2017年欧州出張報告

内藤克彦

自治体と再エネ

デンマークの事例から

デンマークとは？

- 面積：43,096㎢（九州とほぼ同じ）Størrelse
- 人口：約570万人
  Indbyggere
- 一人当たりGDP：52,002ドル GDP/person/USD, 2015
- 首都：コペンハーゲン Hovedstad
- 対日本貿易黒字国
  Dansk handelsoverskud

2050年までに、化石燃料から脱却

Regeringens energipolitiske milepæle frem mod 2050

For at sikre, at vi opnår 100 pct. vedvarende energi i 2050, har regeringen en række energipolitiske milepæle i årene 2020, 2030 og 2035. Disse målsætninger er hver især skridt i den rigtige retning, der sikrer fremdrift mod 2050.

2020	2030	2035	2050
Halvdelen af det traditionelle elforbrug er dækket af vind	Kul udfases fra danske kraftværker Oliefyr udfases	El- og varmeforsyningen dækkes af vedvarende energi	Hele energiforsyningen – el, varme, industri og transport – dækkes af vedvarende energi

Initiativerne frem til 2020 resulterer i en reduktion af drivhusgasudledningerne på 35 pct. i forhold til 1990

2020年までに 全電力消費量の 50%を風力で	2030年までに 石炭火力全廃 灯油ボイラーも 段階的廃止	2035年までに 電力、熱供給を 再生可能 エネルギーで	2050年までに 電力、熱、産業、輸送 すべてにおいて 再生可能エネルギーで

ロラン島とは？

Lolland i hovedtal

- デンマーク最南端
- ４番目に大きな島
- 面積：1,242.86㎢
- 人口：約6万2500人
- 肥沃な土地＝農業盛ん
- 環境自治体

Renewable energy Lolland

Bjarne Hansen, January 2017

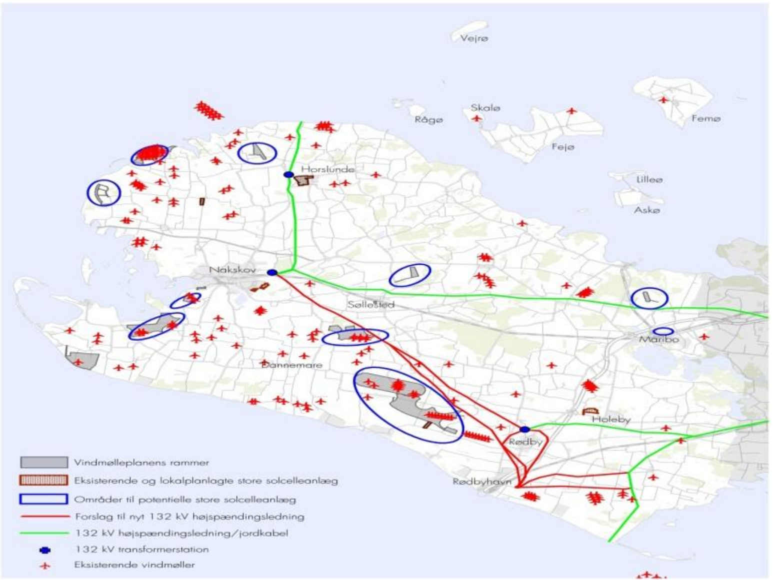
lollandkommune

ロラン島も、
かつては原発予定地だった。 Lolland var kandidat

- 現在は、風力発電パーク Nu vindmøller
- ロラン、ファルスタ両島で　陸海合わせて500基以上 ca. 500 på LF
- 陸上風車の半数は個人または　市民風車 ca 50% privatejet vindmøllelaug – resten er stat eller store selskaber
- 世界初の洋上風力発電パーク Verdens første havmøllepark
- 世界初の風力＋波力ハイブリッド発電実証実験 Verdens første hybrid Vind/Bølgeanlæg

