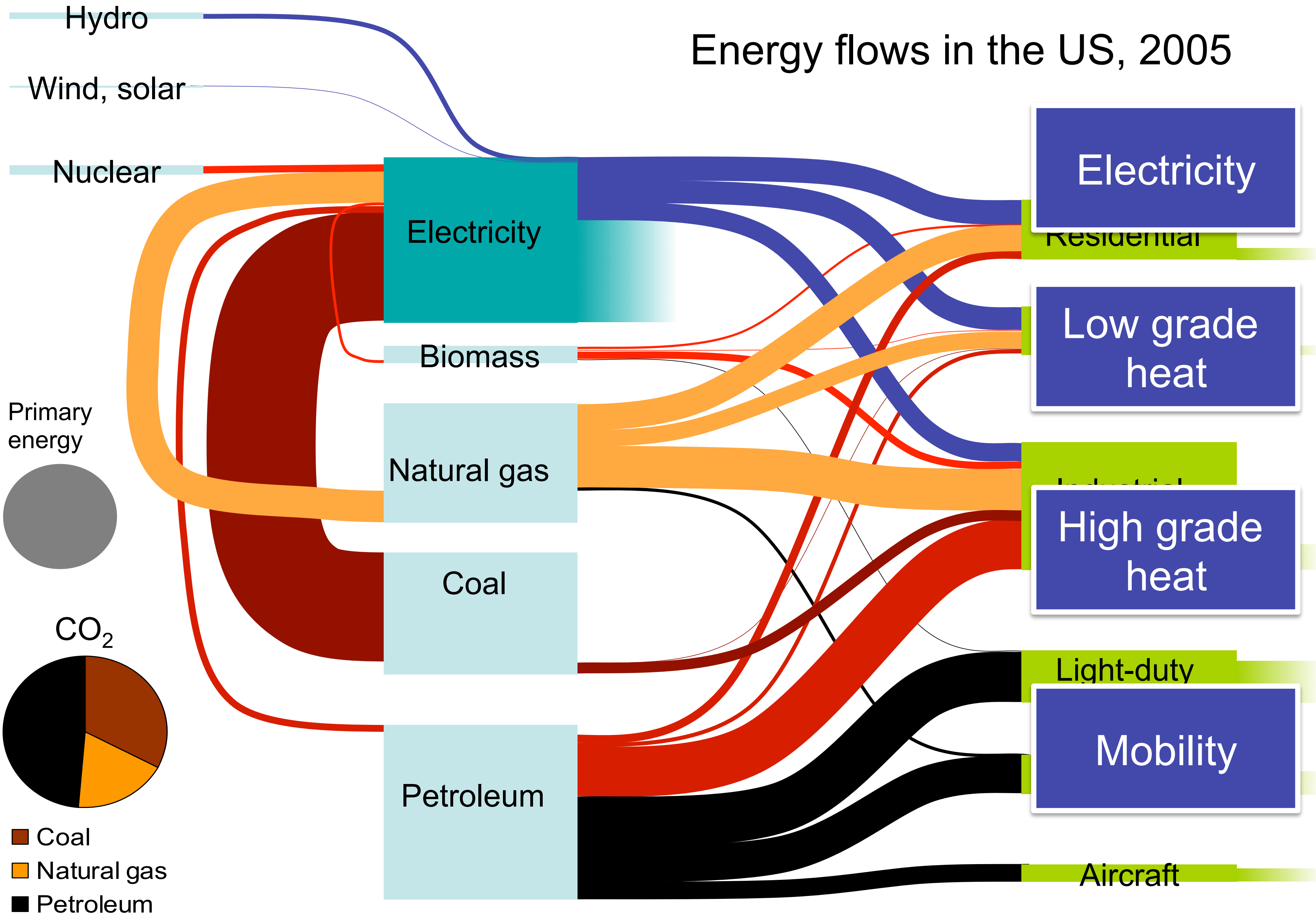
VTT TECHNICAL RESEARCH CENTRE OF FINLAND LTD

How power generation forecasts can affect other energy sectors

FLEXe weather workshop 2.5.2016
Juha Kiviluoma



Sources: Whitesides & Crabtree 2007 & EIA Statistics

Weather dependency in power generation?

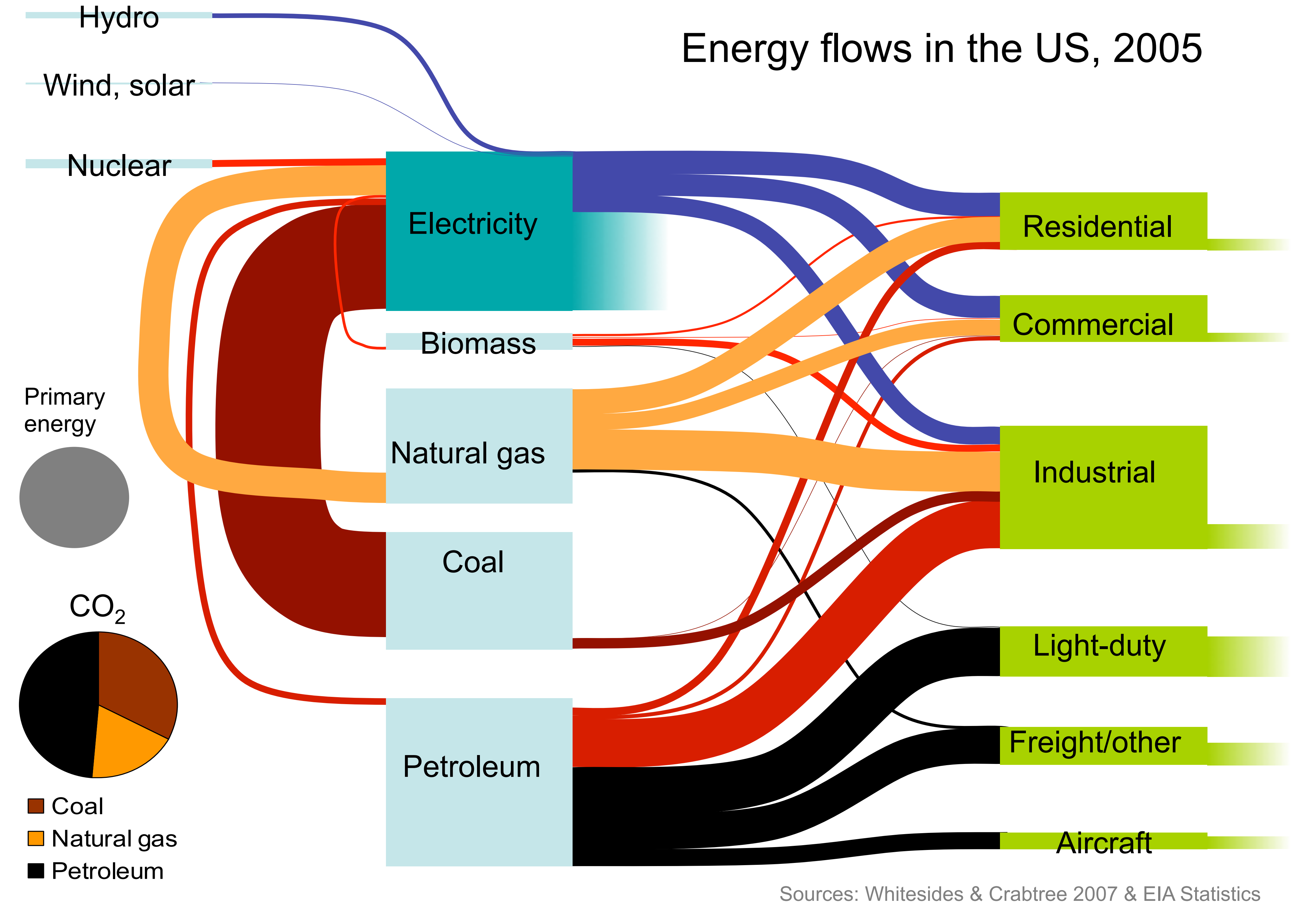
- Instantenous
  - Wind power
  - PV
- Non-electric storage possible
  - CSP
- Lag of hours
  - Run-of-river hydro
  - Wave power
- Lag of days/months
  - Reservoir hydro
  - Peat
- Very long lag:
  - Bioenergy

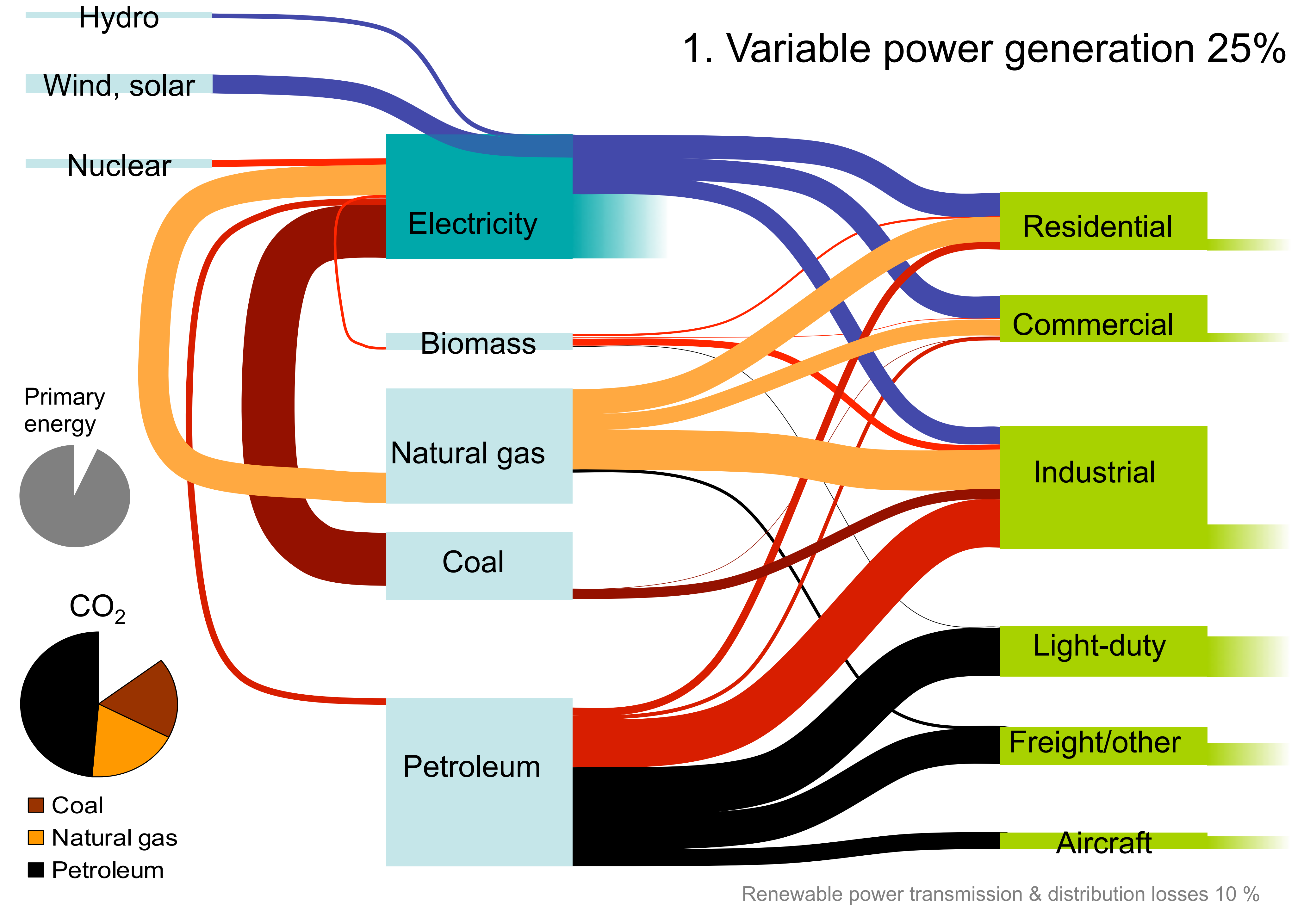
Weather dependecy in energy consumption?

