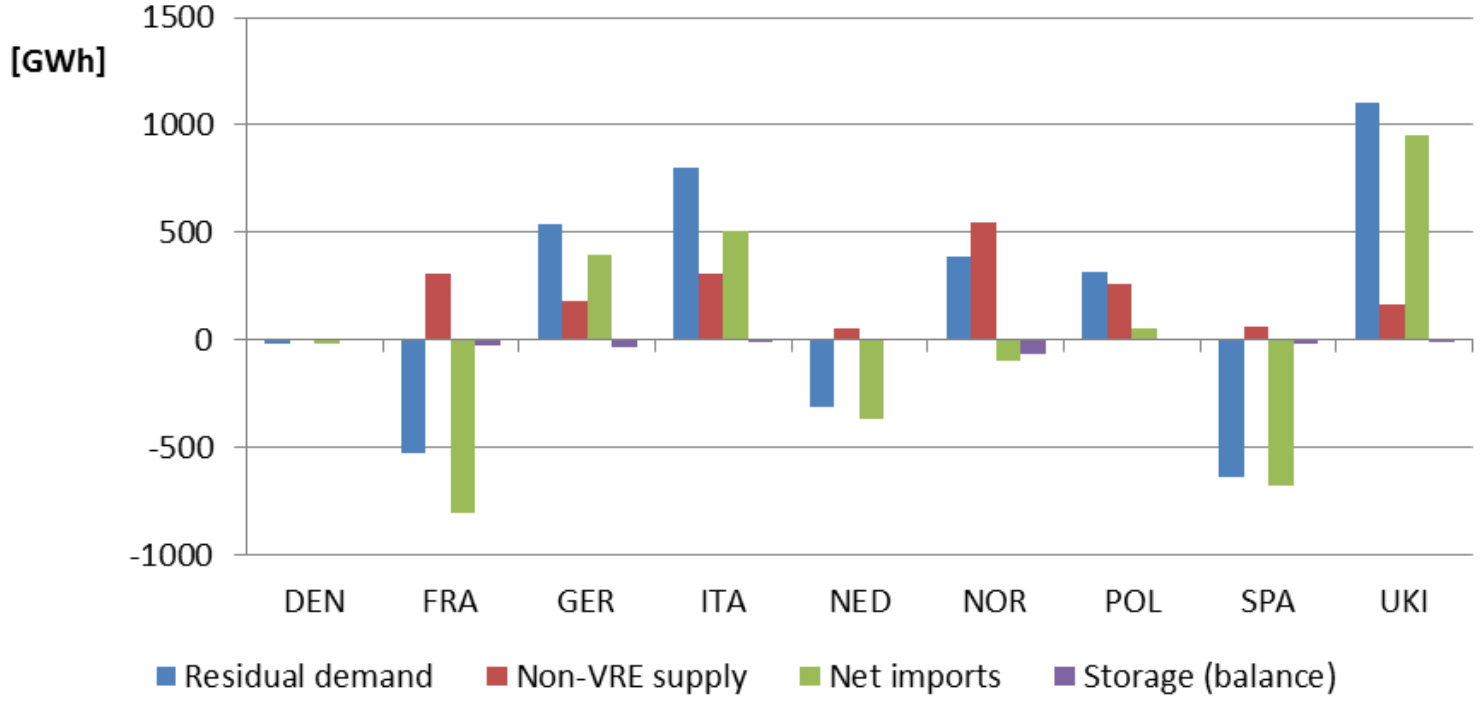
VRE surplus


A2050, Day 114 - Residual load/supply
[GW]
40
30
20
10
0
-10
-20
-30
-40
2713 2715 2717 2719 2721 2723 2725 2727 2729 2731 2733 2735
Residual load
Non-VRE output
Net exports
VRE curtailment