○陸上風力の場合、発電事業者に対し、地元住民から20%以上の出資を受けることを義務付け
→自分たちの風車

○立地規制・・・住宅からの距離を風車の高さの6倍以上
ただし、出資者の住宅は除外



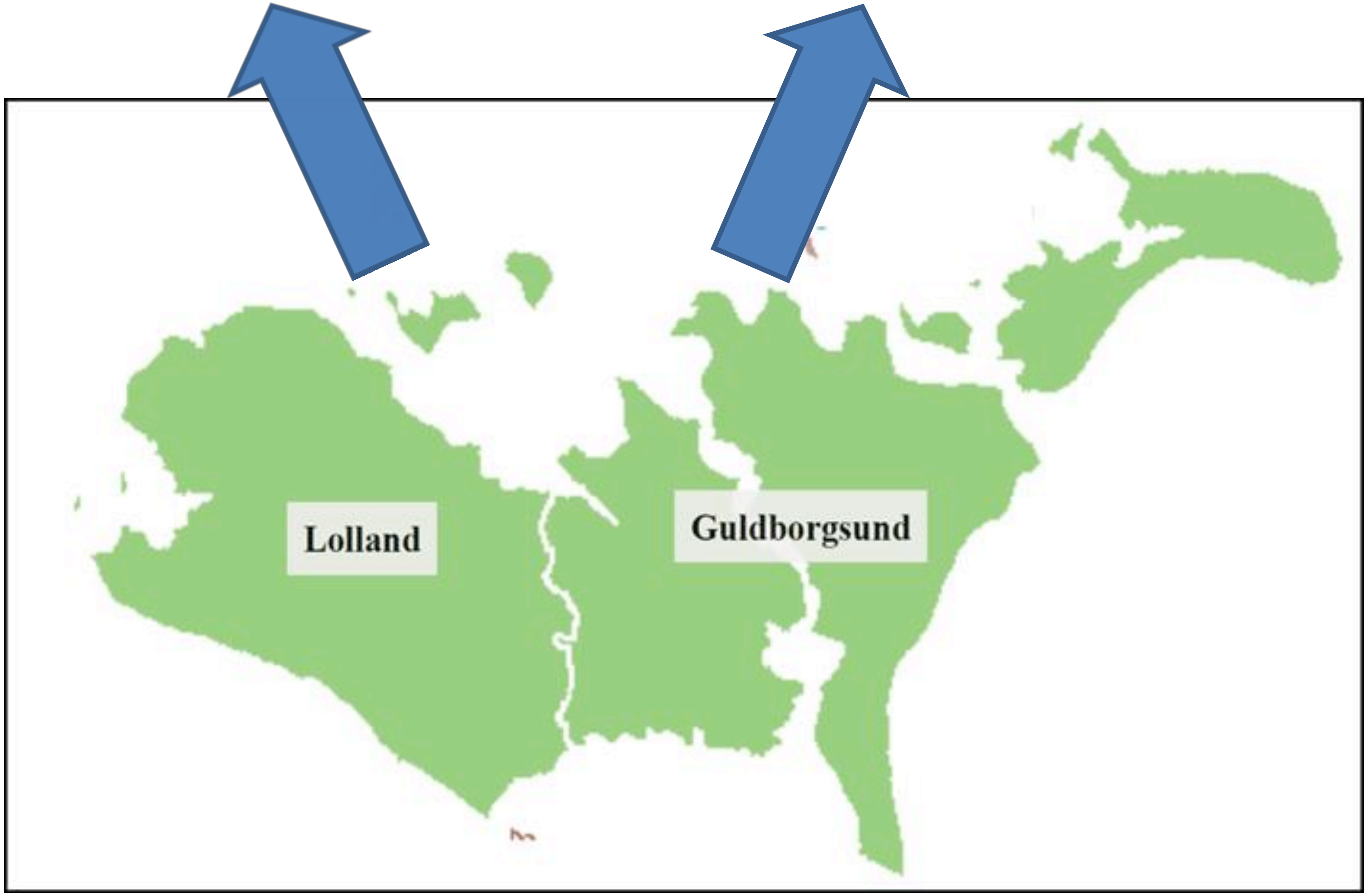
LOLLAND FALSTER

ロラン島
年間電力消費
480GWH

年間電力輸出
2500GWH

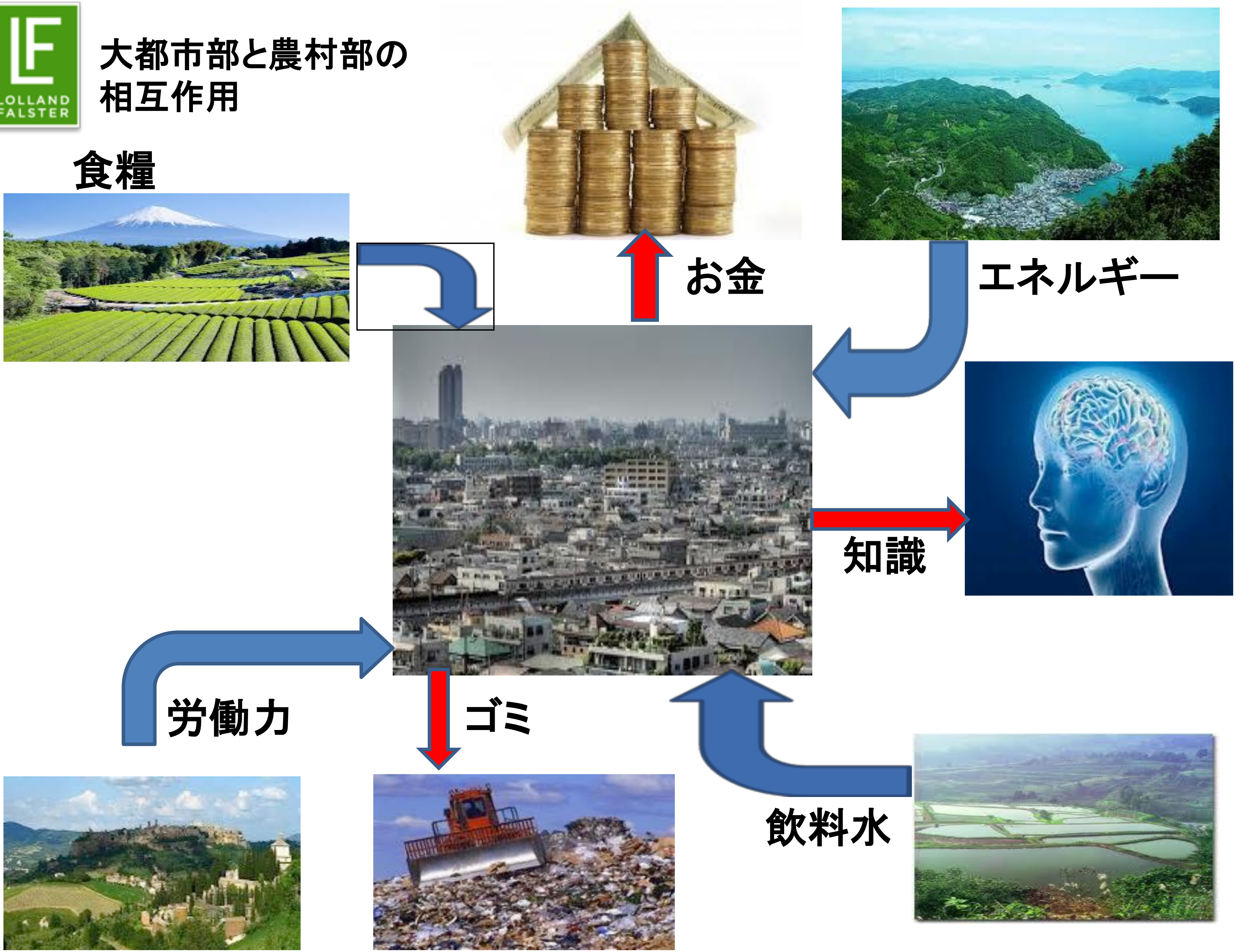
エネルギー年間売上高
300億円

農産物年間売上高
500億円



ロラン島＆ファルスタ島の人口＝11万人

大都市部と農村部の相互作用



〇市議会としての大都市との交渉

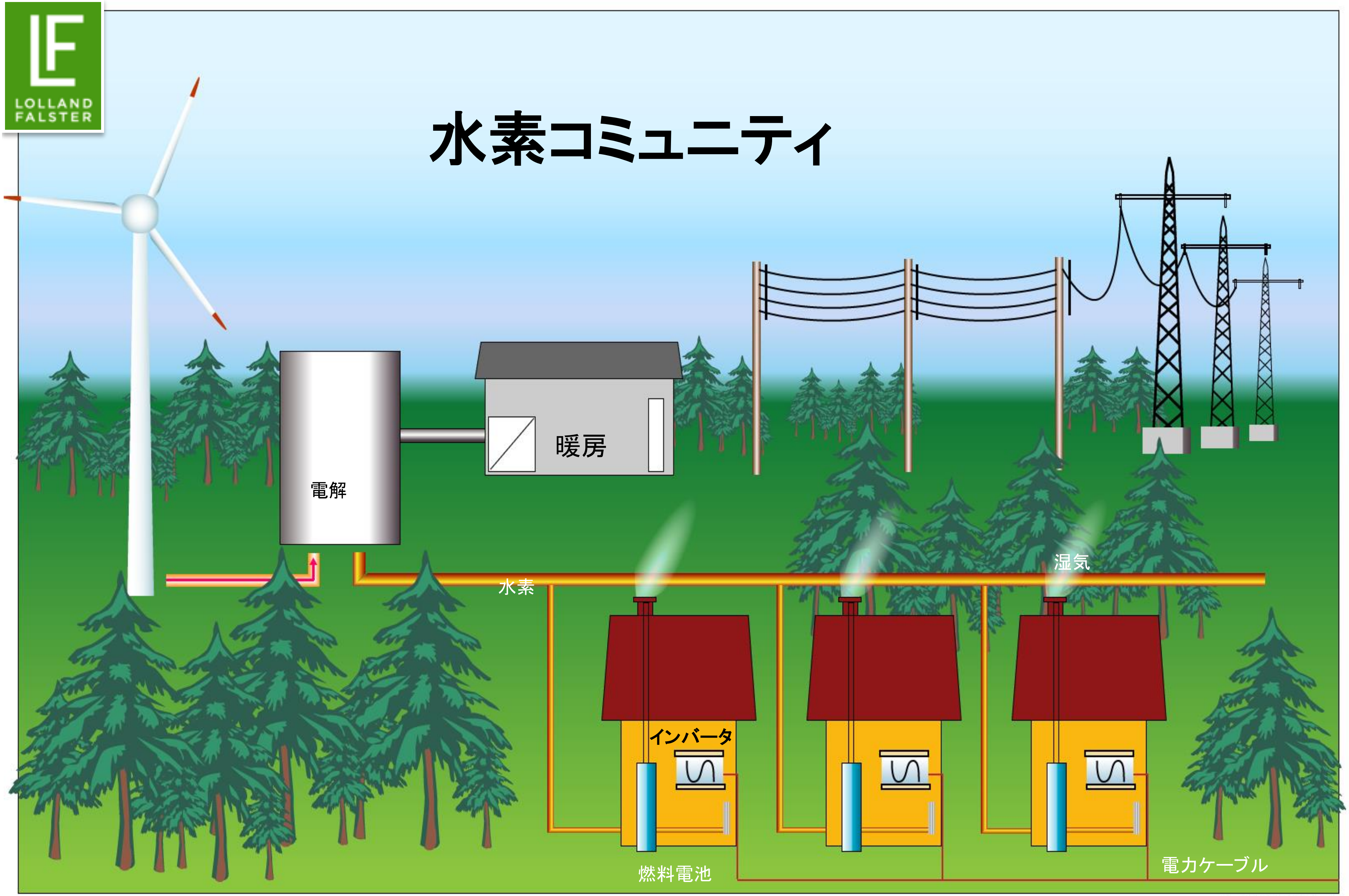
・コペンハーゲン市との売電交渉・・・コペンハーゲン市との協定

・再エネ電力の提供の見返りに大都市の知識の提供

→ 種々の新たなプロジェクト

ロラン・ファルスタCTF

水素コミュニティ



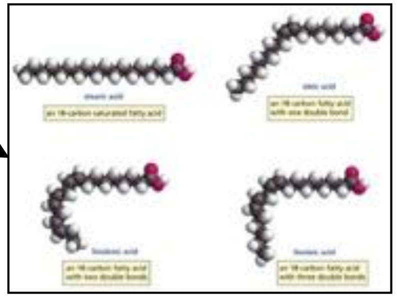
オイル

藻と

油脂植物

プレスケーキ

バイオディーゼル



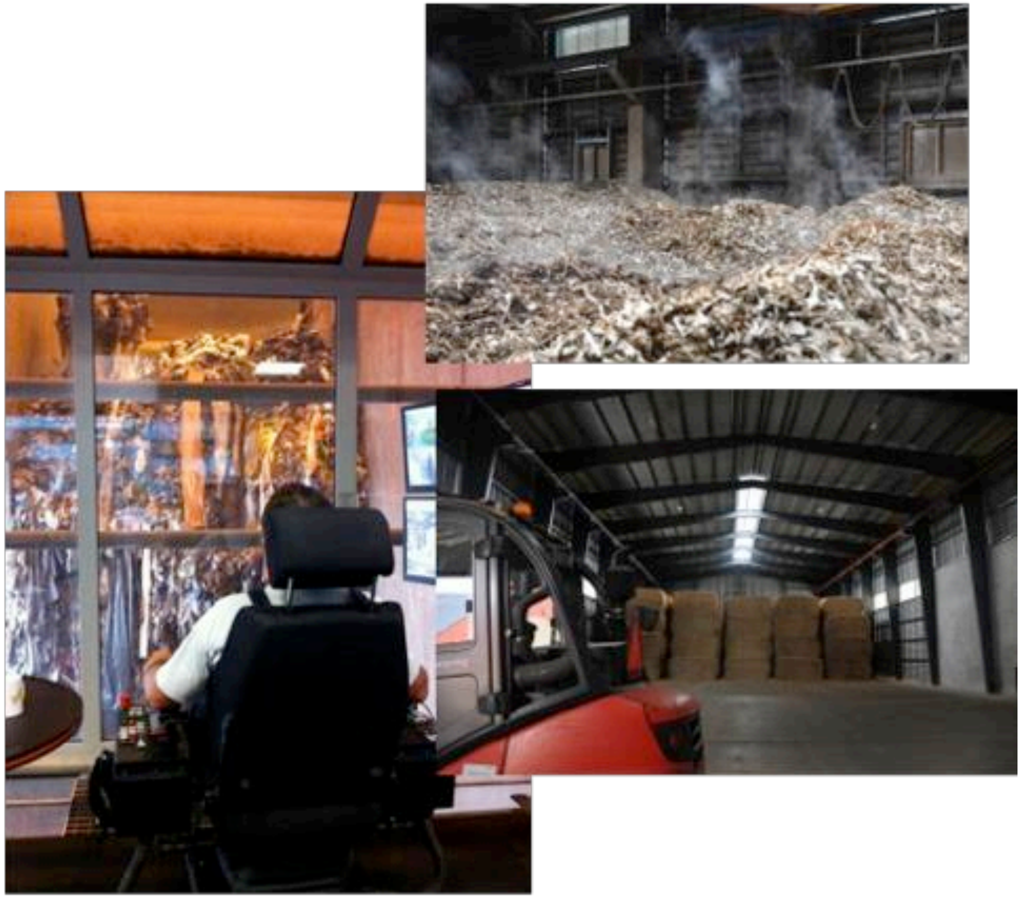
特定の脂肪酸

生理活性成分

最適化された飼料

ロラン島は再生可能エネルギーを最大利用

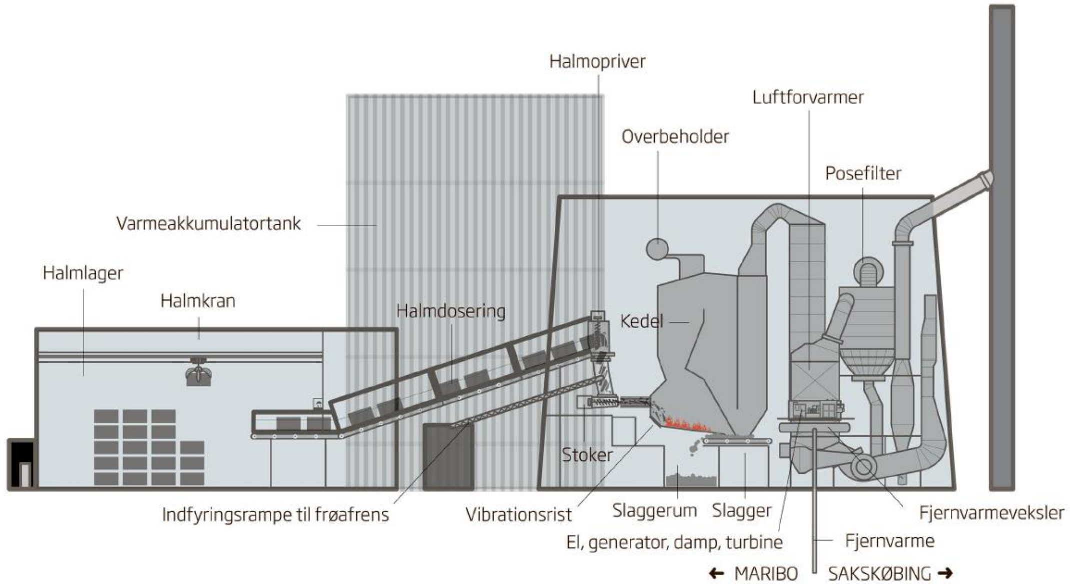
- 風力発電
- バイオマス発電　（ワラ、ウッドチップ）
- バイオガス発電（家畜の糞尿、有機産業廃棄物）
- ゴミ発電（家庭ゴミ、産業廃棄物）
- 資源のリユース
- 熱電併給（CHP）




一日分の熱
供給量の貯
熱タンク
REFA
ENERGI

Brændsel	Halm + frøafrens
Forbrændingskapacitet	8 tons pr. time
El-kapacitet	12 MW pr. time
Varme-kapacitet	25 MW pr. time
Brændselsforbrug	52.000 tons pr. år
Produceret el	60.000 MWh pr. år
Produceret fjernvarme	125.000 MWh pr. år
Indviet	1999
Overtaget af REFA	2012

Maribo – Sakskøbing Kraftvarmeværk



REFA

A few Energy topics from Denmark

65 % of all households are warmed up by district heating systems

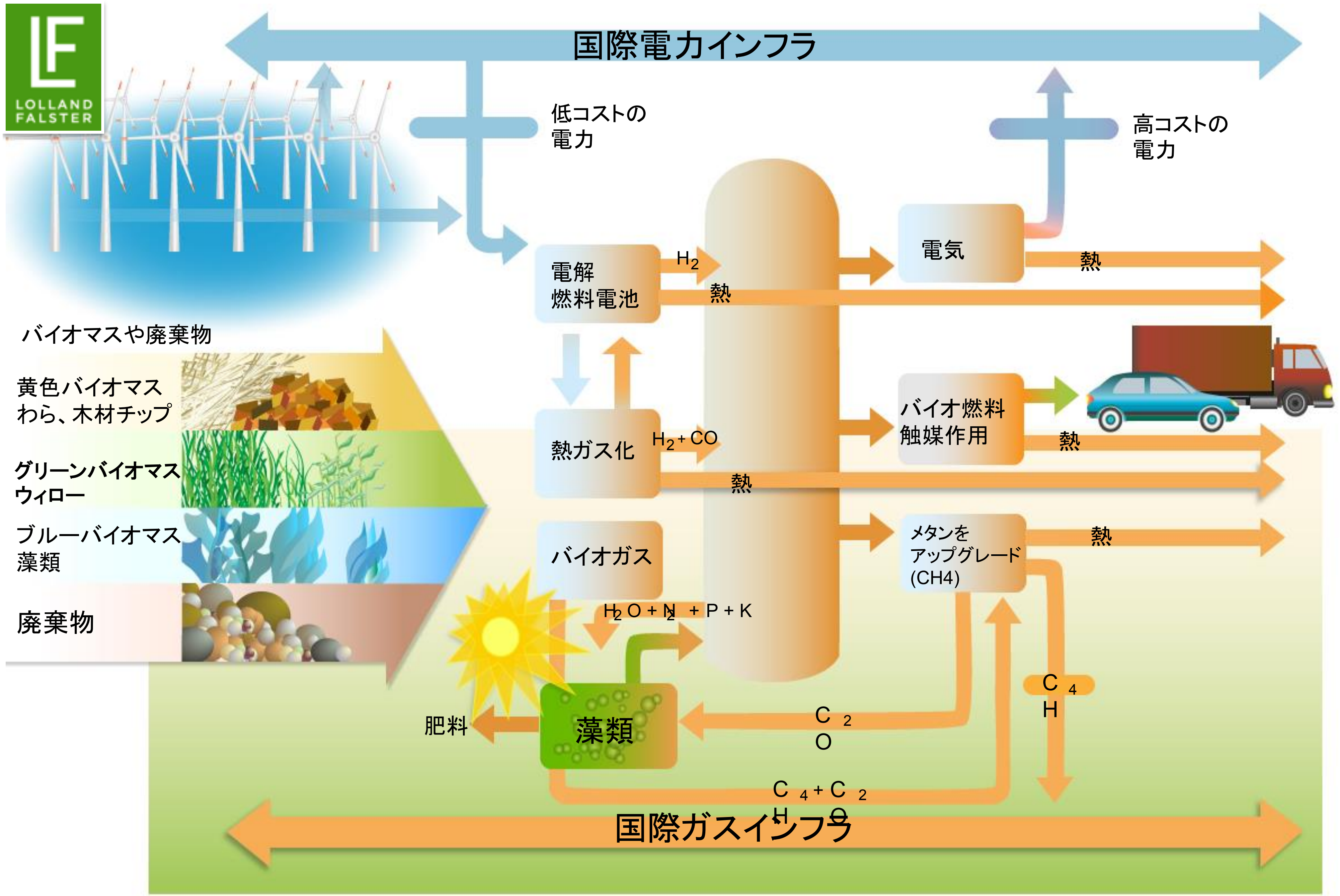
40 % of all electricity is windpower

The rest of the electricity is mainly produced on combined heating and powerplants (CHP)