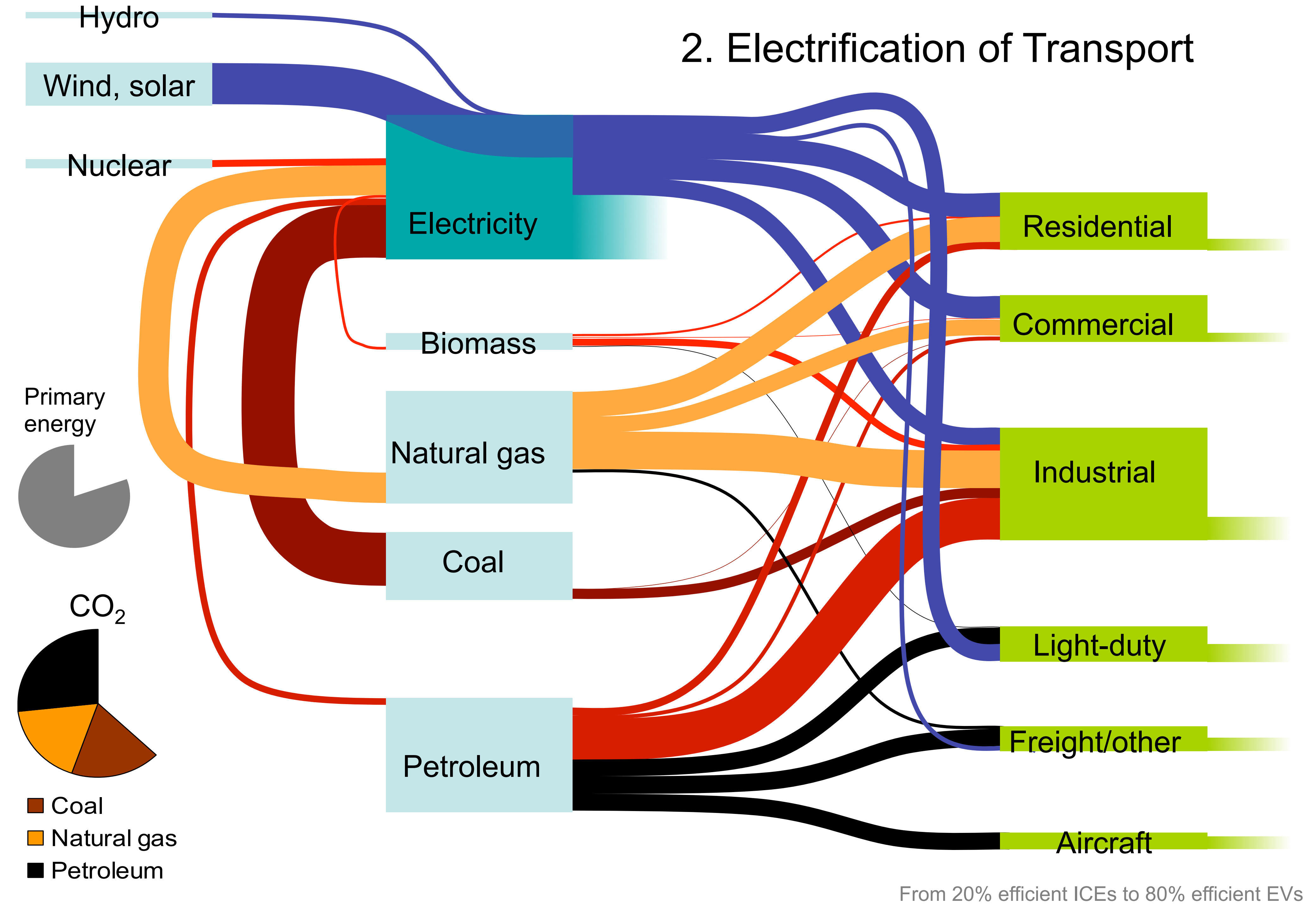
- Lag of minutes to hours:
  - Electric heating and cooling
  - District heating and cooling
  - Lighting

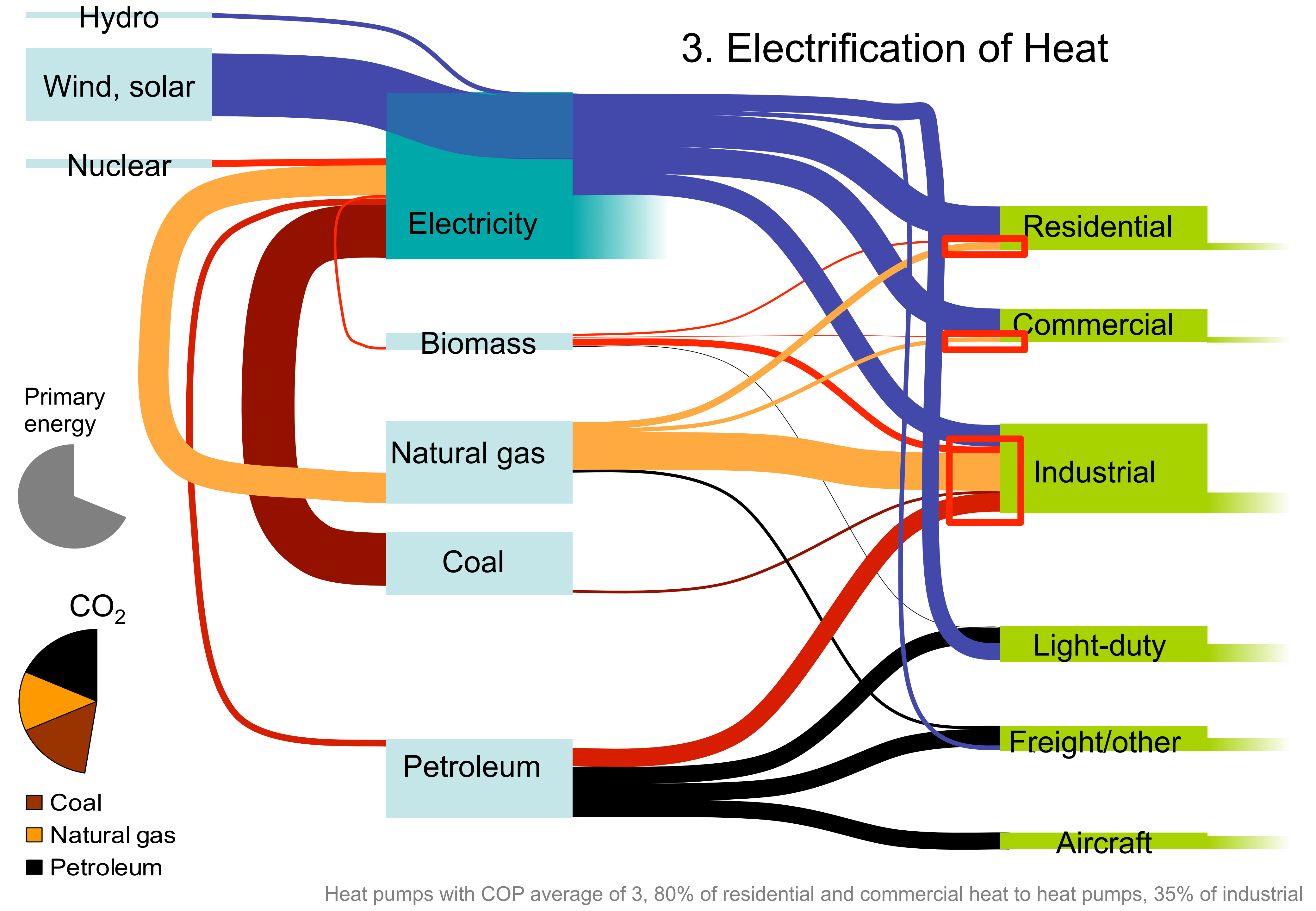
Weather dependency in other energy production?

- Transport fuel production?
- Heat/steam generation for industrial processes?
- Production of space heating?
- Production of space cooling?

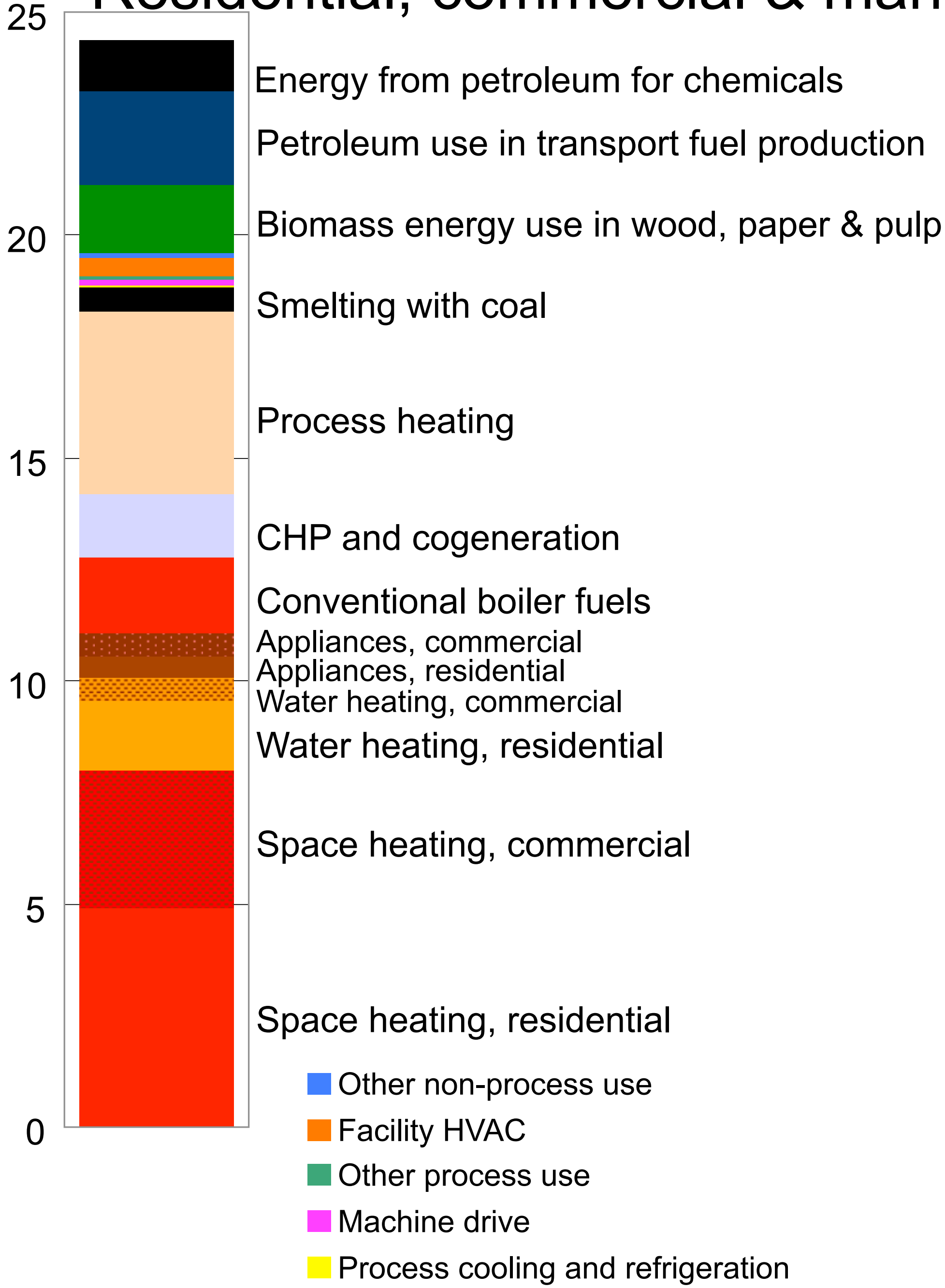

Energy flows in the US, 2005
Hydro
Wind, solar
Nuclear
Electricity
Biomass
Natural gas
Coal
Petroleum
Primary energy
CO_2
Coal
Natural gas
Petroleum
Residential
Commercial
Industrial
Light-duty
Freight/other
Aircraft
Sources: Whitesides & Crabtree 2007 & EIA Statistics