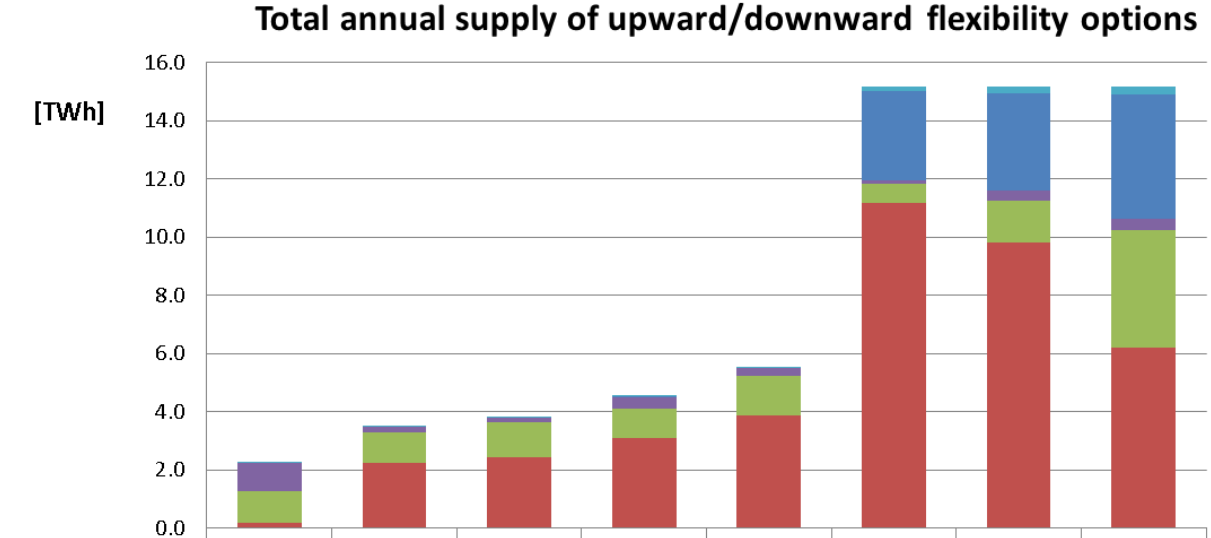
NL-EU VRE shortage: Day 15



NL-EU VRE surplus: Day 114

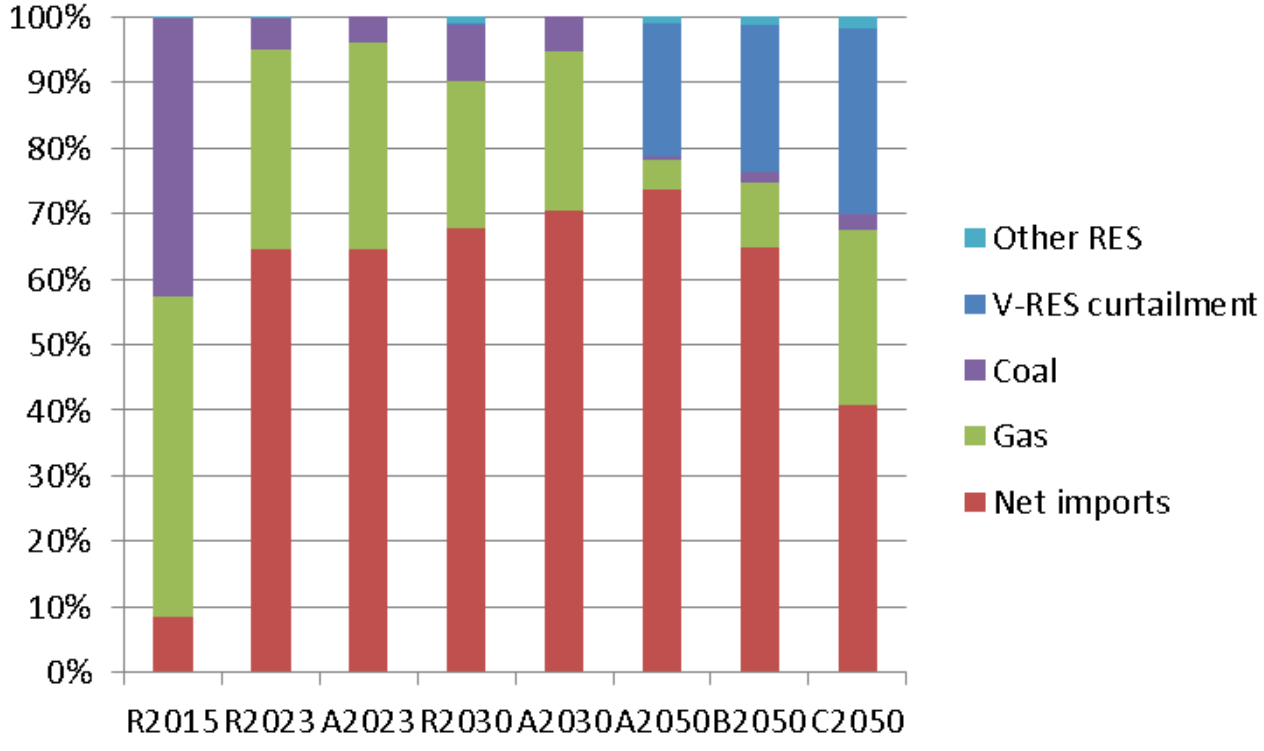


Options to meet flexibility due to total annual ramps of residual load

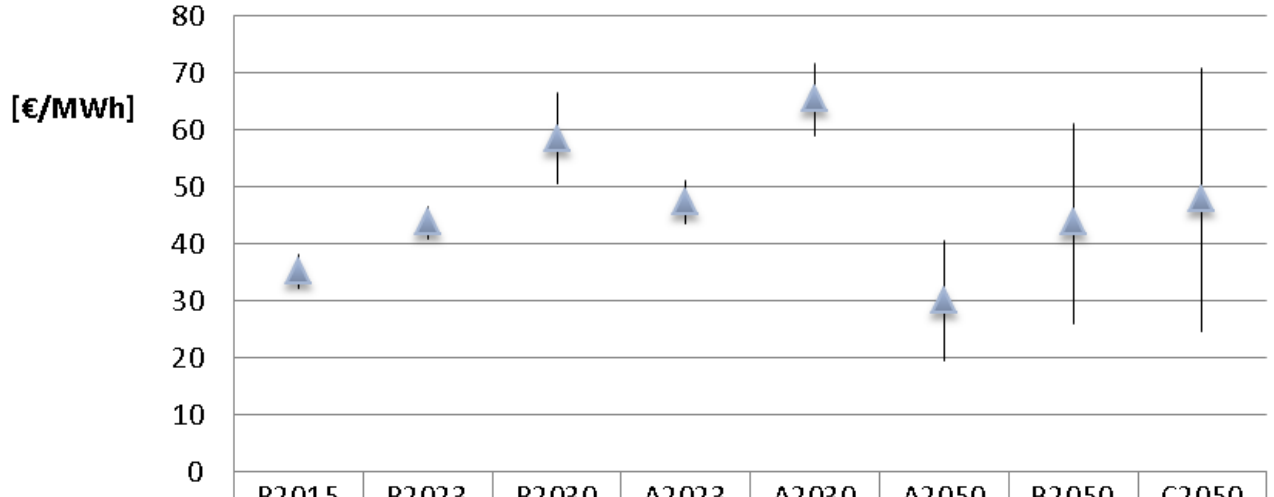


	R2015	R2023	A2023	R2030	A2030	A2050	B2050	C2050
Other RES	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.3
V-RES curtailment	0.0	0.0	0.0	0.0	0.0	3.1	3.4	4.3
Coal	0.9	0.2	0.2	0.4	0.3	0.1	0.3	0.4
Gas	1.1	1.1	1.2	1.0	1.3	0.7	1.4	4.1
Net imports	0.2	2.2	2.4	3.1	3.9	11.1	9.8	6.2

Options to meet flexibility due to total annual ramps of residual load



Annualised price volatility



	R2015	R2023	R2030	A2023	A2030	A2050	B2050	C2050