The heat is maily used for district heating

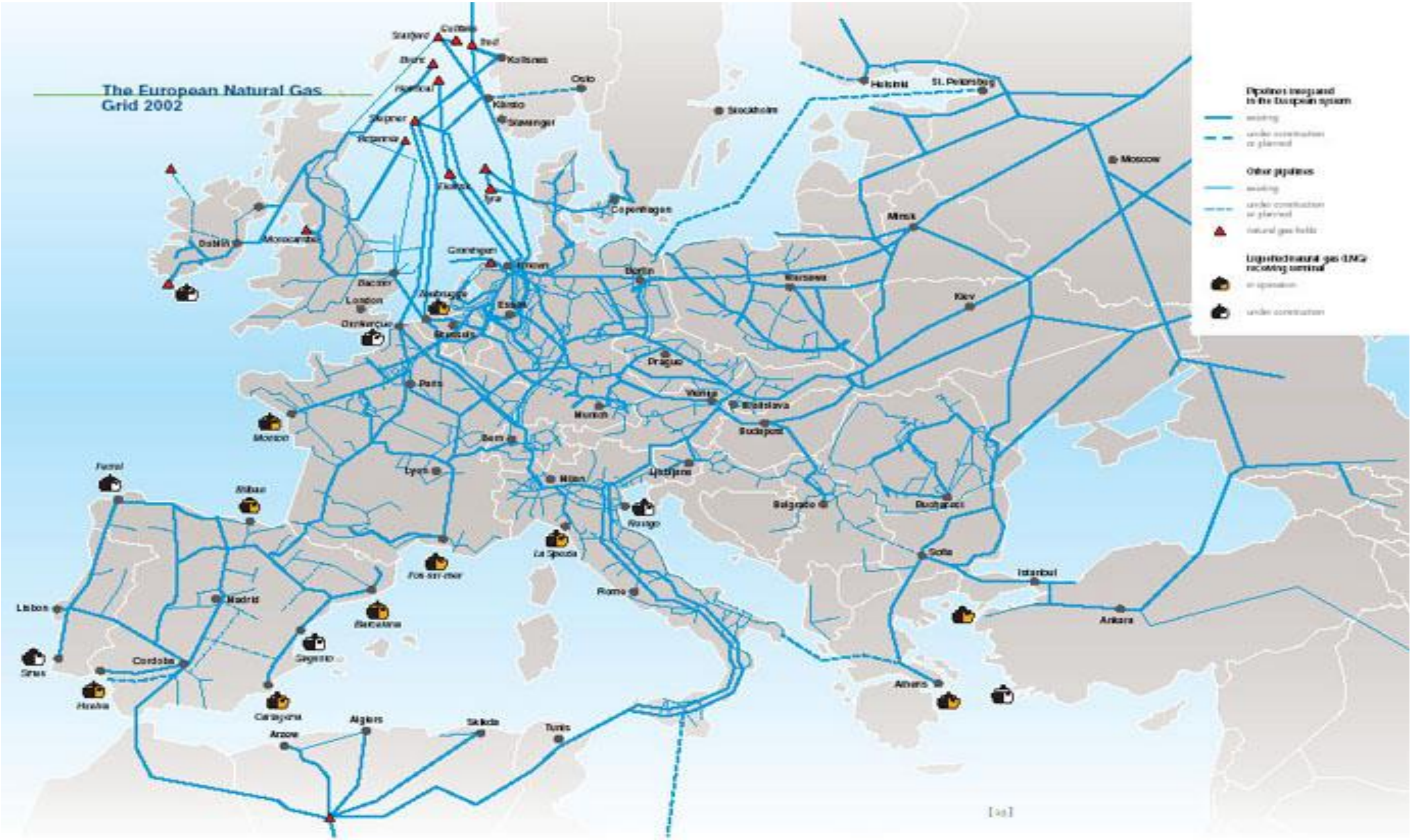
REFA ENERGI

REFA



LOLLAND FALSTER
国際電力インフラ
低コストの
電力
高コストの
電力
電解
燃料電池
H2
熱
電気
熱
バイオマスや廃棄物
黄色バイオマス
わら、木材チップ
グリーンバイオマス
ウィロー
ブルーバイオマス
藻類
廃棄物
熱ガス化
H2 + CO
熱
バイオ燃料
触媒作用
熱
バイオガス
メタンを
アップグレード
(CH4)
熱
H2O + N2 + P + K
CH4
肥料
藻類
CO2
CH4 + CO2
国際ガスインフラ

欧州のガスTSOパイプライン整備状況



Created from European Gas Industry Federation material（2003）

バイオメタン　受入基準

〇IN・OUTの料金制
〇カロリーベースの受入

〇水素も可

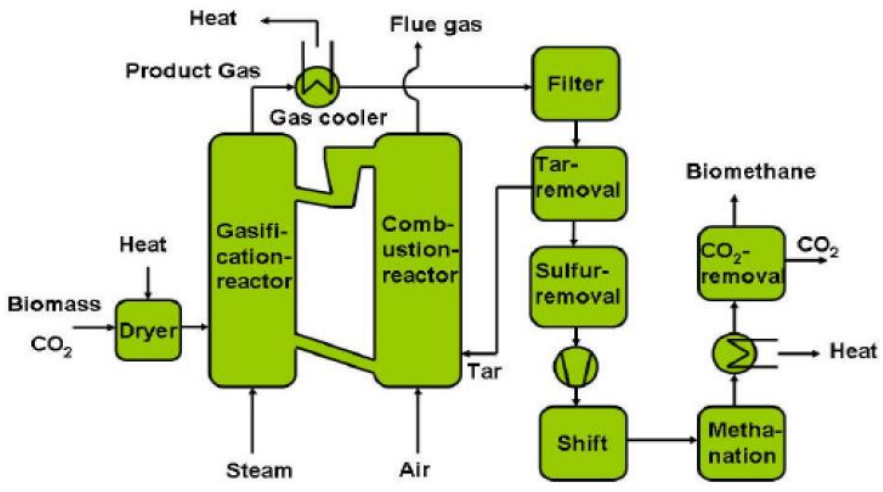


Figure 1: Schematic layout of biomass combustion and methanation to produce biomethane

5.16 *Gas Safety (Management) Regulations 1996*: A partial summary of the key gas quality requirements from Schedule 3 of the GS(M)R is shown below.

Content or characteristic	**Value**
Hydrogen Sulphide (H2S)	Less than or equal to 5 mg/m3;
Total Sulphur (including H2S)	Less than or equal to 50 mg/m3;
Hydrogen (H2)	Less than or equal to 0.1% (molar);
Oxygen (O2)	Less than or equal to 0.2% (molar);
Impurities and water and hydrocarbon dewpoints	The gas shall not contain solids or liquids that may interfere with the integrity or operation of the network or appliances
Wobbe Number (WN) (Calorific Value divided by the square root of the relative density)	Between 47.20 and 51.41 MJ/m3
Odour	Gas below 7 bar will have a stenching agent added to give a distinctive odour

洋上風力の時代の
自治体の対応

○陸上風力の時代は、地元が一定割合の事業参加

○洋上風力の場合、設置場所は、デンマークでは国が地権者である上、投資資金規模が大きくなり過ぎて、地元の零細資本では手が出せない。

①実証フィールドを提供

②洋上風力のメンテナンスを地元が担う

③洋上風力の出荷基地を作ること―などである。

①実証フィールドを提供

Strategic cooperation with HOFOR

- Lolland Kommune og HOFOR etablerer et langsigtet strategisk samarbejde, med følgende formål:

  At fremme en fælles interesse i udvikling af Lolland, med udgangspunkt i vindprojekter og andre vedvarende energiformer (VE) og baseret på konkret samarbejde om fem spor

- Hvert år udarbejdes en konkret plan for aktiviteterne det kommende år.
- For Lolland er der fokus på, at projekterne bidrager til jobskabelse direkte eller indirekte via erhvervs- og turismeudviklingsaktiviteter.

〇実際に洋上に設置する前に新機種の風車を1年間陸上設置し、実証試験

〇実証試験の場を提供することで、メンテナンス要員の地元居住や関連産業の立地が促進

1．信頼性の高い風車の投入：実証試験

陸上で徹底した事前検証を行ったのち洋上へ

Østerild国営大型風車実証試験センター

- 2011年、デンマーク政府がユトランド半島北部に大型風車実証試験センターの建設を決定
- デンマーク工科大学(DTU)がセンターを運営
- 2012年より実証機の建設が始まり、当社V164を含め、現在７地点で4社[1] が実証試験中

Østerild Test Center, V164, Denmark

Stand space	Manufacturer	mill type	Power MW	rotor Diameter	Nav-height	Tip-height
1	EDF Energies Nouvelles	Haliade 150-6 MW	6.0	150	117	192
2	Vestas Wind Systems	V164-8.0 MW	8.0	164	140	222
3	Vestas Wind Systems	V126-3.3 MW	3.3	126	116	179
4	Vestas Wind Systems	V110-2.0MW	2.0	110	98	153
5	Envision Energy	EN-120 / 3.0MW	3.0	120	90	150
6	Siemens Wind Power	SWT-7.0-154	7.0	154	120	197
7	Siemens Wind Power	SWT-4.0-130	4.0	130	110	175