1. Variable power generation 25%
Hydro
Wind, solar
Nuclear
Electricity
Biomass
Natural gas
Coal
Petroleum
Residential
Commercial
Industrial
Light-duty
Freight/other
Aircraft
Primary energy
CO_2
Coal
Natural gas
Petroleum
Renewable power transmission & distribution losses 10 %


2. Electrification of Transport
Hydro
Wind, solar
Nuclear
Electricity
Biomass
Natural gas
Coal
Petroleum
Primary energy
CO_2
Coal
Natural gas
Petroleum
Residential
Commercial
Industrial
Light-duty
Freight/other
Aircraft
From 20% efficient ICEs to 80% efficient EVs


3. Electrification of Heat
Hydro
Wind, solar
Nuclear
Electricity
Biomass
Natural gas
Coal
Petroleum
Residential
Commercial
Industrial
Light-duty
Freight/other
Aircraft
Primary energy
CO_2
Coal
Natural gas
Petroleum
Heat pumps with COP average of 3, 80% of residential and commercial heat to heat pumps, 35% of industrial

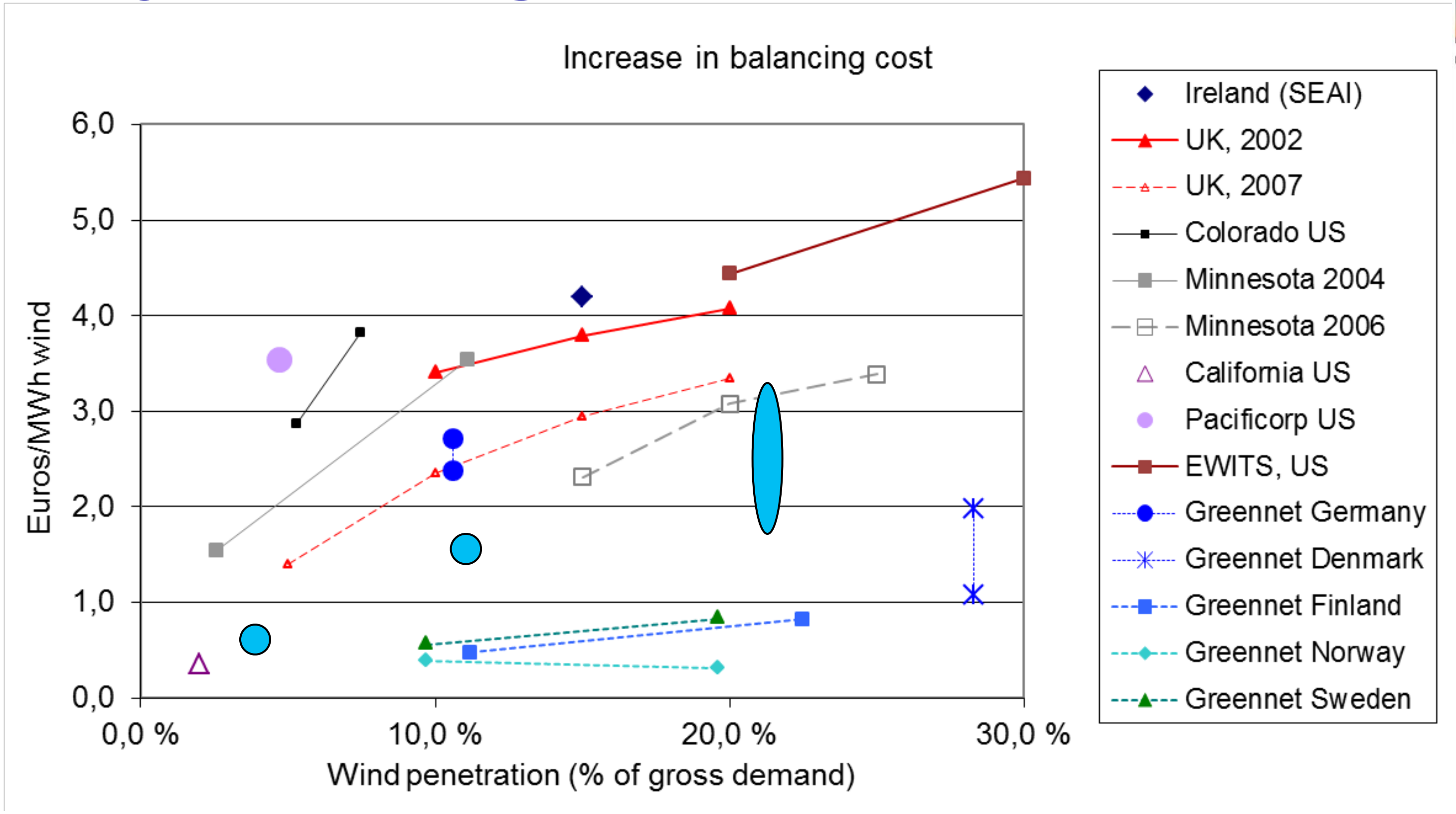
Residential, commercial & manufacturing fuel use in US [Quads]



Wind Power Forecasting – Why Is it Important

- Economics
  - Better forecasts mean lower operating reserves
  - Lower operating reserves mean lower operating costs
  - Avoid penalties for bad forecasts
- Reliability
  - Situational awareness for operators
  - System positioning for ramping events
  - Preparation for extreme events
- Market Operation
  - Understand need for and provide incentives for the right market products with high VG penetration
  - Align market rules with forecasting capabilities

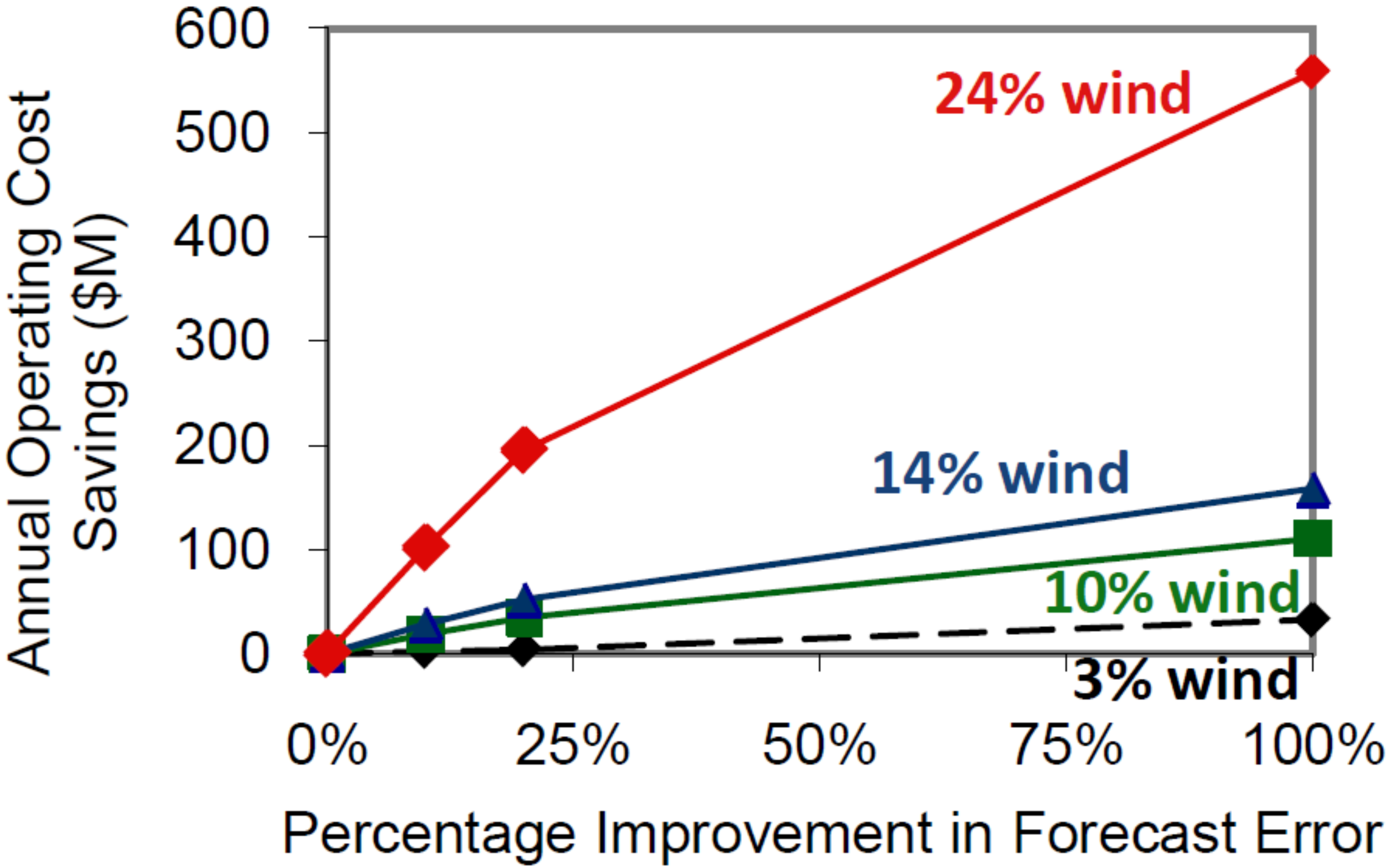
Summary balancing costs



- Integration costs 0.5 – 4.5 €/MWh up to 20 % penetration level
  - Integration costs are challenging to estimate for a single part of

Experience from Denmark/Spain/NL, cost of balancing from electricity markets for wind power producers

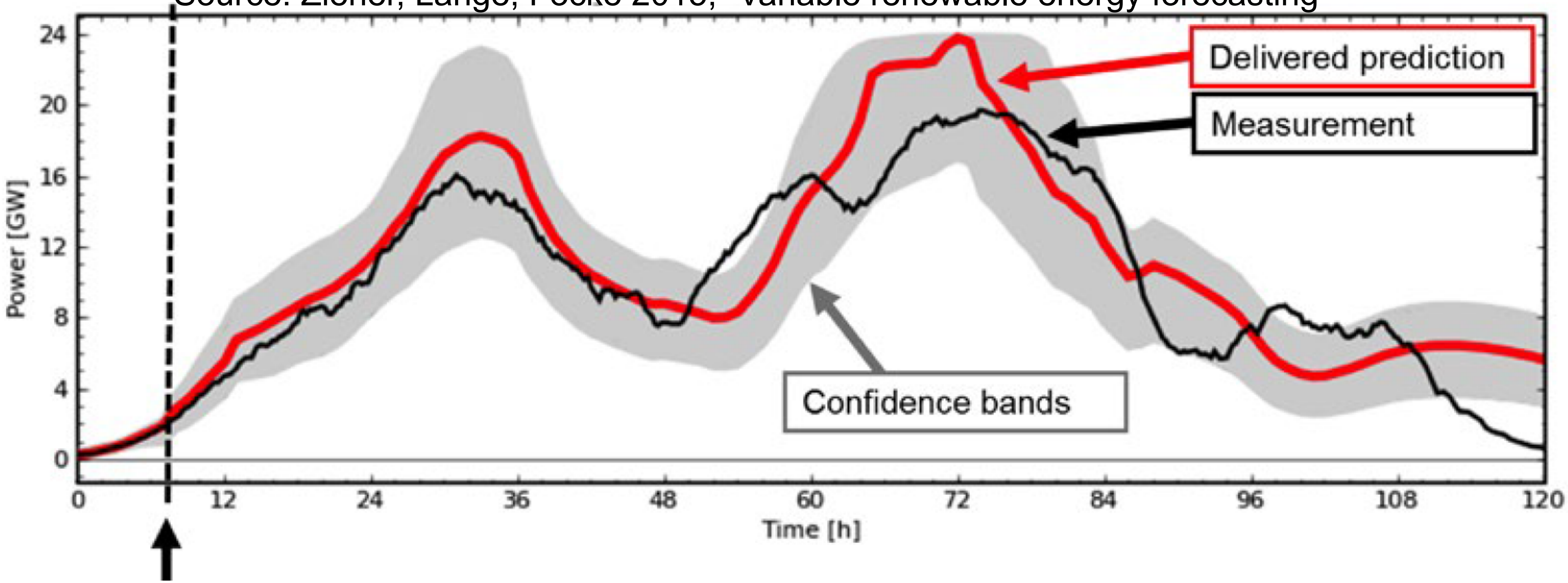
or not; assumptions on thermal power costs