Price volatility up	38	47	66	51	72	41	61	71
Price volatility down	32	41	50	44	59	19	26	25
weighted average	35	44	58	47	65	30	44	48

Difference in power system costs: EU

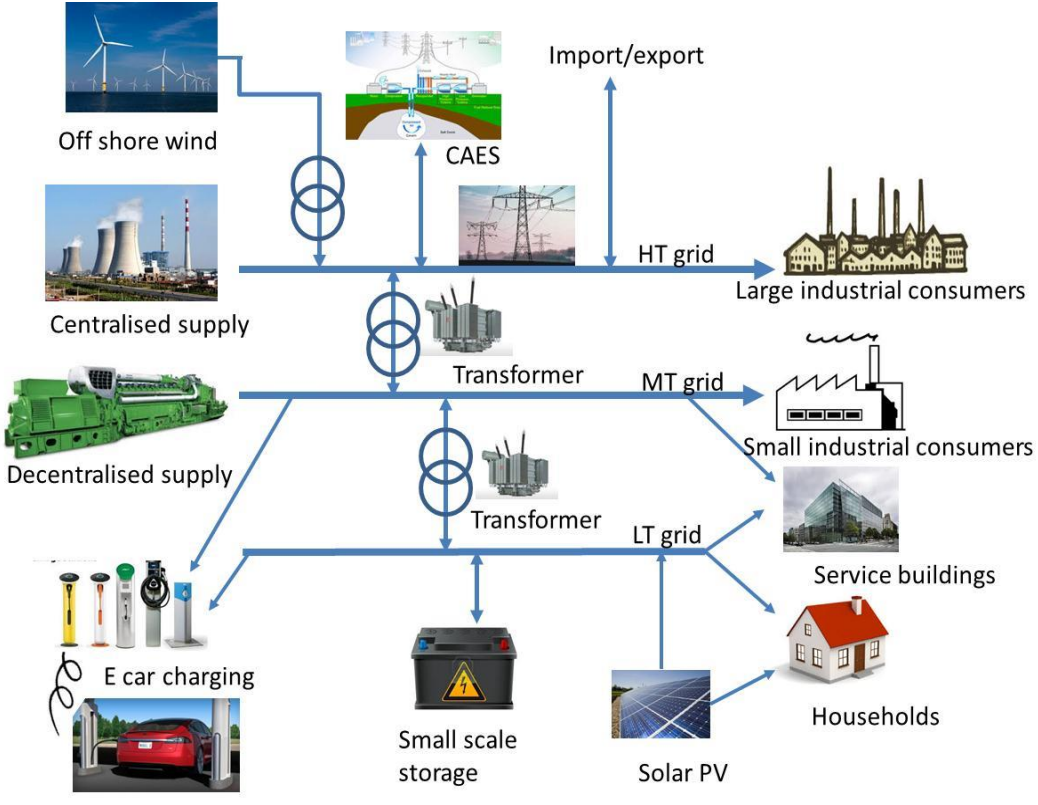
	Generation Costs	Fixed O&M	Transmission Investment costs	Generation Capacity Investment costs	Demand curtailment costs	Total
Difference (in M€)						
B2050-A2050	4133,5	0,0	-2511,9	522,4	35,7	2179,7
C2050-B2050	7019,9	-0,1	-2511,9	3418,5	13,7	7940,1
C2050-A2050	11153,3	0,0	-5023,8	3940,9	49,4	10119,9
Difference (in %)						
B2050-A2050	19%	0%	-50%	-	165%	8%
C2050-B2050	27%	0%	-100%	654%	24%	27%
C2050-A2050	51%	0%	-100%	-	229%	38%