Esbjerg Mådeサイト

- デンマークの南西Esbjergにおいて2機のV164陸上機を設置（納入先：*European Energy A/S*）
- 20年のサービス契約

2 x V164-8.0MW , Måde Denmark

[1] Data source: DTU Vindenergi as of 1 Feb 2017

②洋上風力のメンテナンスを地元が担う

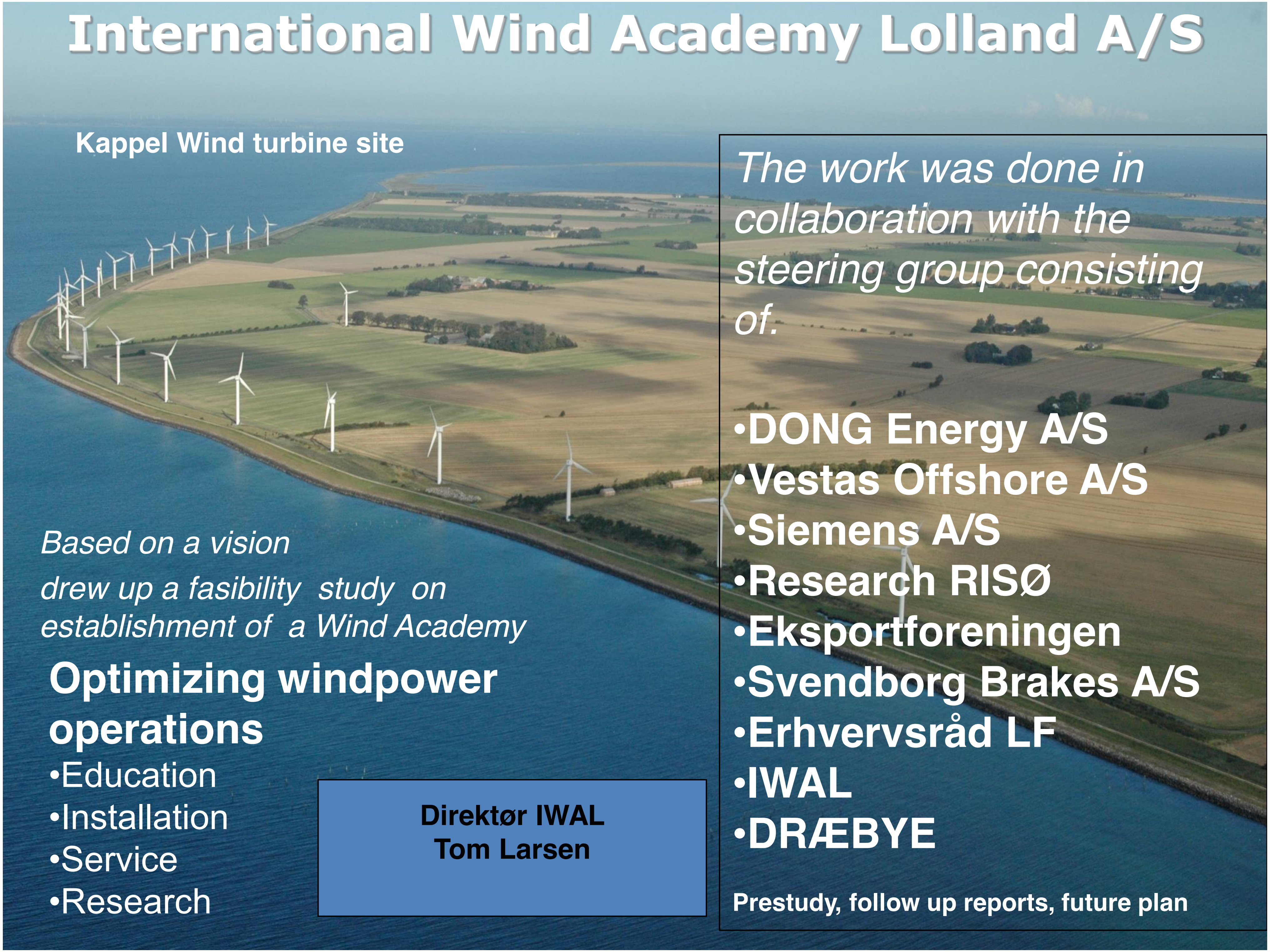
International
Wind Academy
Lolland A/S

IWAL

Wind turbine fitter courses

Wind Energy tecnician

Basic Safety Training


International Wind Academy Lolland A/S
Kappel Wind turbine site
Based on a vision
drew up a fasibility study on establishment of a Wind Academy
Optimizing windpower operations
•Education
•Installation
•Service
•Research
Direktør IWAL
Tom Larsen
The work was done in collaboration with the steering group consisting of.
•DONG Energy A/S
•Vestas Offshore A/S
•Siemens A/S
•Research RISØ
•Eksportforeningen
•Svendborg Brakes A/S
•Erhvervsråd LF
•IWAL
•DRÆBYE
Prestudy, follow up reports, future plan

Optimizing Wind Turbine operation

- Education
- Installation
- Service
- Research

〇メーカーは初期の保証期間のメンテナンスに関心を持つが、それ以後は関心が薄れる。

〇一方で、洋上風力の出資者・オーナーは、メンテナンス等のノウハウは持たないが、稼働率を維持するためにメンテナンスには最後まで関心を持つ。

〇この間を埋めるのがIWALを卒業したメンテナンスのプロ

Global Wind Organisation
GWO Sea Survival

〇海上作業や船に親和性があるので、日本との提携も面白い

③洋上風力の出荷基地を作る

2． 建設工事期間の最短化：最新工法

20年の経験とたえまない工法改善

- 洋上での作業を極力陸上にシフトする：コストとリスクの低減
  → 洋上風車仮組立・出荷基地でのタワーの全組立、
  ナセルの試運転 (Plug & Play Operation)

- 仮組立基地の整備と建造船の能力が重要

100日間で100基の洋上風車を建設

サネット, 英国 (V90-3.0MW) 2010年

一日に最大2基の洋上風車を据付

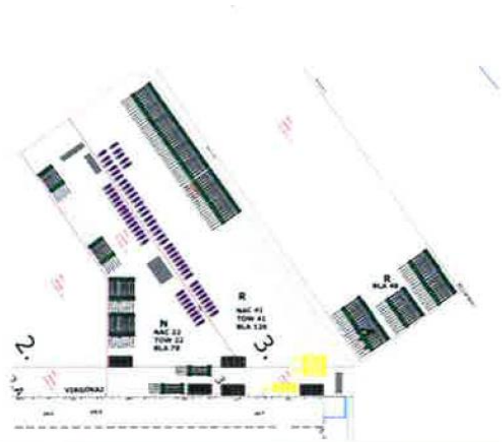
ルフタダウネン, オランダ (V112-3.0MW) 2015年

○陸上の出荷基地内でできる作業は陸上で済ませたいので、部品を可能な限り組み立てそこから洋上に運搬し、洋上作業は１日で終わらせる。このためには、出荷港において広い組み立てヤードが必要となる。

○これらの港湾施設は、港湾管理者たる地元自治体が積極的に整備。

○洋上風力を普及させるには、このような出荷港とメンテナンス港が不可欠。





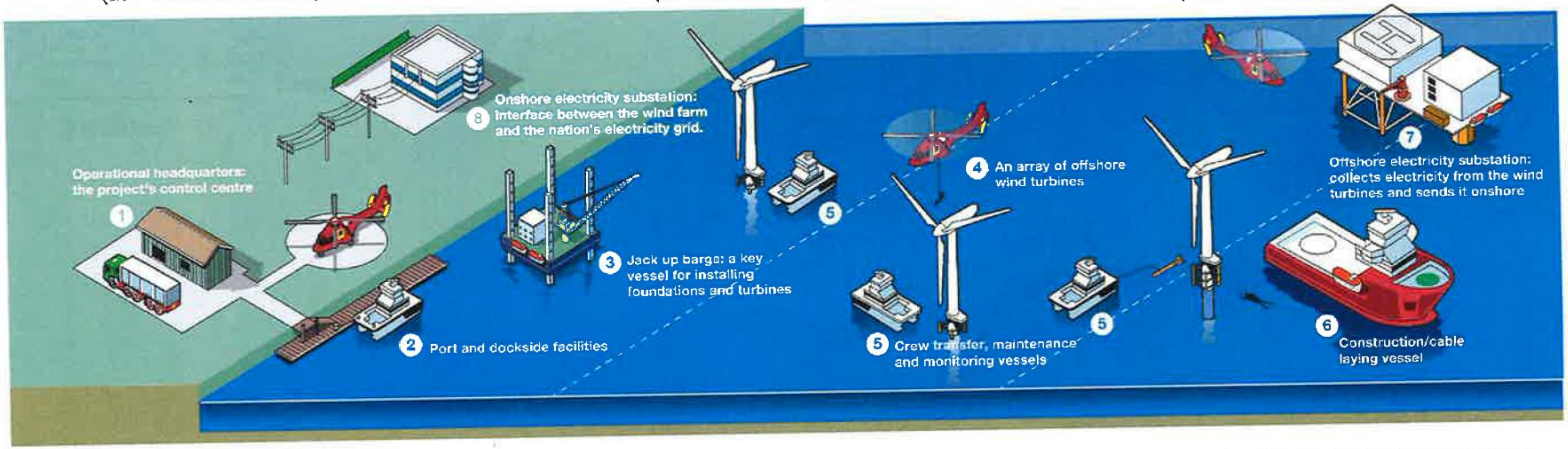

港湾インフラの整備

洋上の各施設(風車、変電所)のほか、その建設や保守を支える様々な港湾インフラ(港/SEP船/CTVなど)が不可欠

Esbjerg港
(蘭：Luchterduinen向け)

洋上風車建設風景
(英：Burbo Bank Ext.)

洋上風車メンテナンス風景
(ベルギー：Belwind)



実潮流ベースの送電容量管理
欧米の常識

日本で良く見かけるキャパシティの一覧表

「○○系統空容量」(イメージ表)

番号	電圧	空容量	番号	電圧	空容量
S1	6kV	0	L1	110kV	0
S2	66kV	0	L2	110kV	0
	6kV	0	L3	110kV	0
S3	22kV	0	L4	110kV	0
	6kV	0	L5	110kV	0
S4	22kV	0	L6	110kV	0
	6kV	0	L101	66kV	0
S5	6kV	0	L102	66kV	0
S6	6kV	0	L103	66kV	0
S7	6kV	0	L104	66kV	0
S8	6kV	0	L105	66kV	0
S9	6kV	0	L106	66kV	0
S10	6kV	0	L107	66kV	0
H1	6kV	0	F1	22kV	0

（S:変電所、H:高圧送電線、L:低圧送電線）

本当にキャパシティは０？

○欧米には見られない送配電キャパシティの一覧表
→我が国の方法とどうも根本的に違うのではないか？

○欧米はどのように送電キャパシティを割り振っているのか？

○市場運営と送電キャパシティの関係は？

○いつ送電キャパシティの計算を行っているのか？

○あまりにも基本的なことなので、欧米の最新の文献に出て来ない。

The Nord Pool model for trading power

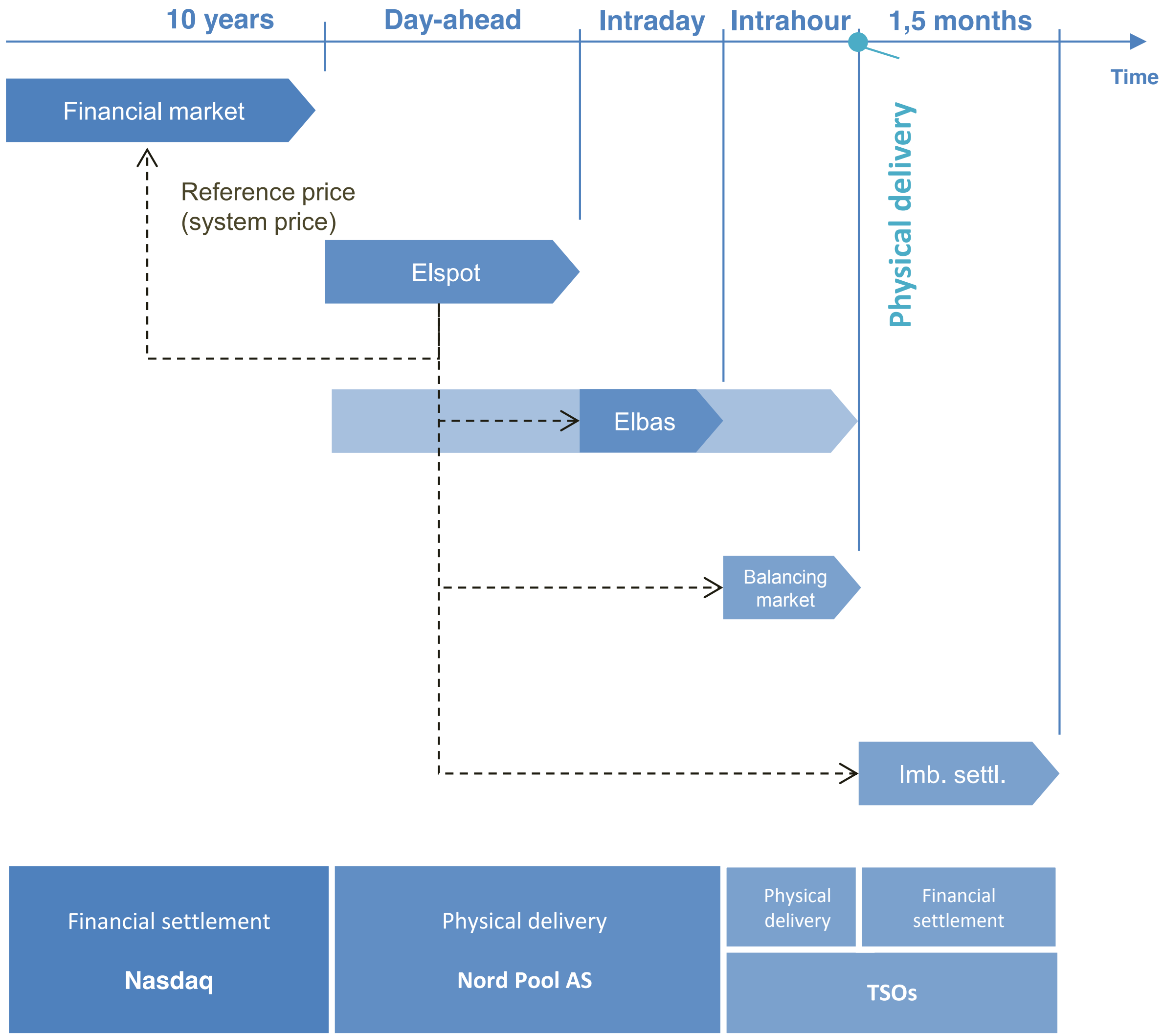
Financial market
Hedging of prices

Day Ahead market (AKA Elspot)
The DAM is a daily auction that closes at 12:00 every day.
System price and area prices are calculated for delivery each hour the following day.