600
500
400
300
200
100
0
Annual Operating Cost Savings ($M)
24% wind
14% wind
10% wind
3% wind
0%
25%
50%
75%
100%
Percentage Improvement in Forecast Error

	Load day-ahead	Wind day-ahead	
CAISO, 2011	2,6 %	13,0 %	
NYISO, 2010	3,6 %	11,9 %	

Source: Zieher, Lange, Focke 2015, "Variable renewable energy forecasting"



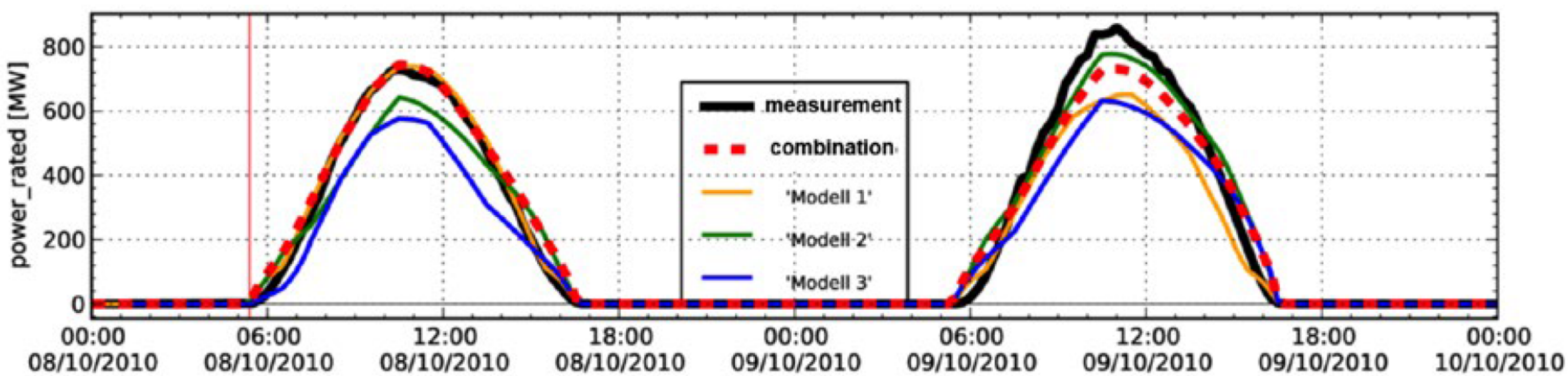
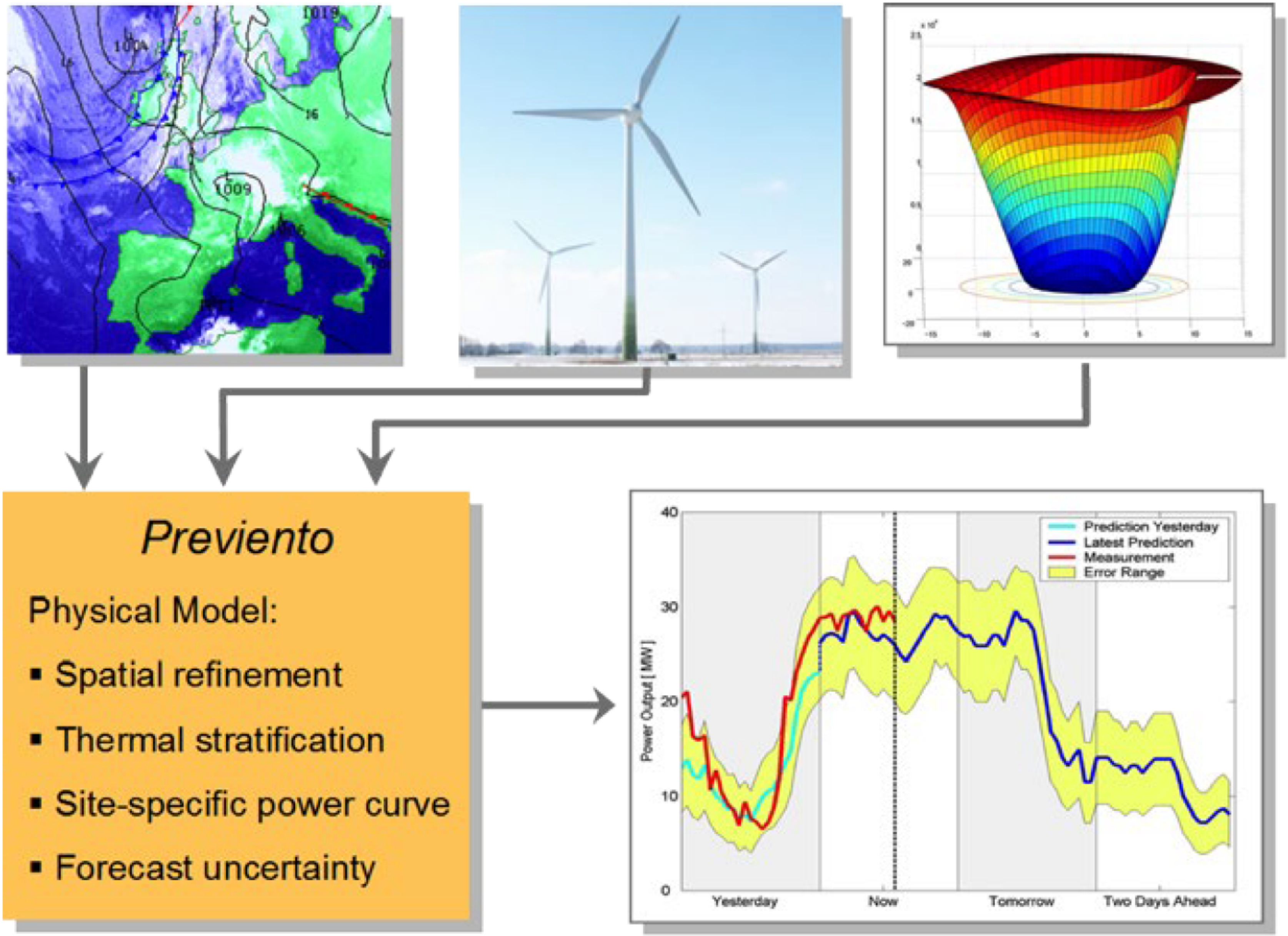


Figure 9: Solar power forecast for two days based on weather dependent combination. The dashed red line is the combination forecast, the thin coloured lines are single NWP models. The black line is the observed production. Source: energy & meteo systems.



© energy & meteo systems

Source: Zieher, Lange, Focke 2015, ”Variable renewable energy forecasting”

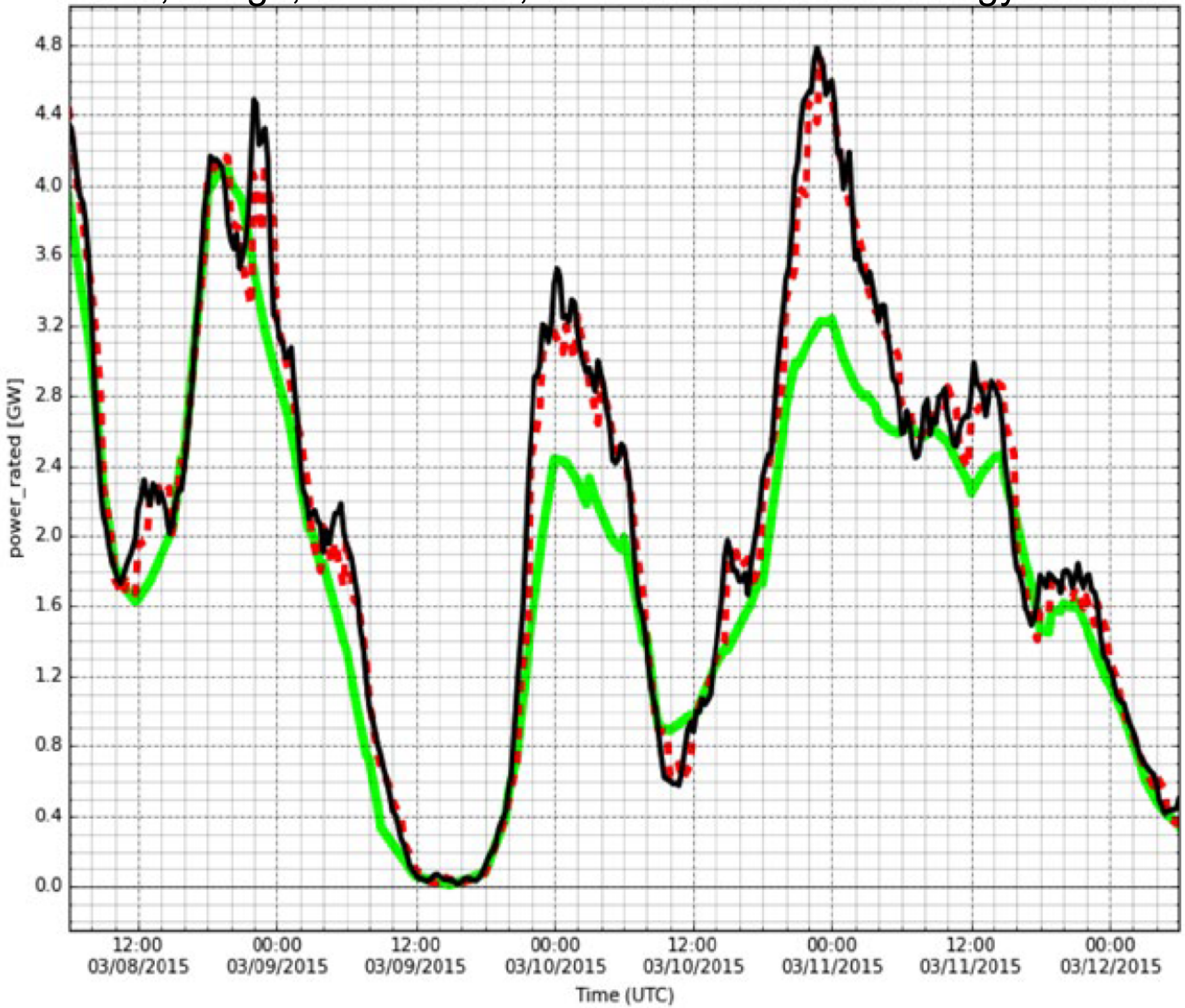


Figure 11: Benefit of shortest-term prediction based on real-time data in a difficult weather situation: the shortest-term prediction for 1 hour ahead (red line) is far closer to the real production (black line) compared to the most recent forecast only based on meteorological forecasting data (green line). Source: energy & meteo systems.