Difference in power system costs: NL

	Generation Costs	Fixed O&M	Transmission Investment costs	Generation Capacity Investment costs	Demand curtailment costs	Net trade costs	Total
Difference (in M€)							
B2050-A2050	464,0	0,0	-169,2	522,4	10,3	388,8	1216,3
C2050-B2050	1880,3	0,1	-169,2	1051,5	37,3	-1306,8	1493,2
C2050-A2050	2344,3	0,2	-338,4	1573,9	47,5	-918,0	2709,5
Difference (in %)							
B2050-A2050	47%	1%	-50%	-	267%	27%	44%
C2050-B2050	130%	3%	-100%	201%	264%	-71%	37%
C2050-A2050	238%	4%	-100%	-	1236%	-63%	98%

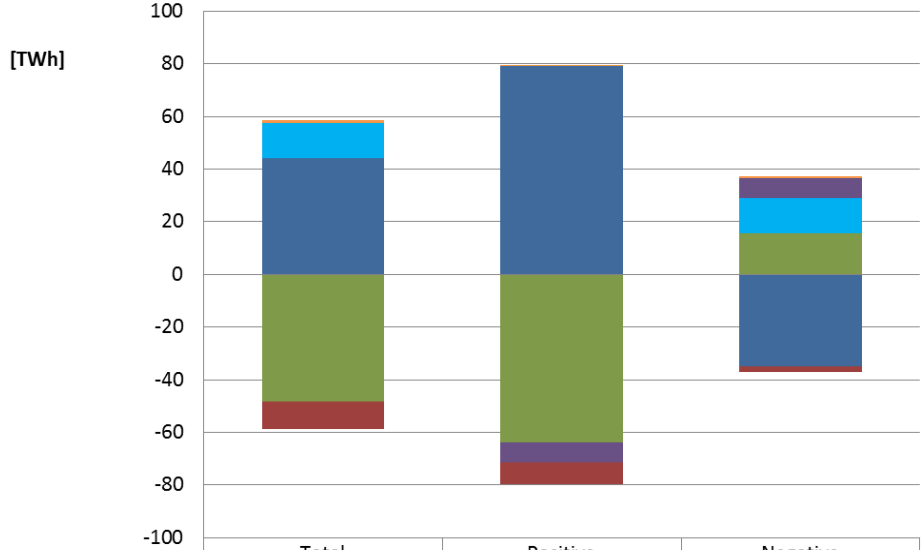
Phase 2:
Main OPERA results

Methodologie
Schema elektriciteitssysteem in OPERA



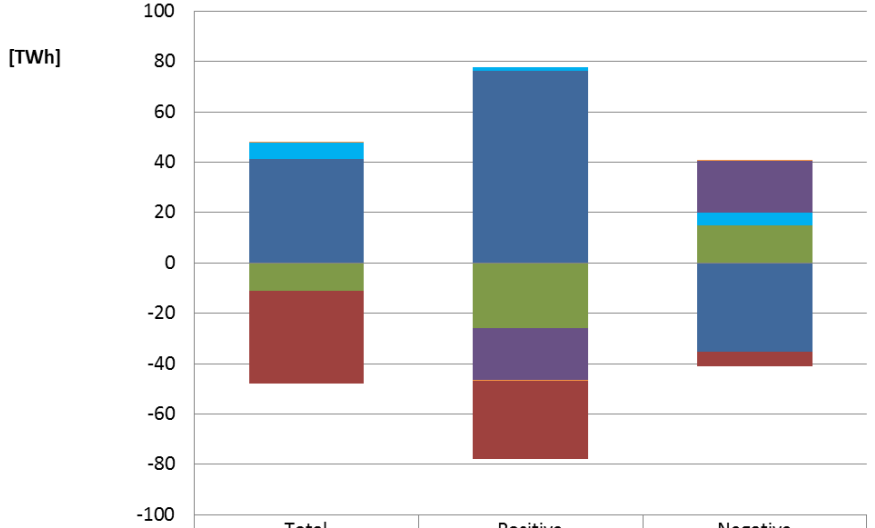
- PM: ook gas netwerk op 3 niveaus

Total residual demand/supply: A2050



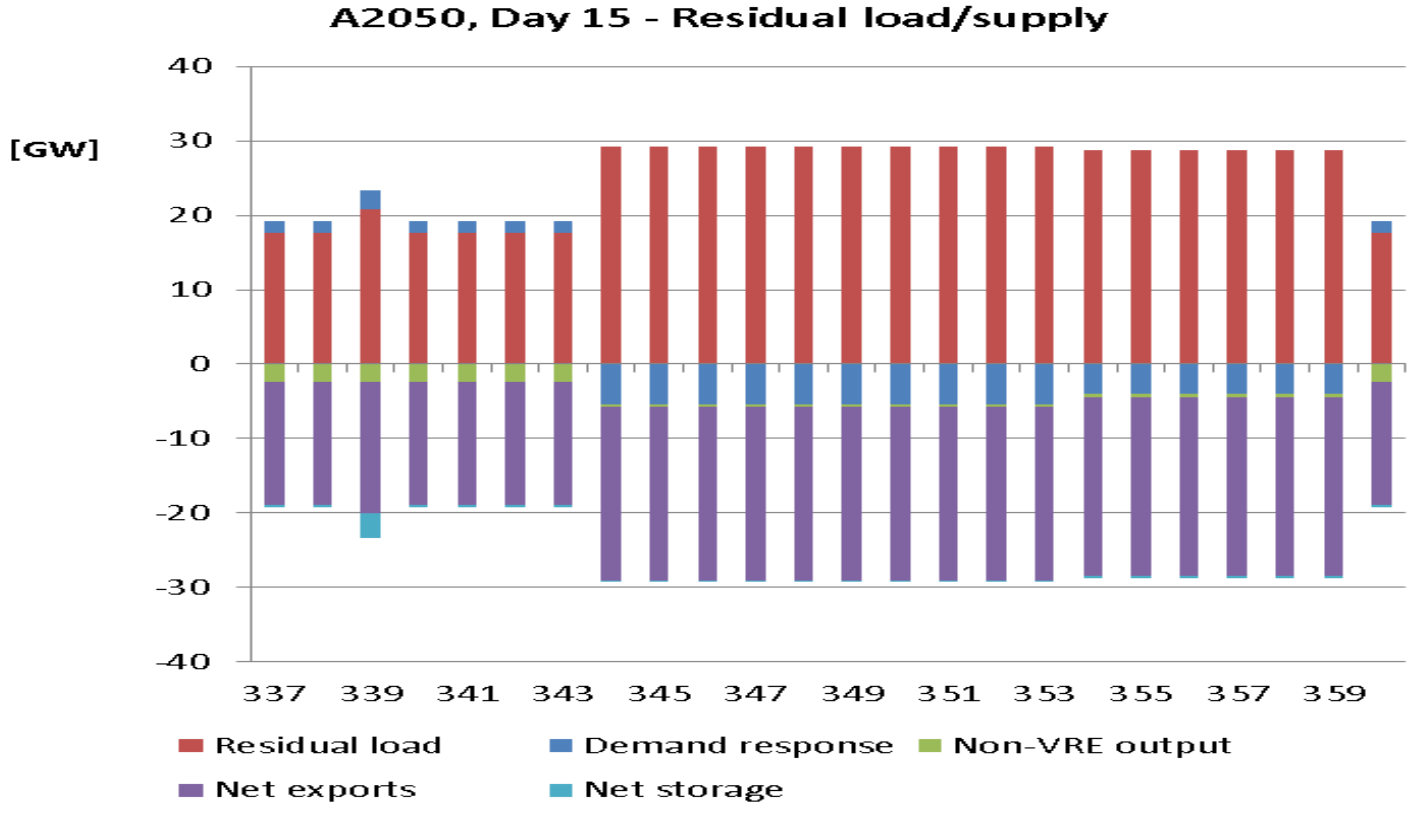
	Residual demand/supply (A2050)		
	Total	Positive	Negative
Total non-VRE supply	-10,5	-8,1	-2,4
Storage (balance)	1,0	0,5	0,5
Demand response - total	0,0	-7,7	7,7
VRE curtailment	13,4	0,0	13,4
Net exports	-48,2	-63,8	15,7
Residual demand (uncurtailed)	44,3	79,0	-34,7