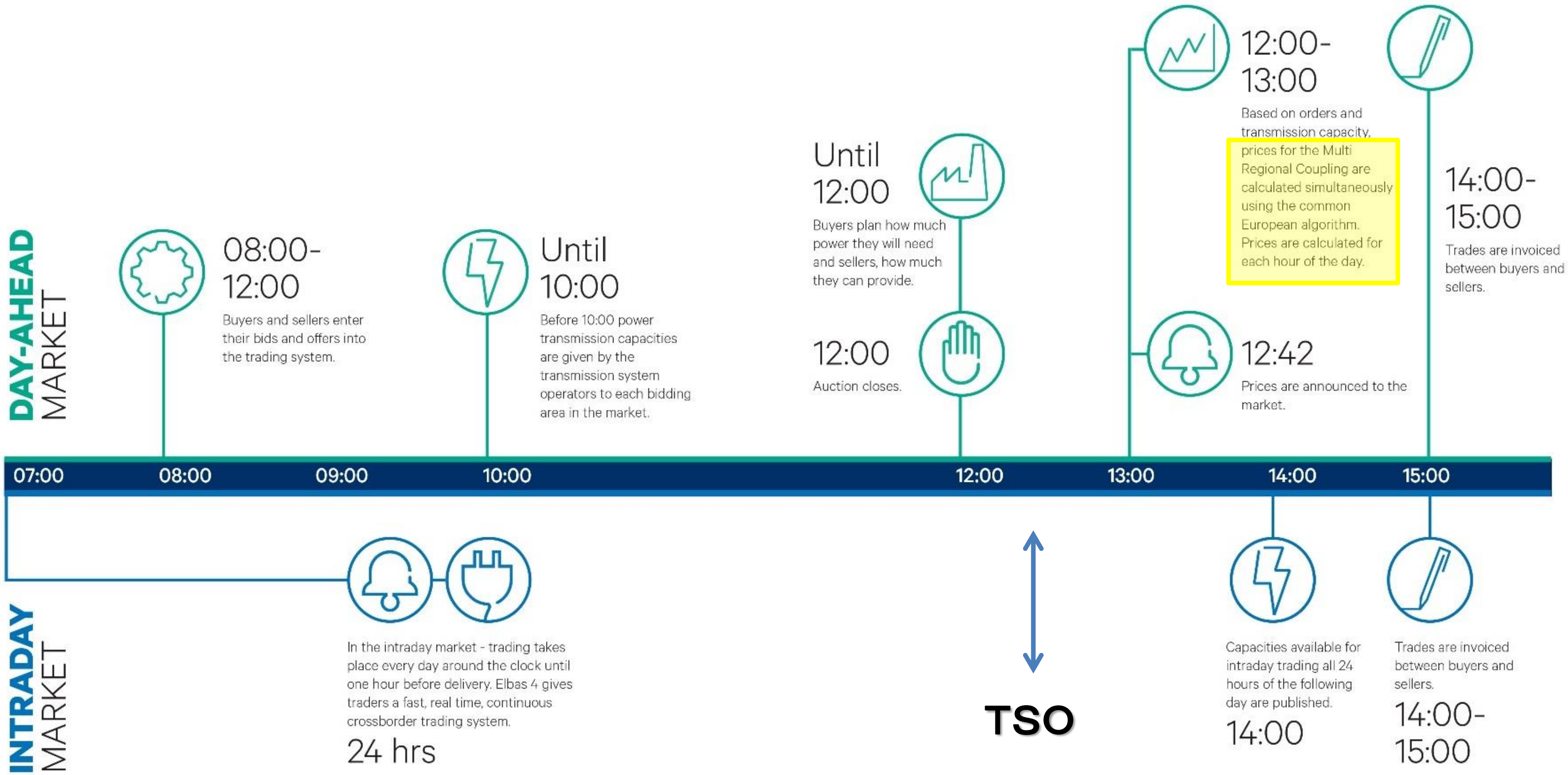
Intraday market (AKA Elbas)
The ID is a continuous (24/7) market and closes shortly before each delivery hour.
Remaining transmission capacity after the publication DAM prices is allocated to ID.

Balancing markets
Intra-hour market for maintaining the power balance

Imbalance settlement
Post-hour settlement of deliveries between market participants



Trading at Nord Pool markets



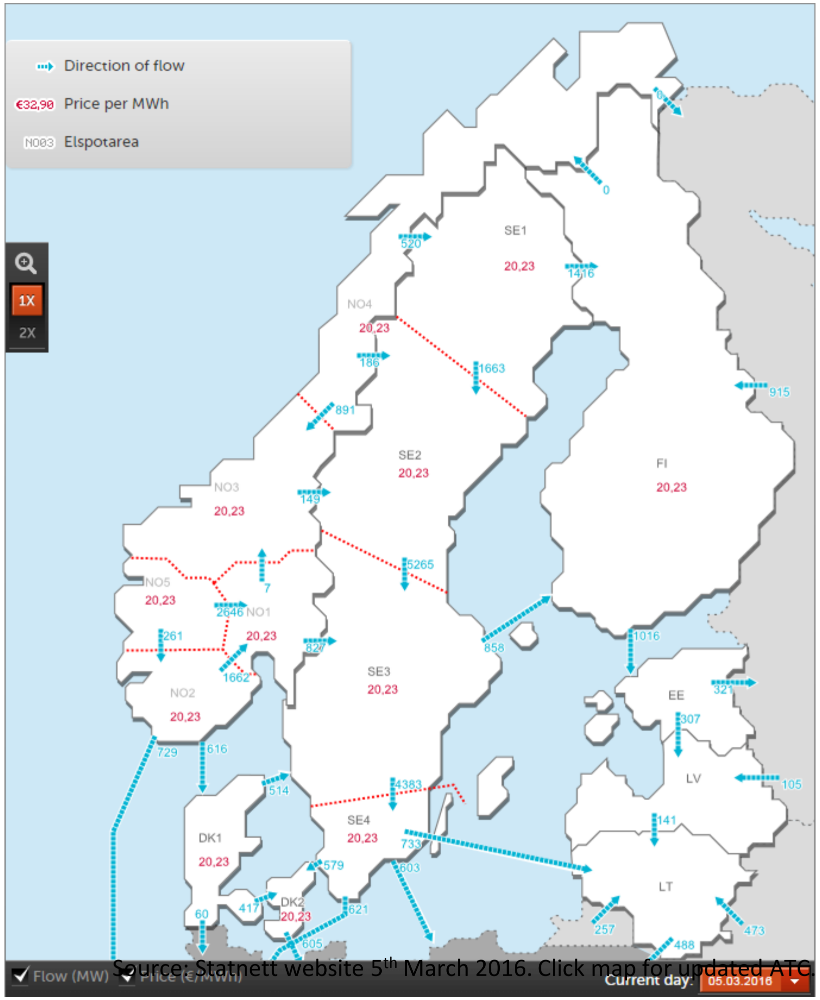
Source: Nord Pool

Trading at Nord Pool markets Day-Ahead (Elspot) trading schedule

– During morning	Collateral reports sent to members
– Approximately 10:00 CET	Publication of transmission capacities←TSO
– 12:00 CET	Auction closes
– 12:00-12:42 CET	**Calculation of prices and flows ⇔TSO**
– 12:42 CET	Publication of preliminary auction results
– Approximately 12:51	Publication of final auction results
– 14:00 CET	Nord Pool Intraday market for the following day opens (08:00 in Germany)
– Approximately 14:30 CET	Invoice information available

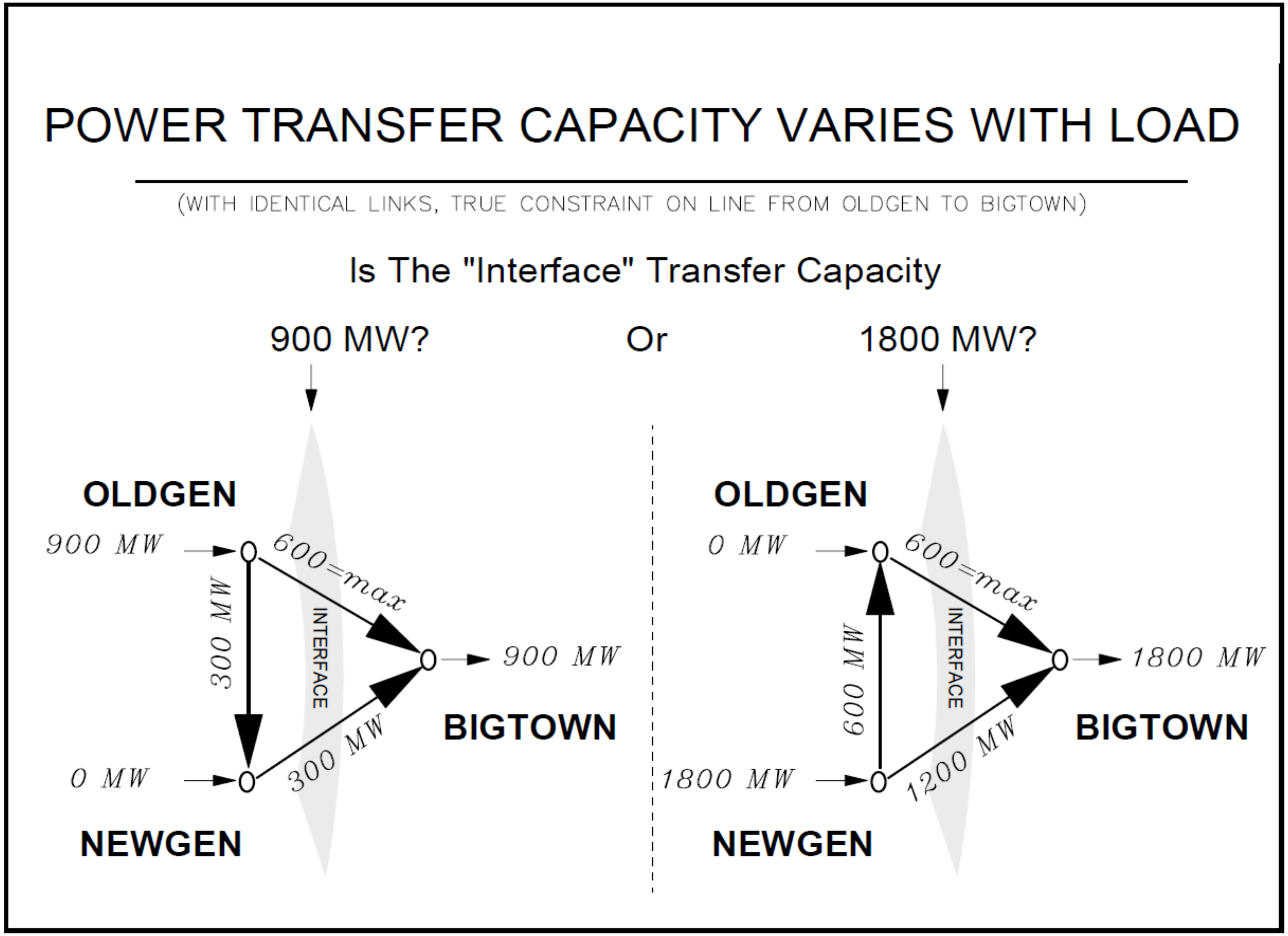
Transmission capacities and implicit auction

- Each morning the TSOs determine the trading capacity between each bidding area:
    - Trading capacities for the next day are published on Nord Pool's website at 10:00 CET
    - All trading capacity between the Nordic and Baltic bidding areas is dedicated to Nord Pool for implicit auction
- **Implicit auction, performed through market coupling, simultaneously determines prices, sell and purchase volumes and flows between bidding areas:**
    - All trading capacity is available to all market participants on equal terms
    - There are no explicit capacity auctions on these connections