Source: Zieher, Lange, Focke 2015, "Variable renewable energy forecasting"

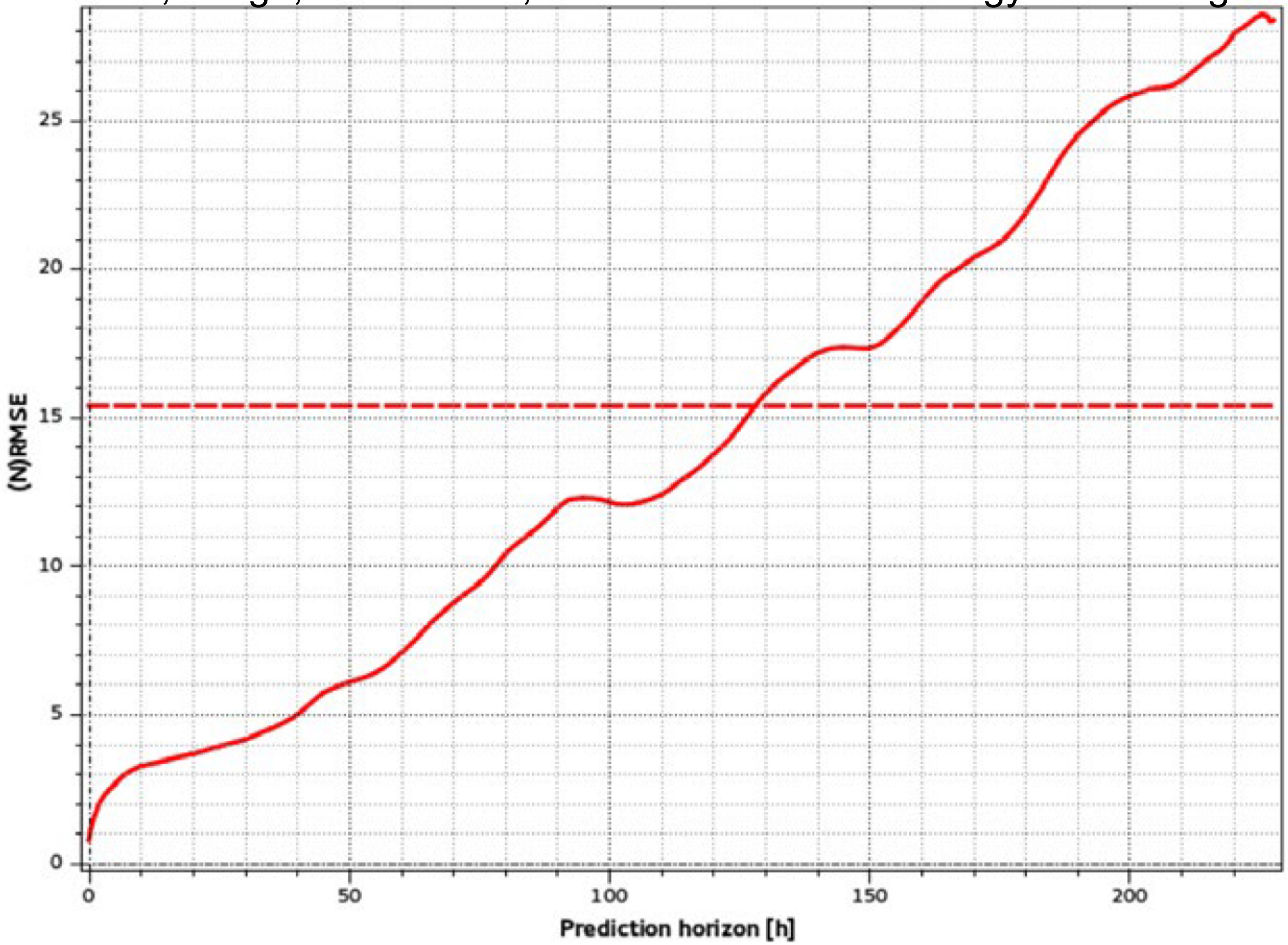
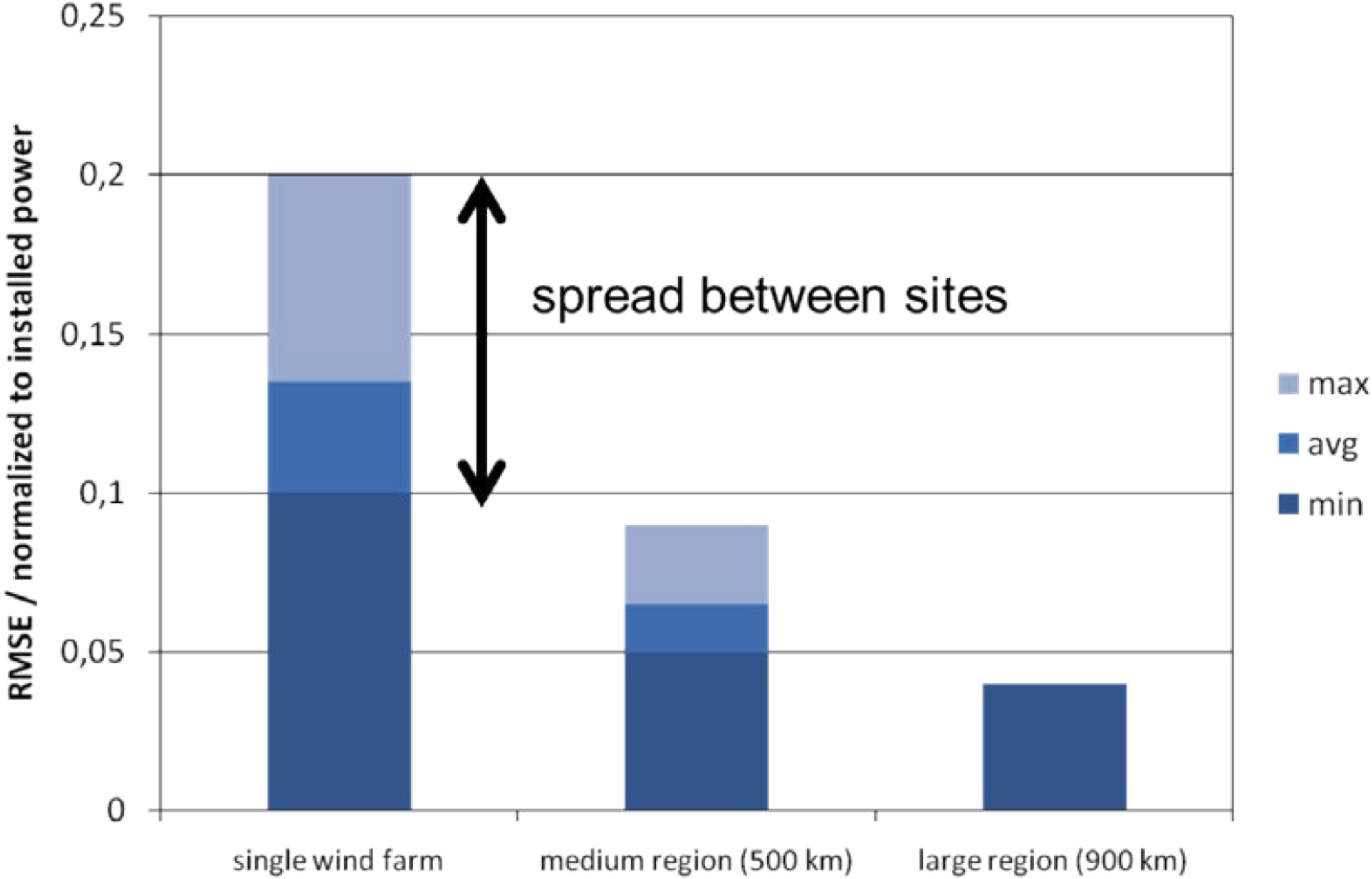


Figure 12: Increase of the forecasting error (RMSE / installed power) of a medium sized regional wind portfolio over the prediction horizon of 240 hours (10 days). For the first few hours the benefit of real-time production data leads to a small forecasting error. After 10 hours the forecasting error increases nearly linearly. Source: energy & meteo systems.

Source: Zieher, Lange, Focke 2015, ”Variable renewable energy forecasting”