Total residual demand/supply: C2050

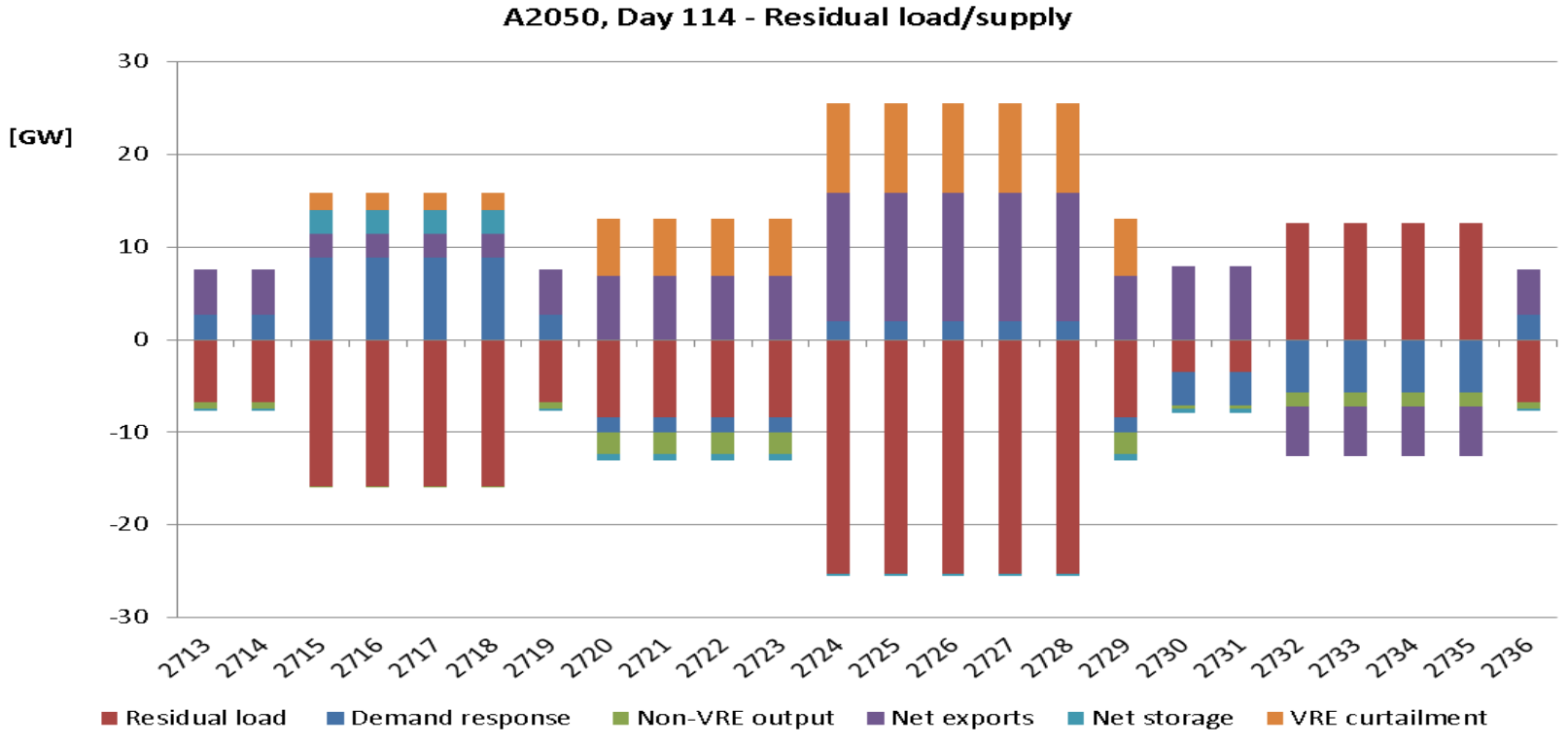


	Total	Positive	Negative
	Residual demand/supply (C2050)		
Total non-VRE supply	-36,9	-31,1	-5,9
Storage (balance)	0,1	-0,1	0,3
Demand response - total	0,0	-20,6	20,6
VRE curtailment	6,4	1,3	5,1
Net exports	-11,0	-26,0	15,0
Residual demand (uncurtailed)	41,4	76,5	-35,1