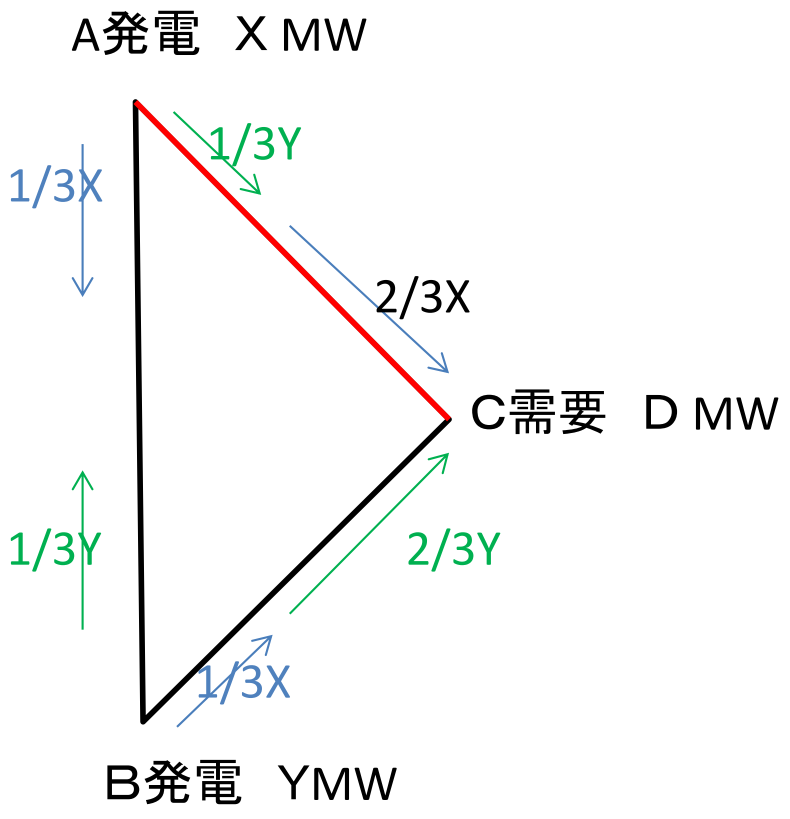
Source: Statnett website 5th March 2016. Click map for updated ATC

フローベースの計算の考え方　　米国ハーバード Hogan



１９９６年，Transmission Capacity Reservations and Transmission Congestion Contract

送電模式図



A→Cの電力：２／３＊X　＋１／３＊Y

B→Cの電力：２／３＊Y　＋１／３＊X

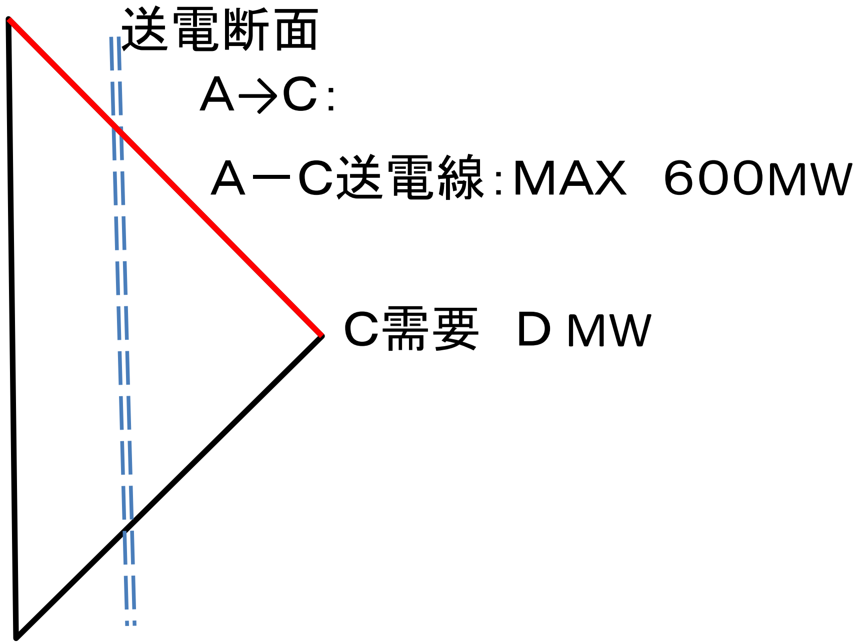
A⇔Bの電力：１／３＊X　＋１／３＊Y

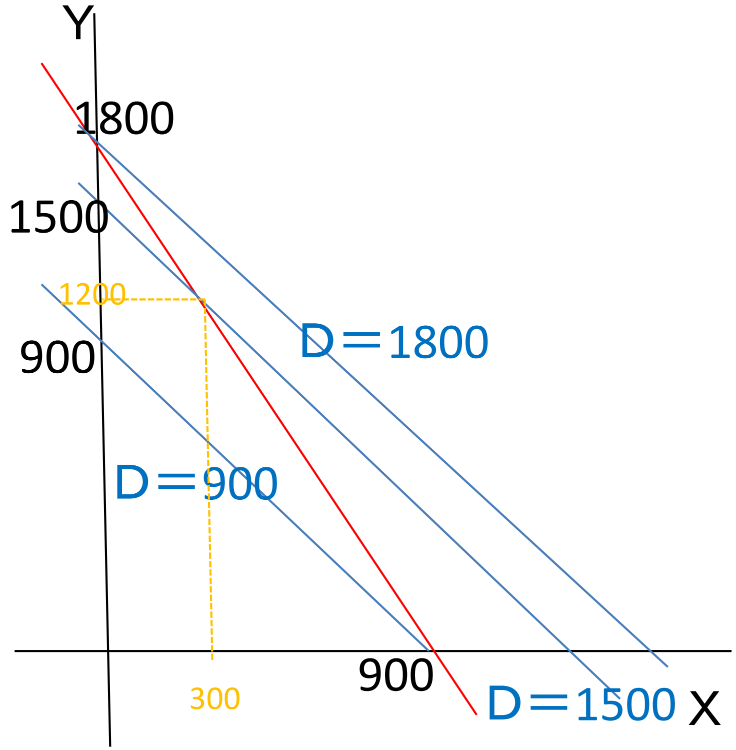
D　＝　X　＋　Y

A－B送電抵抗(インピーダンス)＝B－C送電抵抗(インピーダンス)＝A－C送電抵抗(インピーダンス)　と仮定

送電制約がある場合のDispatch ・・・ A, B, C, グリッドの状況の均衡点で実際の電力は流れる。

A発電　発電量X MW　5円/電力





B発電　発電量Y MW　10円/電力

A－C送電線のキャパシティが600MWの場合

600 ≧ 2／3＊X　＋ 1／3＊Y　　・・・　Y≦1800－2X

D　＝　X　＋　Y　・・・　Y＝D－X

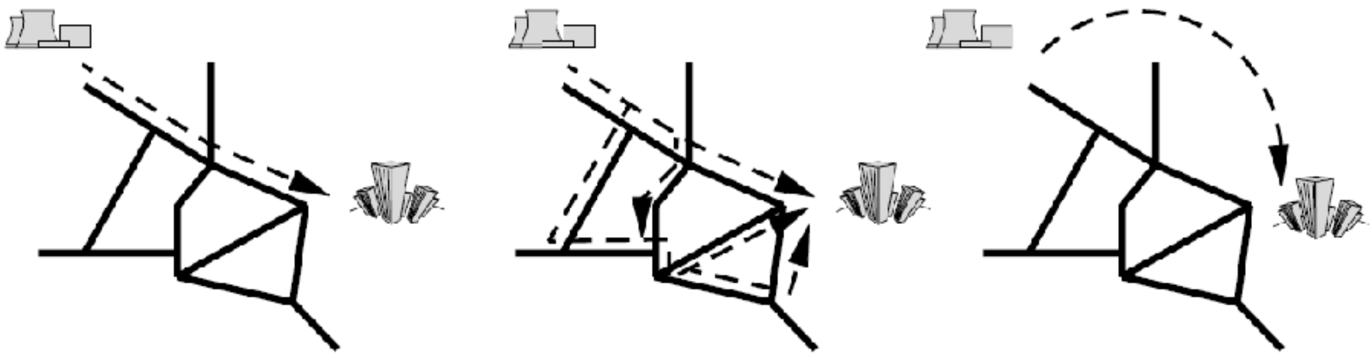
〇需要:900の時は、X＋Y＝900であれば、A、B分担は自由、最も安いのは全てAから供給される場合　⇔　送電制約がない場合と同じ

〇需要1800MW:全てB発電から供給される。

〇需要1500MW:Aから300 (0-300) MW、Bから1200(1500-1200)MW供給される

An Evolution of Transmission Capacity Definitions

Contract Path → Link-Based Paths → Point-to-Point



Contract Path	Link-Based Paths	Point-to-Point
Contract Path Fiction	Parallel Flows	Flows Implicit
Interface Capacity Varies with Conditions	Too Many Links To Acquire Capacity	Simultaneous Feasibility

Hogan等：

○実潮流では、グリッドに接続されるあらゆる送受電は相互に影響を与え合うので、**どのような送電断面であれ利用可能な送電キャパシティを把握するためにはグリッド全体で起こっている全てのことを把握する必要**があり、個別の送電線を切り出して見ても送電キャパシテイは把握できない。
⇒**システム全体の全ての潮流を同時に特定**しない限り将来の如何なる瞬間の実際のキャパシティを議論することはできない。
⇒**区間を区分してキャパシティを議論することはできない**。
⇒このような基礎的かつ物理的な事実から逃れることは出来ず、「Contract Path」に基づき送電キャパシティを定めようとしても行き詰るだけ。

○当初は、全てのループフローを必要量だけ計算・予約することにより、送電キャパシティを予約しようという考えがあったようであるが、これは時々刻々と需給が変化し、実潮流の状況も時々刻々と変化する中で膨大な変化を想定してループフローも含めて全てのキャパシティを全ての時間について予約することは、不可能であることを認識するようになった。

○そこで考案されたのが、**Point-to-Pointの考え方**である。
Point-to-Pointの考え方とは何かというと、全ての送電利用者に、**「IN」と「OUT」地点、時間・期間、量を提出**させ、**グリッド全体で一挙に実潮流計算**を行い、全ての組み合わせが**グリッドに受け入れられるかを同時にかつ時刻毎に判定**するというものである。

欧米におけるグリッド・キャパシティ管理の基本は、ここに置かれており、整理すると、

○IN（発電）またはOUT（需要）の地点、時間・期間、量をグリッドキャパシティを評価する一定の期間の分を全て揃える。
○グリッドを構成する全ての送電線、変電所等のグリッド諸元を揃える。
○これらを同時に入力し、実潮流の送配電シミュレーションを実施し、「Ｎ－１ルール」に収まるかどうかを判定する。

○収まる場合には、入力されたIN（発電）またはOUT（需要）は、キャパシティ内にあるということで、必要に応じて「地点、時間・期間、量」のパッケージとして、さらに取引されることもある。

FERC:1996年に「15Proposed Principles for Capacity Reservation Tariffs 」(RM96-11-000, Washington DC, April 24, 1996, extract of pp. 20-25.)を定めている。

2.に「全てのPORsとPODsに基づき、同時にグリッドに収まるか計算する」という「Point-to-Pointの考え方」を明示。

FERC's Fifteen Proposed Principles

A capacity reservation tariff might have terms and conditions very much like those for point-to-point service in the Final Rule tariff. These would need to be modified to accommodate former network service customers. It is premature to specify detailed terms and conditions of capacity reservation service in advance of the comments and technical conference. However, we propose certain general capacity reservation tariff principles for comment.

1. Purpose of reservation service

（略）

2. Basic service concept

All firm transmission service would be reserved, and all reserved service would be firm service. Reservations of transmission capacity should permit the customer to receive up to a specific amount of power into the grid at specified [Points of Receipt] and to deliver up to a specific amount of power from the grid at specified [Points Of Delivery], on a firm basis. Individual PORs and PODs need not be "paired" with each other. The customer's capacity reservation would be the higher of either (1) the sum of the reservations at all PORs or (2) the sum of the reservations at all PODs. All nominations for a capacity reservation would be evaluated using the same standard; for example, the utility could apply a feasibility criterion that states that the grid must be able to accommodate the scheduled use of all capacity reservations simultaneously.