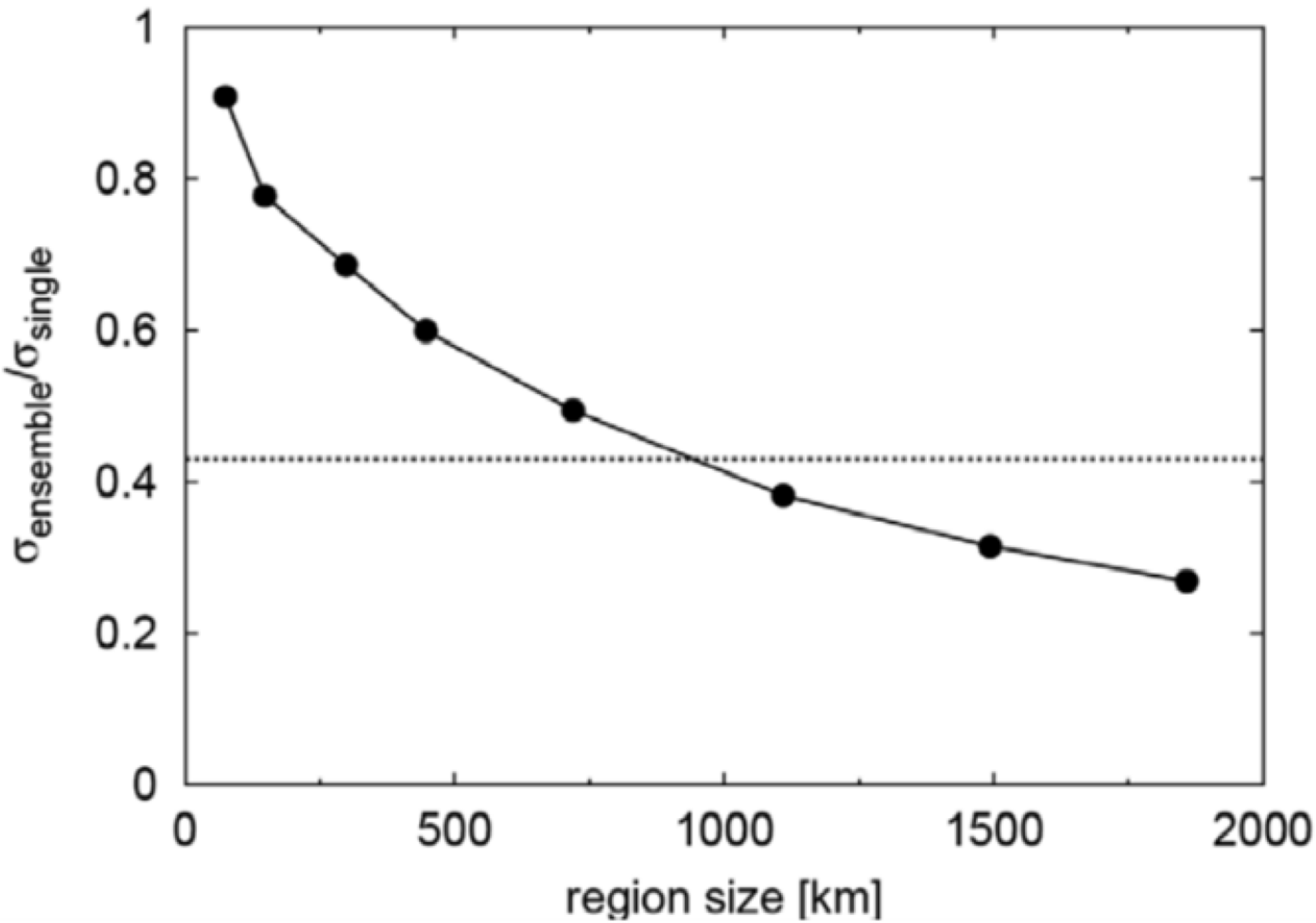
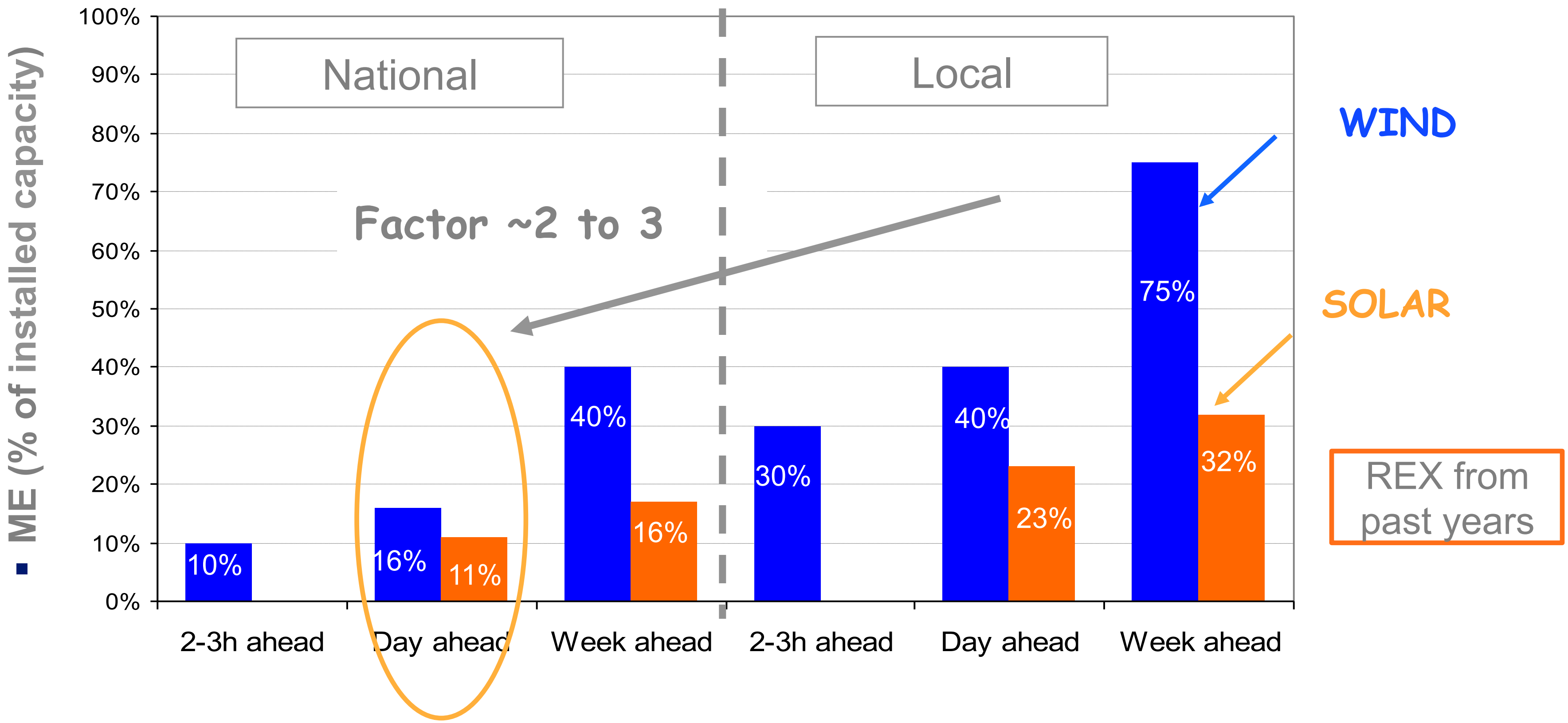


Figure 14: Regional smoothing effects, i.e. decrease of relative forecasting error for a regional forecast (aggregate) compared to single sites. For example, a forecast for region with a diameter of about 900 km has an RMSE/installed power which is only 42 percent of that of a single wind farm. Source: energy & meteo systems.

To reduce the impact of Wind and PV EDF deployed wind (2007) and PV (2009) forecast tools

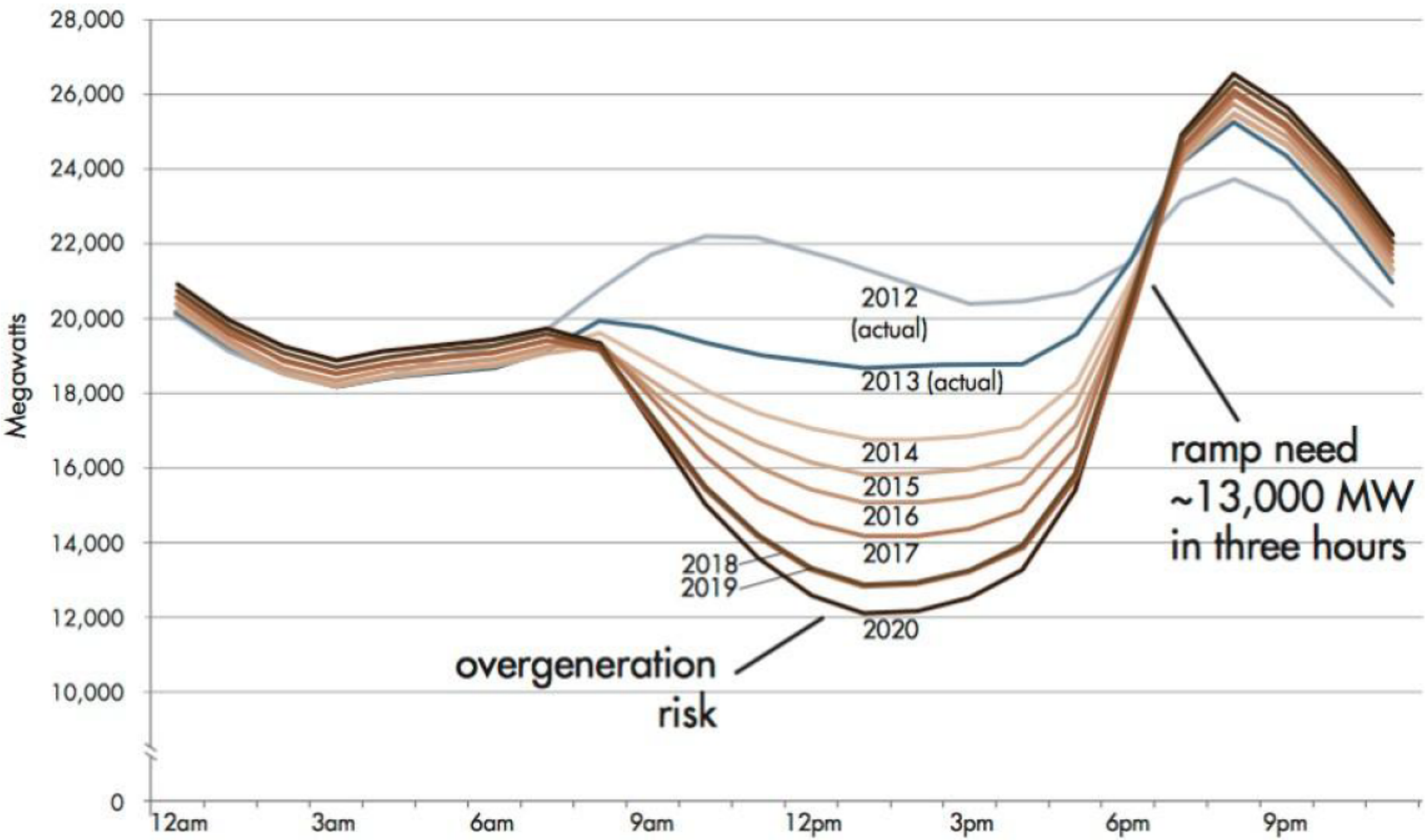
➔ **Agregation at national scale reduces forecasts errors**



1 Day-ahead, ~85% of energy output is accurately forecasted for wind, ~90% for PV

Source: Zieher, Lange, Focke 2015, ”Variable renewable energy forecasting”

Time scale of forecast	Area of application	Stakeholder
Shortest-term (0 – 6 h)	Trading on intraday energy market Control of curtailment due to negative market price Correct activation of regulation power (secondary and tertiary reserve)	Traders
	Influence of vRE on market price	Speculators
	Balancing Unit re-dispatch Curtailment of power plants	Grid operators, load dispatch centers, independent system operators
Short-term (6 – 48 h)	Trading on day-ahead energy market Participation in regulation market Influence of vRE on market price	Traders
	Unit dispatch Load flow calculations DACF congestion forecast	Grid operators, load dispatch centers, independent system operators
	Day-ahead planning of maintenance	vRE operators
Medium-term (2 – 10 days)	Trading on long-term markets	Traders
	2DACF congestions forecast Week-ahead planning	Grid operators, load dispatch centers, independent system operators
	Medium-term planning of maintenance	vRE operators



California perspective: PV is about variability
Source: Mark Ahlstrom, Windlogics

TECHNOLOGY FOR BUSINESS

FINNISH METEOROLOGICAL INSTITUTE

Buildings and built-up areas in weather models

FLEXe WP1 workshop, Calle Fortelius

carl.fortelius@fmi.fi

Finnish Meteorological Institute

May 2, 2016

Contents

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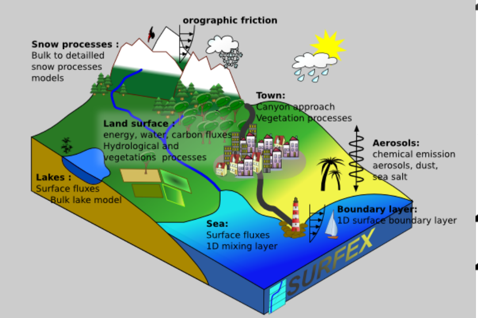
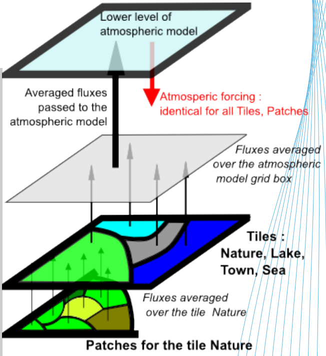
Uses of urban forecasting
(more than half the population lives in towns and cities)

- Temperature (urban heat island)
- Heating demand, cooling demand
- Conditions of roads and pavements
- Rainwater sewage loading
- Freezing and thawing of soil
- Local energy production: Solar, wind
- Urban planning, (e.g. building density, vegetated roofs) and local interpretation climate scenarios
- ...