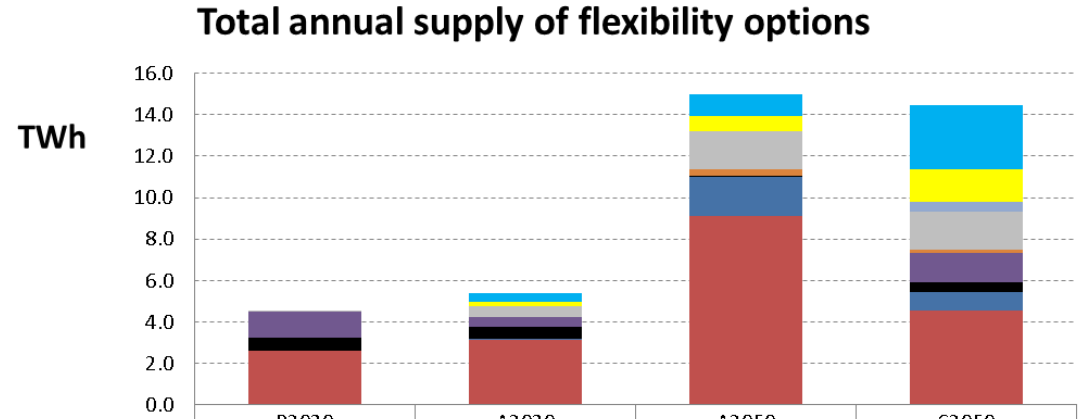
VRE shortage



VRE surplus

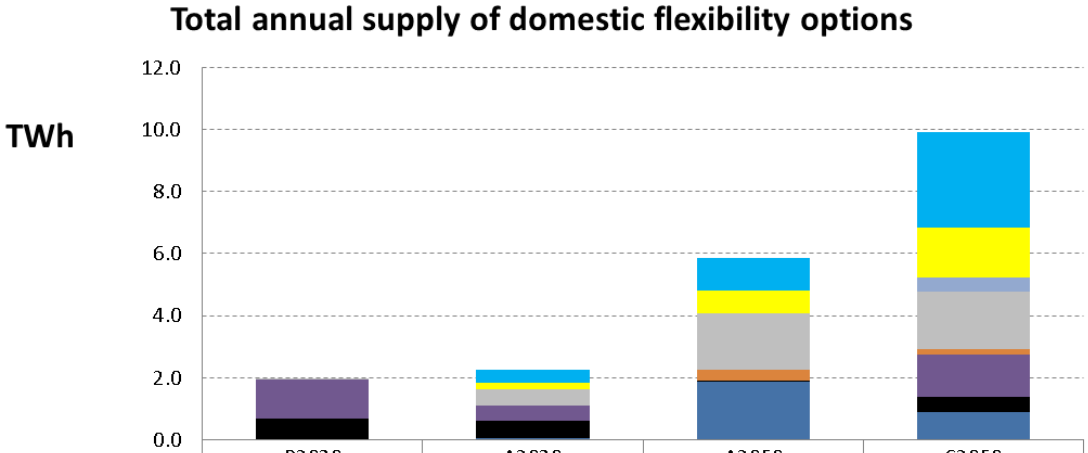

A2050, Day 114 - Residual load/supply
[GW]
30
20
10
0
-10
-20
-30
2713
2714
2715
2716
2717
2718
2719
2720
2721
2722
2723
2724
2725
2726
2727
2728
2729
2730
2731
2732
2733
2734
2735
2736
Residual load
Demand response
Non-VRE output
Net exports
Net storage
VRE curtailment

Options to meet flexibility due to total annual ramps of residual load (1)