3.以下略

2009年の再エネ20%導入を加盟国に義務付けるEU指令と同時に電力グリッドの改革のための基本的なEU指令を出している。これと同時にEU規則を定め、グリッド改革の細則を定めている。このEU規則において、まず第2条定義の部分で送電混雑を「物理的な流れによる混雑」と定義し、「契約上の送電線満杯」を排除している。

2009ＥＵ規則714 第2条 *Definitions*

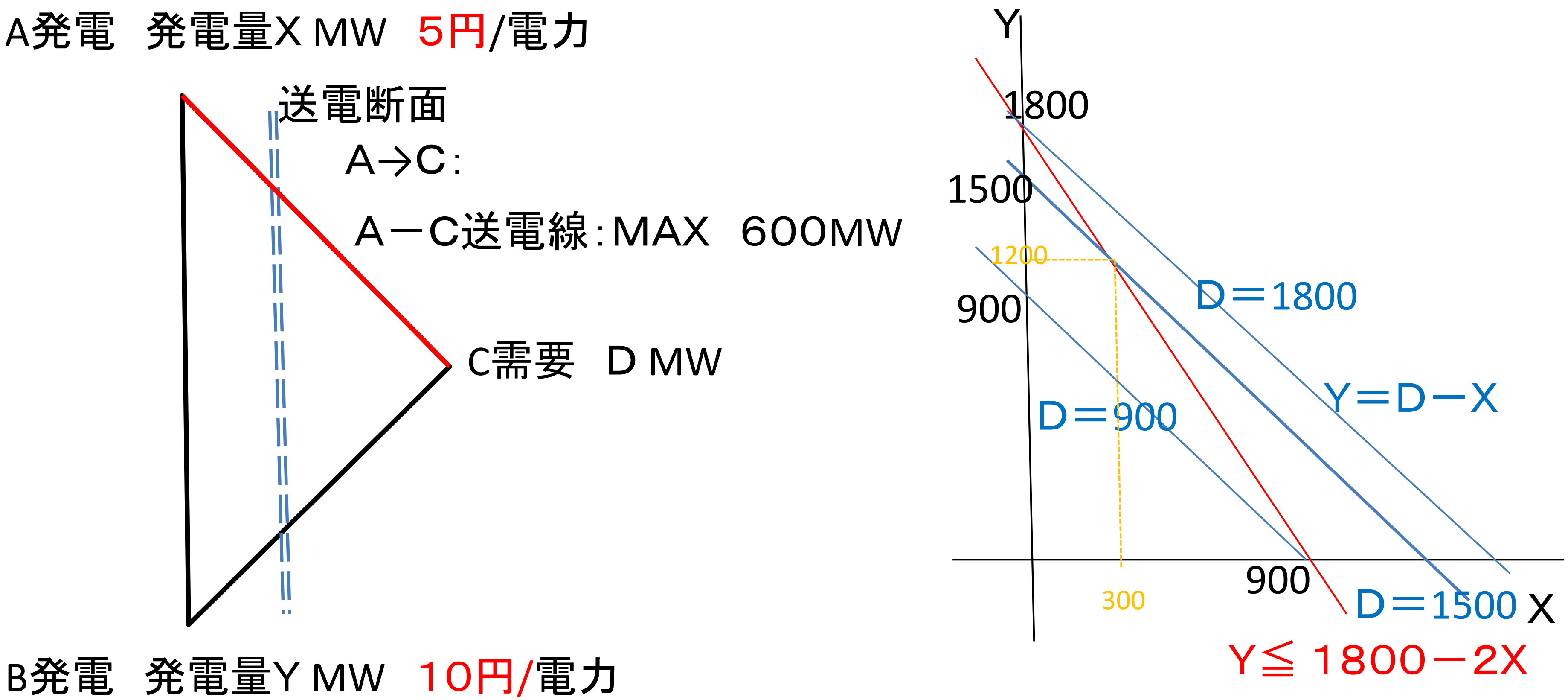
'congestion' means a situation in which all requests from market participants to trade between two bidding zones cannot be accommodated because they would significantly affect the physical flows on network elements which cannot accommodate those flows.

2009EU規則714 Article14

General principles of capacity allocation and congestion management

1. Network congestion problems shall be addressed with non-discriminatory marketbased solutions which give efficient economic signals to the market participants and transmission system operators involved. Network congestion problems shall preferentially be solved with non-transaction based methods, i.e. methods that do not involve a selection between the contracts of individual market participants.

送電制約がある場合のRe-Dispatch

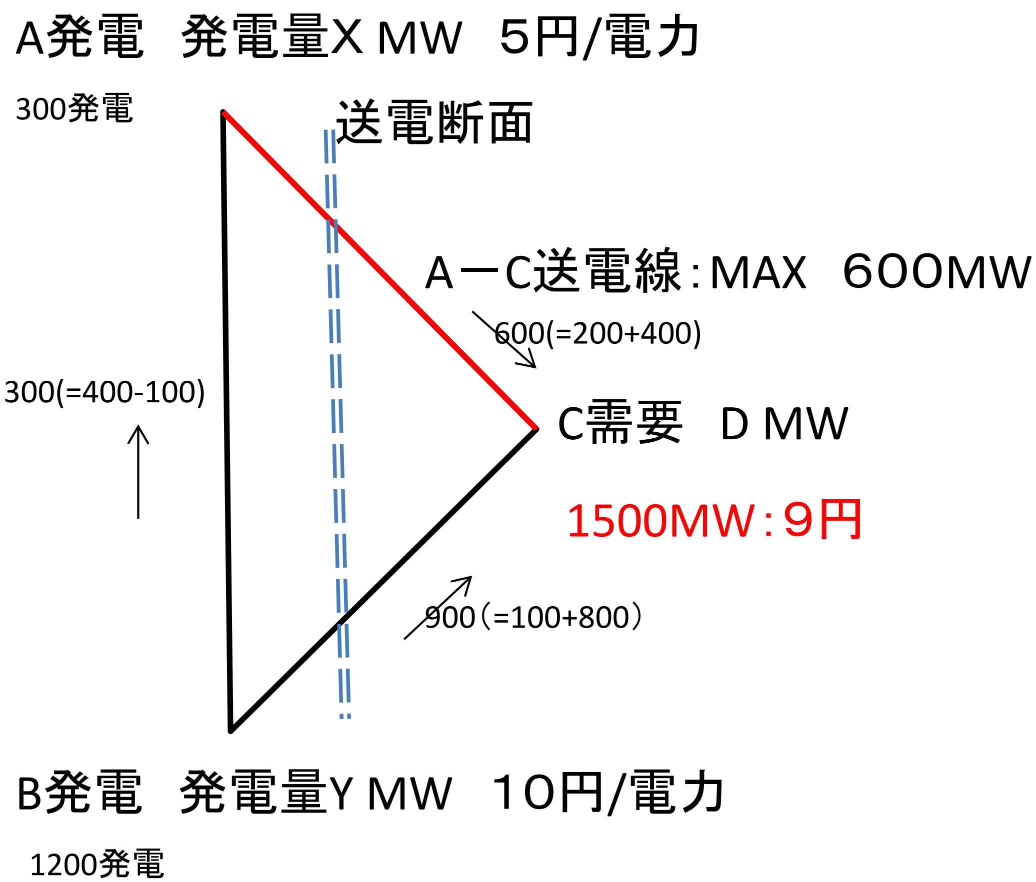


〇需要：1500MWの時にメリット・オーダーでAにて1500MWのIN、Cにて1500MWのOUTとすると、A－C間のキャパシティ・オーバーとなる。

〇需要：1500MWの時にキャパシティに収まり、最もCの調達価格が安くなるのは、Aから300MW(0-300)、Bから1200MW(1500-1200)の供給の時。

〇A発電：1500→300、B発電：0→1200へのre-dispatch、C需要：5円で供給（統一価格）
調達価格のアップ分は、TSOの経費としてグリッド・タリフで徴収

送電制約がある場合のプライシング・・・ノーダル・プライシング



需要が９００ MW以下で送電制約の影響を受けない場合（A－C間が600MW以下）には、
最も安いC＝５円（ ＝A＝B ）

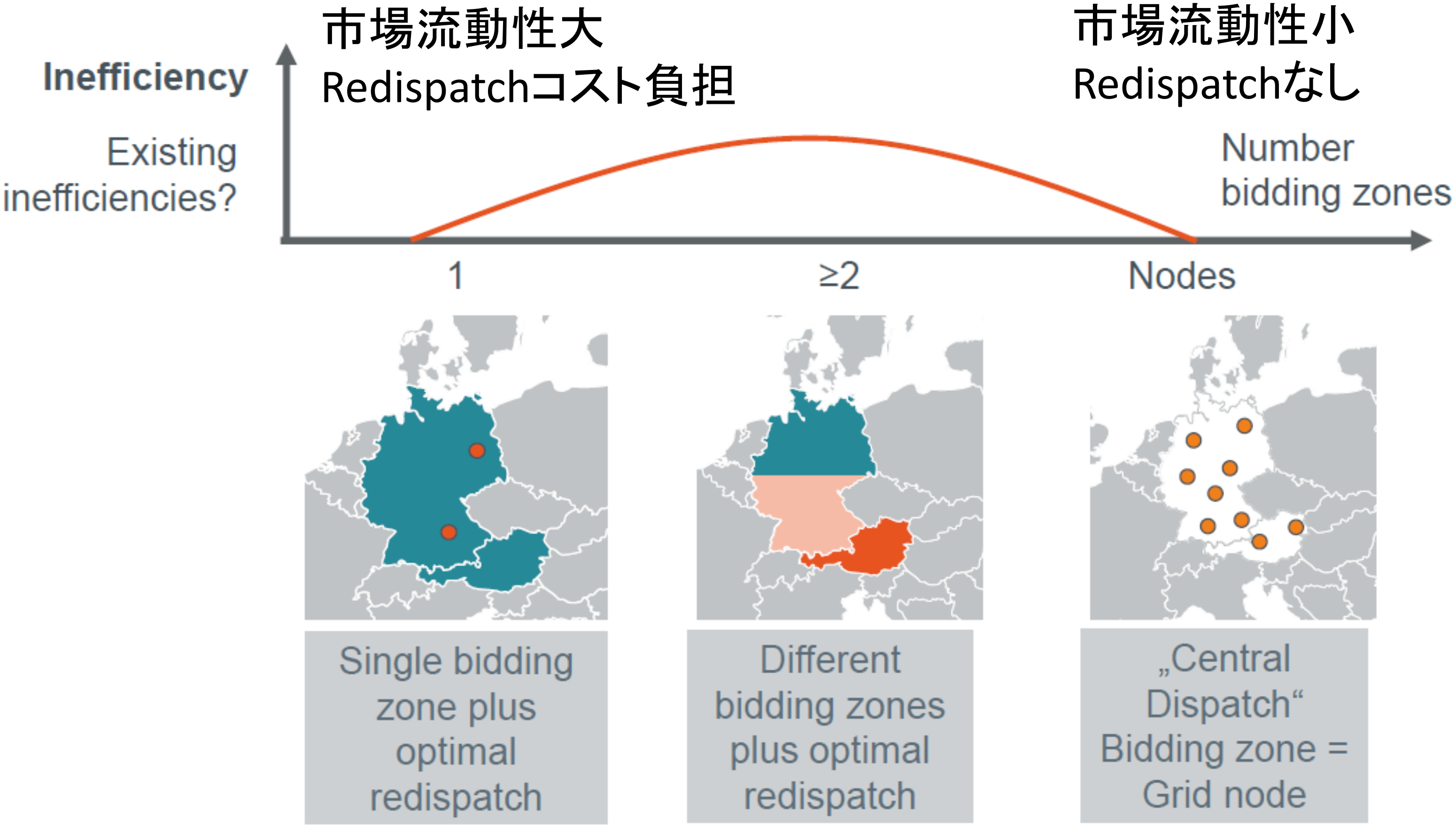
需要が１８００MWの時は、
最も高いC＝１０円（ ＝A＝B ）

需要が1500MWの時は、
安いA発電を最大限利用すると
C地点＝９円

C需要地点の価格：（５＊X＋１０＊Y）／（X＋Y）

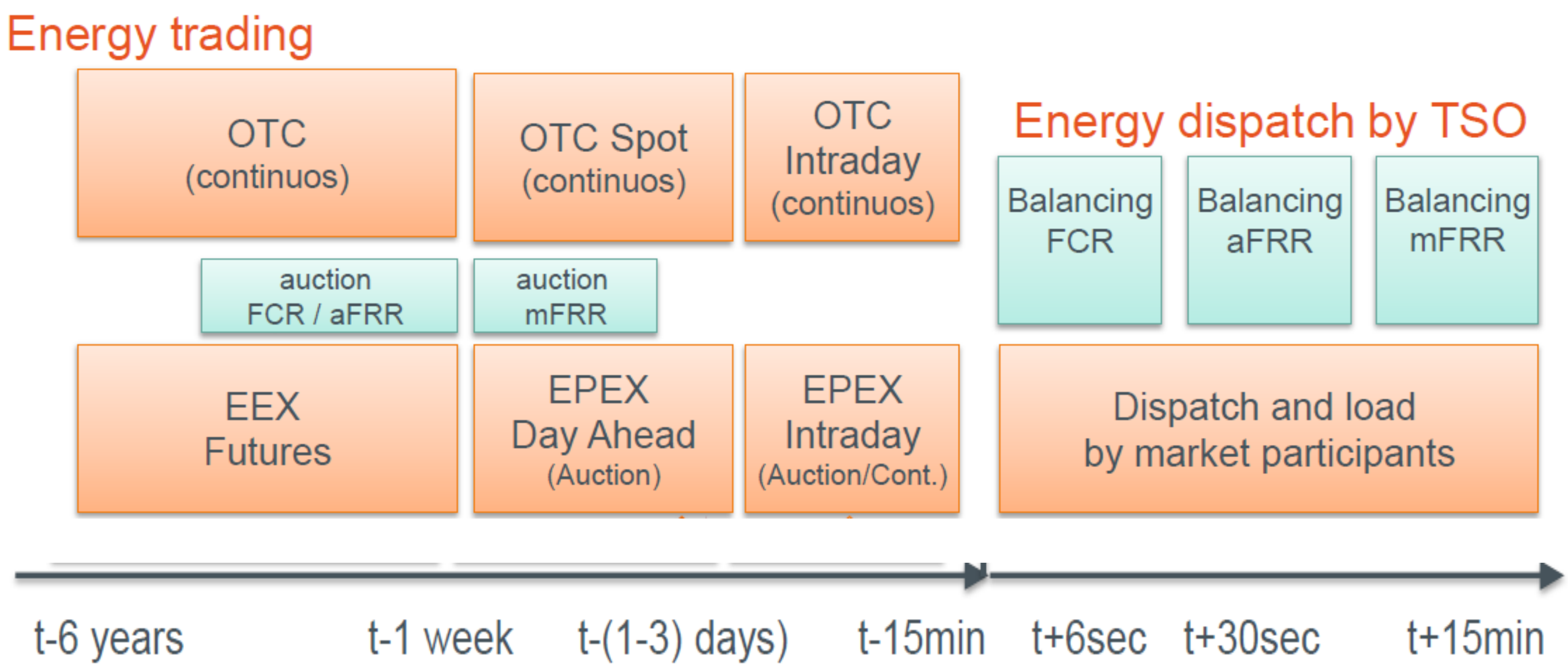
注：ここではイメージ作りのために模式的な計算を行っているが、実際のNode価格は、限界費用に関して行われるので異なる計算になる。