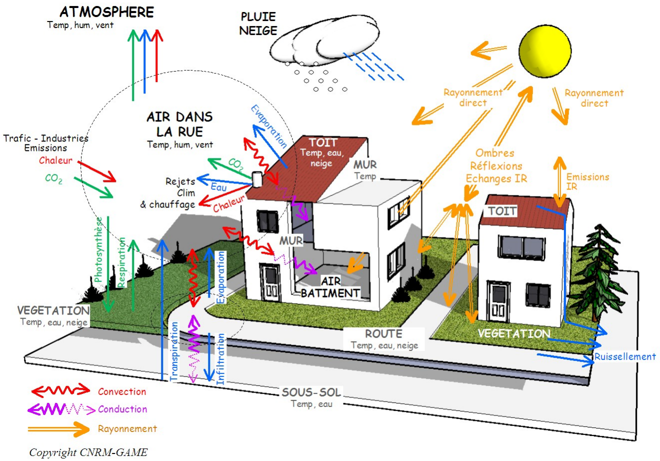
Air-surface interactions in NWP and climate models



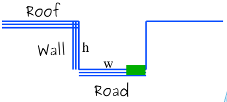


SURFEX tiling and coupling with an atmospheric model

The urban system

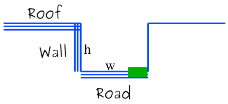


The Town Energy Balance model TEB



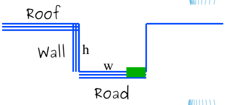
- **Conceptual model:** array of "canyons"
  - Horizontal scale upwards of a city block
  - All buildings have the same height and width located along identical roads without intersections.
  - All canyon orientations exists with the same probability. Orientation effects for roads and walls can be taken into account.

The Town Energy Balance model TEB



- Conceptual model: array of "canyons"
- **Realization**
  - The urban area is represented by three surfaces representing **roofs, walls and roads**, all having separate energy budgets accounting for radiation, turbulent fluxes of sensible and latent heat, and conduction into the materials
  - Snow may exist on roofs and roads
  - Vegetation can be present in the roads
  - Key parameters depend on canyon shape and construction materials.

Radiation



- Sky view factor of roads and walls:
  $\Psi_r = \left[(h/w)^2 + 1\right]^{1/2} - h/w$
  $\Psi_w = \frac{1}{2}\{h/w + 1 - \left[(h/w)^2 + 1\right]^{1/2}\}/(h/w)$
- Shadow effects of direct short wave radiation accounting for orientation
- Infinite number or reflections of scattered short wave radiation
- Trapping of long wave radiation accounting for one re-emission

Turbulent exchange

Controlled by aerodynamic resistances depending on roughness, wind speed, and stability

$$H_R = C_p \rho_a (\hat{T}_R - \hat{T}_a) / RES_R$$

$$LE_R = L \rho_a [q_s(\hat{T}_R, ps) - \hat{q}_a] / RES_R$$

$$H_r = C_p \rho_a (T_r - T_{can}) / RES_r$$

$$LE_r = L \rho_a [q_s(T_r, ps) - q_{can}] / RES_r$$

$$H_w = C_p \rho_a (T_w - T_{can}) / RES_w$$

$$H_{top} = C_p \rho_a (T_{can} - \hat{T}_a) / RES_{top}$$

$$LE_{top} = L \rho_a (q_{can} - q_a) / RES_{top}$$

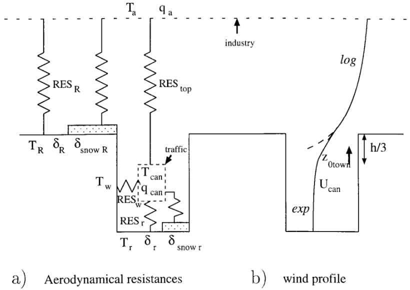


Figure 3. Scheme options for: (a) aerodynamic resistances; (b) wind profile within and above the canyon.

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Town vegetation

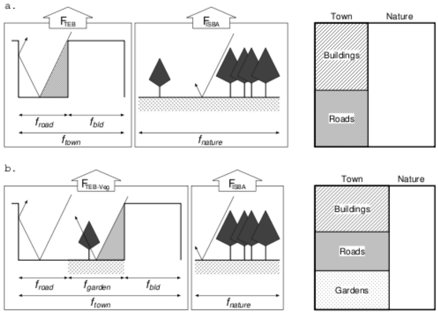

Fig. 1. Comparison of tiling approaches applied in TEB-ISBA (top) and TEB-Veg (bottom) to compute surface fluxes for a SURFEX's grid point containing pervious and impervious covers.

Anthropogenic heating and moistening

- Traffic: Prescribed, released into the canyon
- Industry: Prescribed, released into the atmosphere above
- Building space: Modelled, released through roofs and walls

Air in the canyon

- Option 1:
  Temperature, humidity and wind in the canyon can be solved diagnostically, assuming fluxes to be in balance
- Option 2:
  Prognostic temperature, humidity and wind profiles in the canyon controlled by a turbulence closure model

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Buildings

- Simple:
  Heat conduction through walls and roofs
  Prognostic internal temperature
  Energy used for heating, simple

- Building Energy Model (Optional):
  · Detailed HVAC system (heating, cooling)
  · Ventilation and infiltration
  · Solar radiation through windows
  · Vegetated roofs

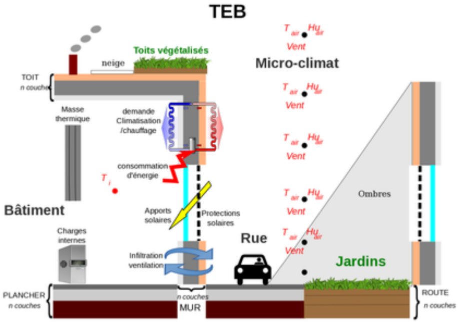
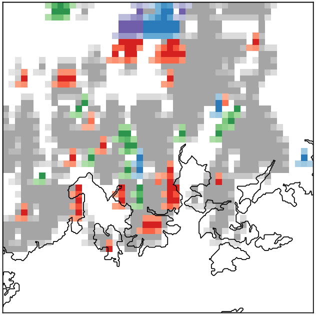


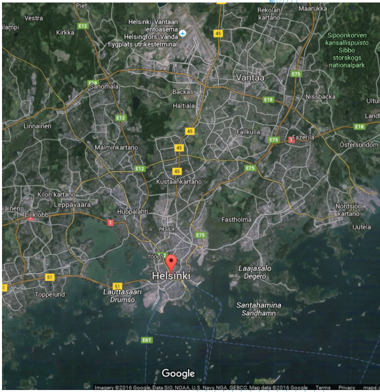
Schéma conceptuel de TEB

Urban characteristics and other physiographic data

- ECOCLIMAP data base (Default)
  More than 550 scenes, each with it's own mixture of plant physical types and types of built-up areas.
- Set by user

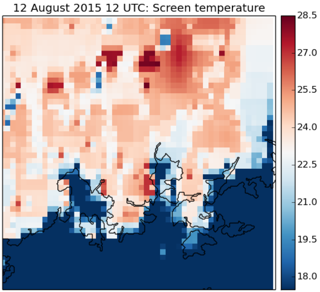
Helsinki area in ECOCLIMAP

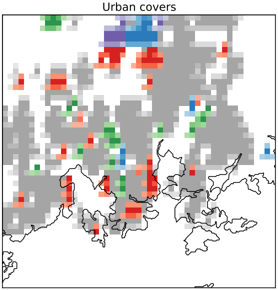




Different types of urban covers: Residential, Industrial and commercial, Parks and sports facilities, Air ports, ports, rails, Mineral extraction sites,

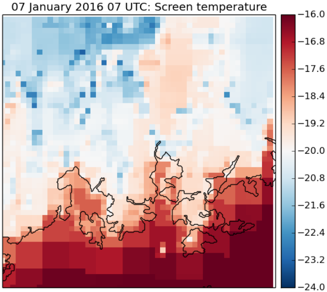
Street-level temperature on a hot summer's day

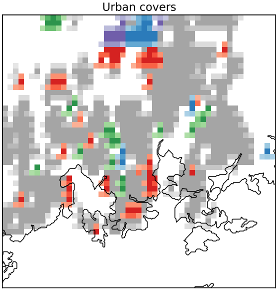




Different types of urban covers: Residential, Industrial and commercial, Parks and sports facilities, Air ports, ports, rails, Mineral extraction sites,

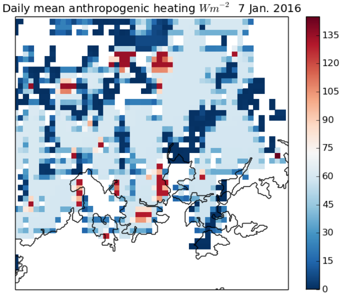
Street-level temperature on a cold winter's morning

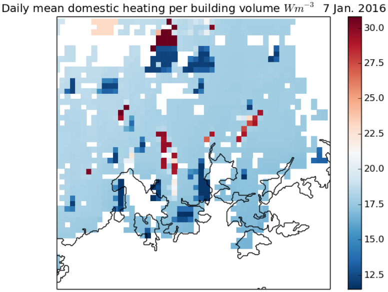




Different types of urban covers: Residential, Industrial and commercial, Parks and sports facilities, Air ports, ports, rails, Mineral extraction sites,

Energy usage on a cold winter's day





***Left.**: Daily mean energy usage for domestic, heating, traffic, and industry per town unit area during 7.1.2016 06UTC - 8.1.2016 06UTC*

***Right.**: Daily mean domestic heating per unit building volume during 7.1.2016 06UTC - 8.1.2016 06UTC*

Evaluation of BEM in Toulouse

B. Bueno et al.: Development and evaluation of a building energy model 443

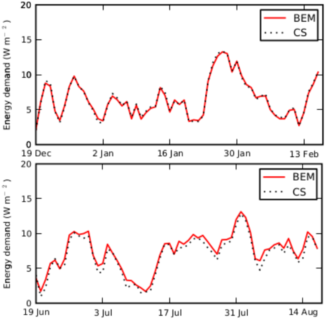


Fig. 6. Daily-average heating (top) and cooling (bottom) energy demand per unit of floor area for winter and summer calculated by the coupled scheme and by BEM-TEB for the dense urban centre of Toulouse.

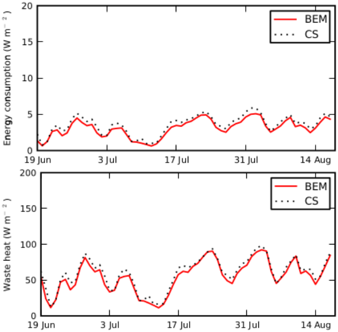
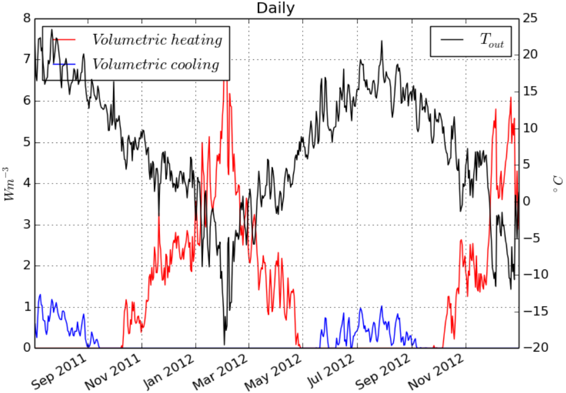


Fig. 8. Daily-average cooling energy consumption per unit of floor area (top) and waste heat emissions per unit of urban area (bottom) calculated by the coupled scheme and by BEM-TEB for the dense urban centre of Toulouse.