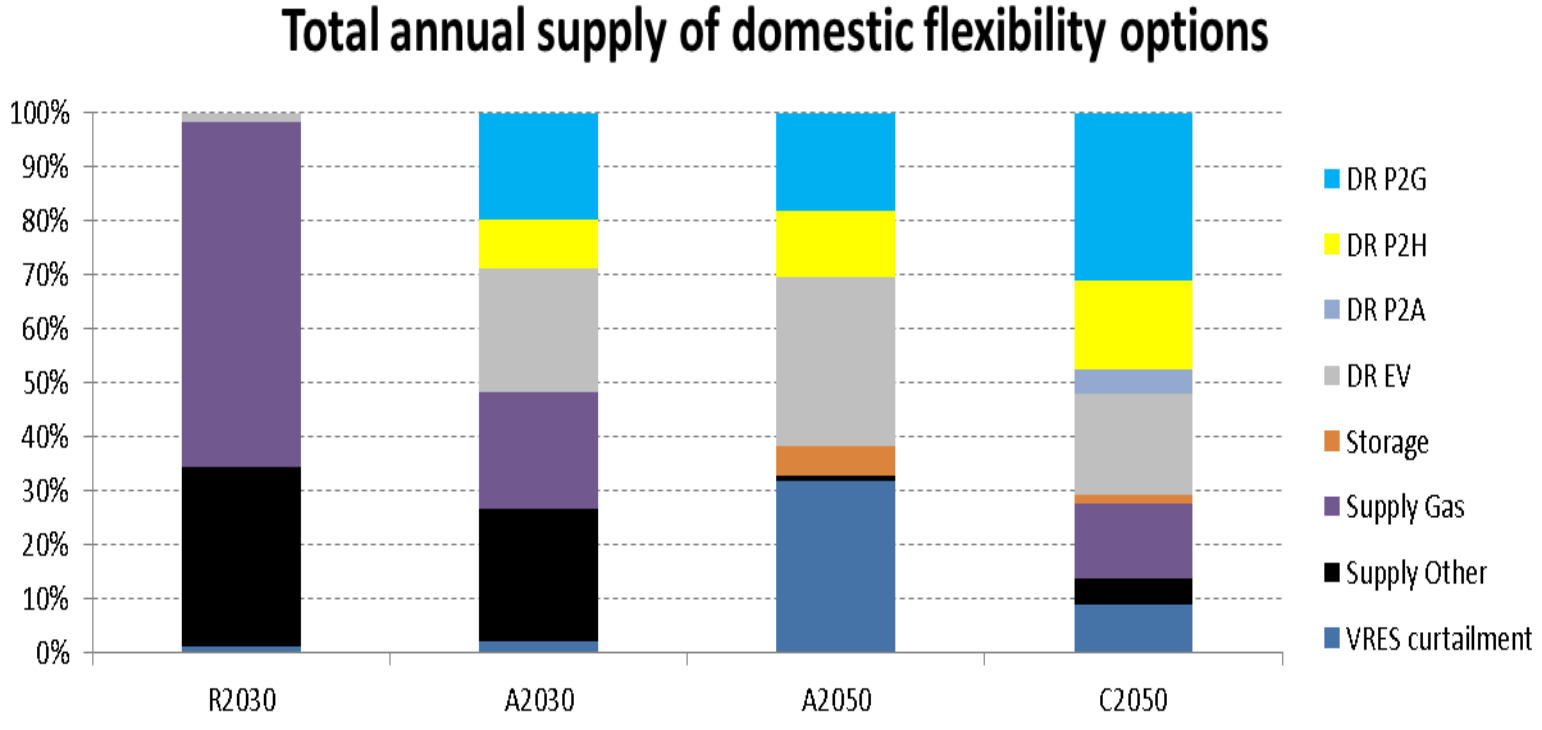
	R2030	A2030	A2050	C2050
DR P2G	0.0	0.5	1.1	3.1
DR P2H	0.0	0.2	0.7	1.6
DR P2A	0.0	0.0	0.0	0.5
DR EV	0.0	0.5	1.8	1.9
Storage	0.0	0.0	0.3	0.2
Supply Gas	1.2	0.5	0.0	1.4
Supply Other	0.6	0.6	0.1	0.5
VRES curtailment	0.0	0.1	1.9	0.9
Net imports	2.6	3.1	9.1	4.6

Options to meet flexibility due to total annual ramps of residual load (2)



	R2030	A2030	A2050	C2050
DR P2G	0.0	0.5	1.1	3.1
DR P2H	0.0	0.2	0.7	1.6
DR P2A	0.0	0.0	0.0	0.5
DR EV	0.0	0.5	1.8	1.9
Storage	0.0	0.0	0.3	0.2
Supply Gas	1.2	0.5	0.0	1.4
Supply Other	0.6	0.6	0.1	0.5
VRES curtailment	0.0	0.1	1.9	0.9

Options to meet flexibility due to total annual ramps of residual load (3)



Summary of major findings and conclusions

Preliminary conclusions: national level (phase 1)

- The demand for flexibility by the power sector grows rapidly up to 2030, and particularly up to 2050, in both capacity and energy terms.
- The main driver of the demand for flexibility is the increase in electricity production from VRE power sources (sun/wind).
- Another, less important driver – at least in a direct sense – is the increase in the additional load due to the further electrification of the energy system.
- In an *indirect* sense, however, the increase in electrification is an important driver of the demand for flexibility if it is assumed that the resulting additional load is largely met by electricity from VRE power sources.

Preliminary conclusions: national level (Phase 2)

- Vraag naar flexibiliteit neemt weliswaar fors toe in de periode 2015-2050 (met een factor 8) maar het grootste deel van deze vraag wordt gedekt via de buitenlandse handelsoptie (60-70%) en in mindere mate door zon/wind curtailment (10-20%).
- De buitenlandse handelsoptie drukt zowel de gemiddelde elektriciteitsprijs als de spreiding (volatiliteit) van de e-prijs waardoor het verdienmodel van bepaalde (binnenlandse) flexopties wordt verkleind.
- Aanbod van overige (binnenlandse) opties is veel kleiner, groeit veelal minder snel of daalt zelfs.
  - Rol van conventionele elektriciteitsproductie in flexibiliteit daalt
  - In 2050 zijn met name VRE curtailment alsmede vraagsturing (‘demand response’) EV’s, P2H en P2G belangrijke binnenlandse flexopties
  - De bijdrage van opslag en vraagsturing P2A in 2050 is beperkt (relatief dure opties).