HVAC energy usage at Hotel Torni

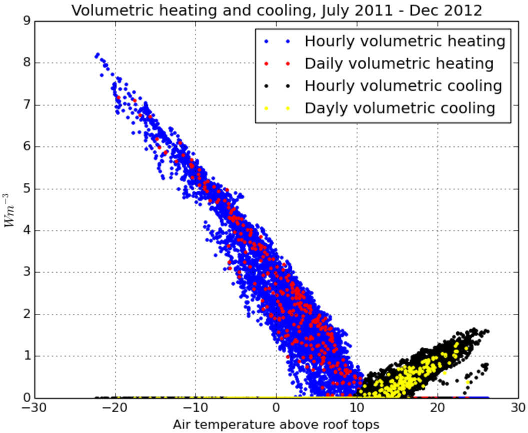


Default BEM settings

Urban characteristics from ECOCLOMAP-II

Meteorological forcing observed at Hotel Torni, July 2011- Dec 2012

HVAC energy usage at Hotel Torni

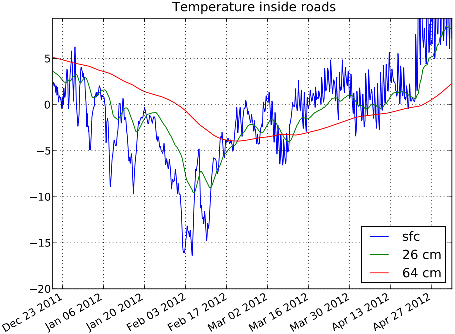


Default BEM settings

Urban characteristics from ECOCLOMAP-II

Meteorological forcing observed at Hotel Torni, July 2011- Dec 2012

Road temperature at Hotel Torni



Default BEM settings

Urban characteristics from ECOCLOMAP-II

Meteorological forcing observed at Hotel Torni, July 2011- Dec 2012

Urban Forecasting System

Input

a: WEATHER

- NWP-model, or
- Climate model, or
- Observations

b: TOWN PROPERTIES

- automatically from ECOCLIMAP data base, or
- specified by user

Output

- Temperature of air and in structures
- Water and snow on surfaces, generation of runoff
- Energy balance of surfaces, including radiative fluxes
- Energy used for heating and cooling of building space
- etc

For Further Reading I

P. Karsisto et al.
Seasonal surface urban energy balance and wintertime stability simulated using three land-surface models in the high-latitude city Helsinki.
Quart. J. Roy. Meteor. Soc. 142, 401-417, 2016

V. Masson et al.
The SURFEXv7.2 land and ocean surface platform for coupled or offline simulation of earth surface variables and fluxes.
Geosci. Model Dev. 6, 563-582, 2013

B. Bueno et al
Development and evaluation of a building energy model integrated in the TEB schem.
Geosci. Model Dev. 5, 433-448, 2012

For Further Reading II

V. Masson
A physically based scheme for the urban energy budget in atmospheric models.
Bound. Layer Meteor. 94, 357397, 2000

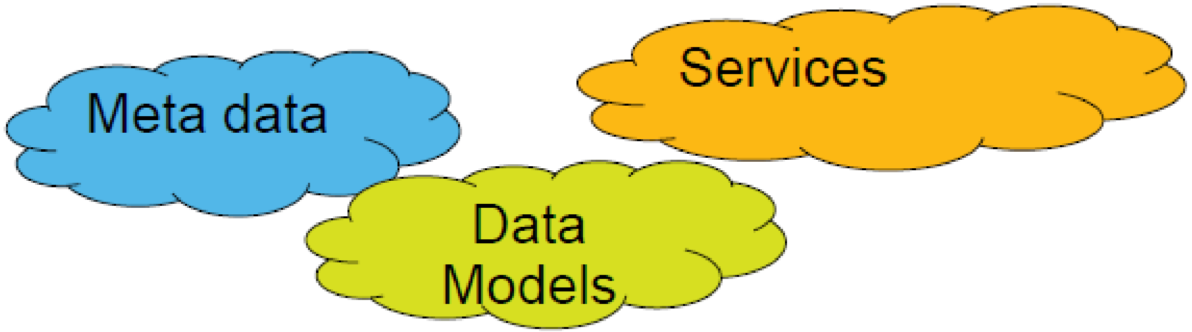
Agenda 2.5.2016 10-12

- 09:30 Coffee
- 10:00 Welcome
- 10:05 How power generation forecasts can affect other energy sectors (VTT)
- 10:40 Towns in Harmonie: Town Energy Balance and Building Energy Balance Models (FMI)
- 11:10 Using weather data to the benefit of district heating systems (Indmeas, FMI)
- 11:40 Pros&Cons of Open Data, what else you might need and what would be the costs (FMI)
- 12:00 Adjourn

Pros&Cons of Open Data,
what else you might need and what would be the costs

FMI Open Data Portal

FMI Open Data Portal follows INSPIRE requirements.



The very same data portal works as Open Data and INSPIRE portal.

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Pros&Cons of Open Data,
what else you might need and what would be the costs

Registration

- Registration is required to use View and Download Services
  - Working email address is the only mandatory information
- After registration the user gets an API key which have to be added into all requests
  - GET parameter *fmi-apikey=…&*
  - Header *fmi-apikey; …*
  - Part of url http:*//wms.fmi.fi/fmi-apikey/…/wms?*
- One can create several API keys with one email

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Pros&Cons of Open Data, what else you might need and what would be the costs

FLEXe
Future Energy System

Usage Limits

With one API key it's allowed to

- do at most **20 000** requests **per day** to Download Service
- do at most **10 000** requests **per day** to View Service
- do at most **600** requests **per 5 minutes** to both services

- If all observations from one time step is calculated to as one, little over **17 000** new data sets are published daily
  - So, with one API key it's allowed load everything once
- View service can be used for testing but can not be used as a back end for popular clients

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Pros&Cons of Open Data,
what else you might need and what would be the costs

- FMI Open data https://ilmatieteenlaitos.fi/avoin-data

Ilmatieteen laitoksen aineistoista avattu:

sää-, meri- ja ilmastohavaintoja

säätutkakuvia ja salamahavaintoja

kansallisen sääennuste- ja merimallien tietoja.

Reaaliaikaiset havainnot:

Asemakohtaiset havainnot (esim. tuuli-, lämpötila-, kosteus-, ilmanpaine-, sade-, merivedenkorkeus- ja aallokkohavainnot)

Säätutkakuvia ja salamoiden paikannustiedot Suomen alueelta

Havaintojen aikasarjat:

Ilmastohavainnot vuodesta 1959 (asemakohtaisia päivä- ja kuukausiarvoja)

Meriveden korkeushavainnot vuodesta 1971

Aaltohavainnot vuodesta 2005

Pros&Cons of Open Data,
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- FMI Open data https://ilmatieteenlaitos.fi/avoin-data

Ennustemallit:

Kansallisen säämallin tuorein ennuste, joka sisältää mm. pintasäätietoja tunnin välein 2 vuorokauden ajalle

Merimallien (meriveden korkeus, virtaus ja aalto) tuoreimmat ennusteet

Ilmastonmuutosskenaariot 30-vuotisjaksoille 2010 - 2039, 2040 -2069 ja 2070-2099 (keskimääräiset lämpötilan ja sateen muutosarvot)

STUK datasets included

OPEN DATA is available on best effords basis => there may be interruptions in operations for several days and/or missing data

Pros&Cons of Open Data,
what else you might need and what would be the costs

FMI Closed Data interface (CD)

- Technically identical to OD
- Same API Key can be used both for OD and CD
- Basic Contents identical to OD
- Extra data sets on customer demand for example ECMWF forecasts (upto 14 days)
- SLA per customer has not used until so far, but
- Internal target availability 99.95% (last 3 months 99.4% ☹)
- => 24/7 operations, considerably more computer power that on OD
- Number of requests per customer configurable (and controlled)

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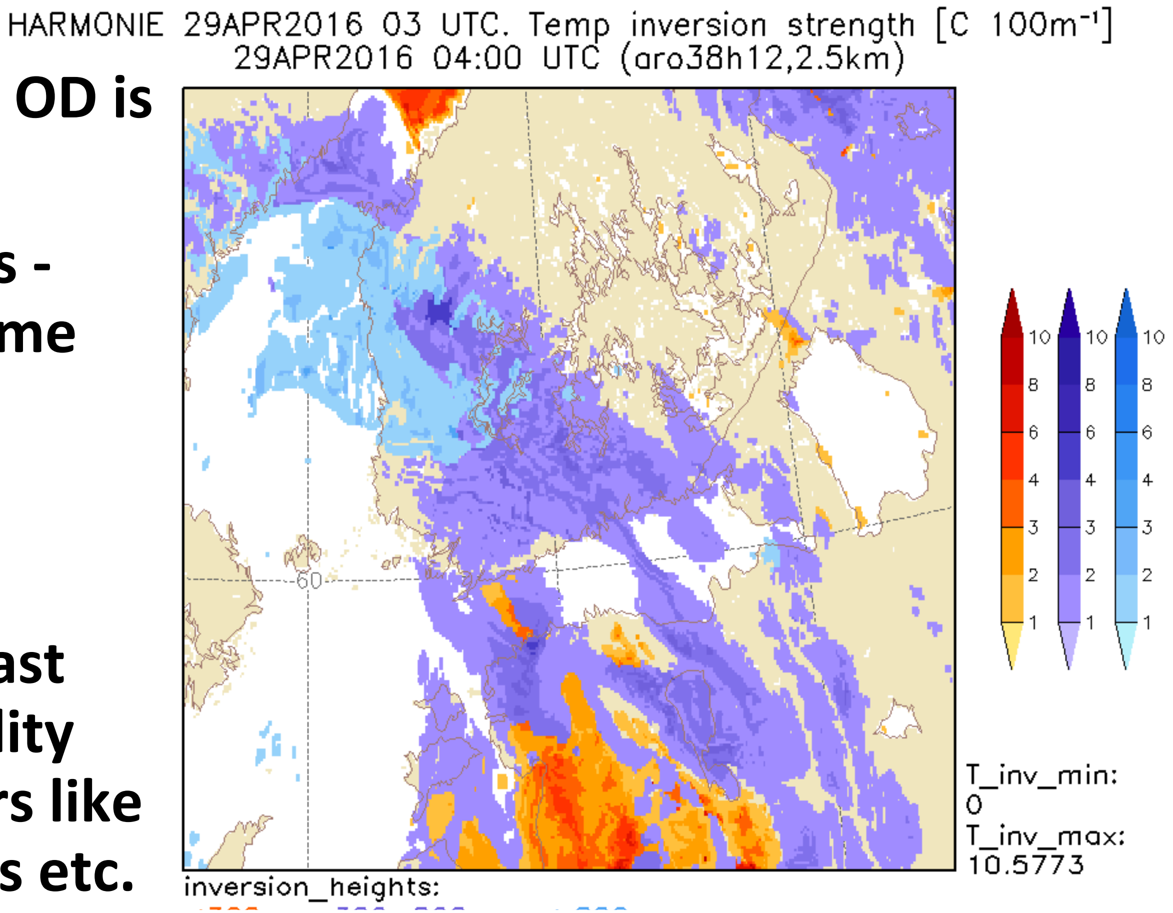
Pros&Cons of Open Data, what else you might need and what would be the costs

Closed Data interface (CD)

- All data, which is available on OD is free
- Extra data sets have price tags - especially data sets, which come from other sources than FMI
- Examples of extra data sets:
  - ECMWF 14 day forecasts
  - Special postprocesses forecast model data such as probability forecasts, special parameters like height of inversion, lightness etc.



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Pros&Cons of Open Data,
what else you might need and what would be the costs

max req/pv	max req/s
200000	3
300000	6
400000	8
500000	10
600000	12
700000	14
800000	16
900000	18
1000000	20

Closed Data interface (CD)

- **Configurable max requests per day and per second are basis of the pricing**
- **This means in practise that the customer could base all data requests for their application from FMI CD. No need for own data interface**

Pros&Cons of Open Data,
what else you might need and what would be the costs

Class	max req/day	max req/s
1	200000	3
2	300000	6
3	400000	8
4	500000	10
5	600000	12
6	700000	14
7	800000	16
8	900000	18
9	1000000	20

Closed Data interface (CD)

- **Monthly prices ranging from hundreds to several thousands €**
- **If either of max /day or per second requests are exceeded during one month, pricing will be applied according to the higher request class**
- **Customers, who need data reqularly and reliably, but only small data sets per day will be considered separately**

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Pros&Cons of Open Data, what else you might need and what would be the costs

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Finnish Meteorological Institute

Customer Services

Security