Efficiency of market splitting



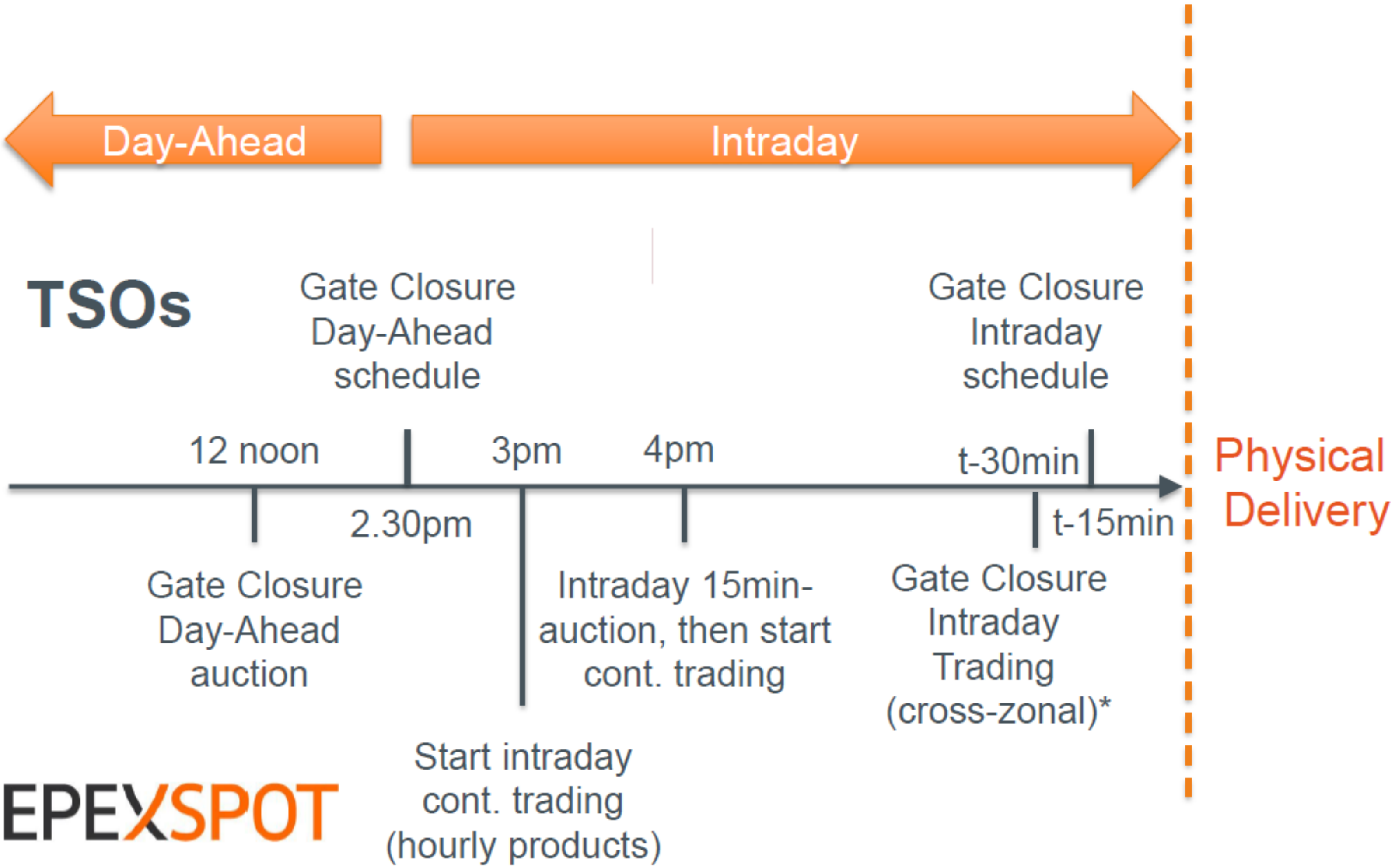
➢*An inefficient configuration of bidding zones can lead to high welfare losses*

Market System in Germany



FCR – Frequency Containment Reserve (PRL)
aFRR – automatic Frequency Restoration Reserve (SRL)
mFRR – manual Frequency Restoration Reserve (MRL)

Day-Ahead Market



* Nordpool allows local trading within the control area until real time

Mechanisms for balancing: stakeholder roles and responsibilities

- **Balancing responsible parties (BRPs)**: market entities (utilities, sales companies, industrial consumers) that balance portfolio of generators and/or loads. Each physical connection point is associated with one BRP. Quarter-hourly[1] schedules are submitted one day ahead (but can be adjusted one hour ahead of delivery). Deviations from these schedules are penalized.
- **TSO**: activate balancing power in balance area if the sum of BRP imbalances is non-zero.
  1. Determine capacity of reserves required *ex ante*
  2. Acquire capacity and determine price (capacity and/or energy) *ex ante*
  3. Activate balancing power and determine imbalance price (energy) in *real-time*
  4. Allocate costs (via imbalance price and/or grid fees) *ex post*
- **Suppliers of balancing power**: generators and consumers that meet prequalification criteria. Remunerated with capacity payment (EUR/MW per hour) and energy payment (EUR/MWh)

1: half-hourly in France

Transmission System Operator (TSO)

- Overall a financial neutral position is achieved
  - Costs for activated Balancing Energy are charged to BRP
  - Costs for procured Balancing Capacity are part of grid tariff

Imbalance Settlement

BRP

Balancing Responsible Parties (BRP)

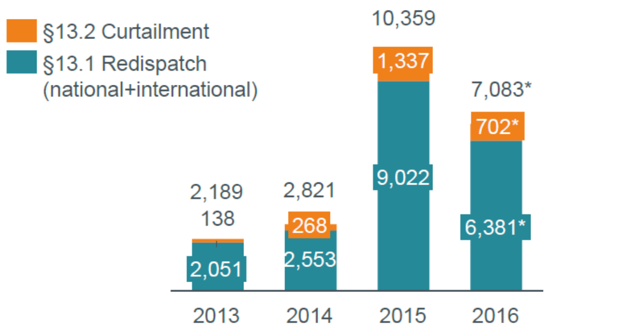
- Settlement to BRPs is based on activated Balancing Energy
- Germany has an 1-price-system (symmetric price)
  - price for positive or negative imbalances of BRPs (reBAP) is the same
  - Imbalance Settlement Period = 15min
- Additional price components:
  - Benchmark with Intraday price (intraday price is always “better”)
  - If activated Balancing Energy exceeds 80%: +50% but min. 100 €/MWh

- Incentive to be balanced
  - By contract BRP is forced to be balanced
  - reBAP gives an additional financial incentive

- Determination of imbalance price
  - EUR/MWh deviation from submitted schedule by BRP
  - All costs are born by unbalanced BRPs (same price for under and over supplied BRPs)
  - Since May 2010, there is a common German imbalance price reBAP, set for 15-minute settlement intervals as the **average dispatch cost (net energy payments divided by net balancing energy)**, which is different to the energy price in the balancing market (not the marginal cost of activating balancing reserves, even though this would be most efficient allocation)
  - Prices are published with delay of several months

Congestion Management at 50Hertz

Congestion management energy in GWh



*preliminary data as of January 2017; Source: 50Hertz

In 2016 congestion management costs have decreased in comparison to the previous year.

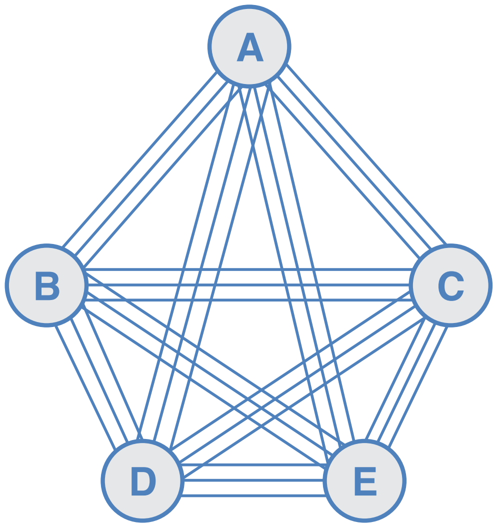
50Hertz at a glance

	2015	2010
Area	109.589 km² (~31%)	109.360 km² (~31%)
Total length of lines	10.150 km (~30%)	9.800 km (~30%)
Maximum load	~ 16 GW (~20%)	~ 17 GW (~20%)
Energy consumption (based on electricity supplied to end-consumers in acc. With the EEG)	~ 95 TWh (~20%)	ca. 98 TWh (~20%)
Installed capacity: - of which Renewables - of which Wind	50.685 MW (~27%) 27.132 MW (~30%) 16.171 MW (~39%)	38.354 MW (~35%) 15.491 MW (~30%) 11.318 MW (~40%)
Workforce	955	650
Turnover - of which grid	9,8 bn. € 1,4 bn. €	5,6 bn. € 0,6 bn. €

As at 2015/12/31; Source: 50Hertz

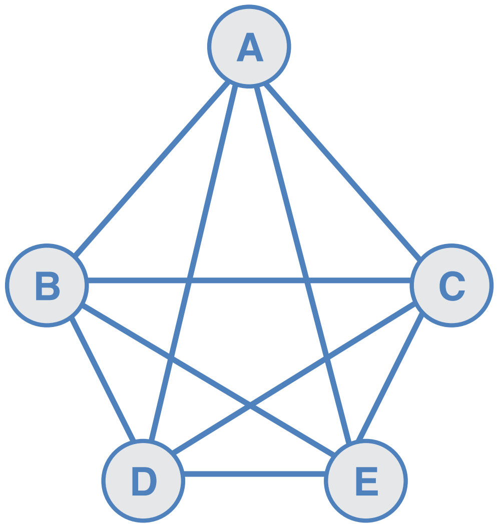
Clearing

Old world:
Bilateral trading
without netting



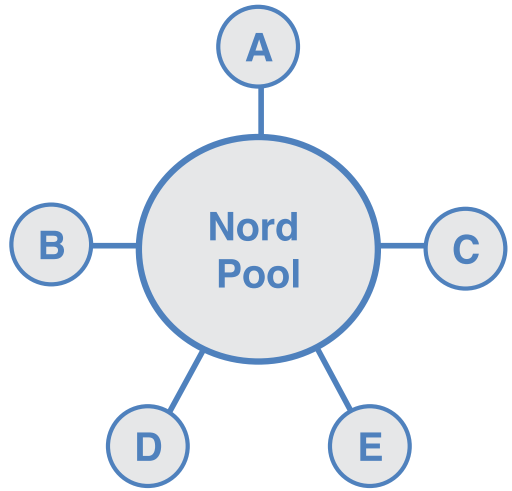
Several counterparties
and transactions

Bilateral trading
with netting



One transaction for
each counterparty

Most trading nowadays:
Trading with several
counterparties



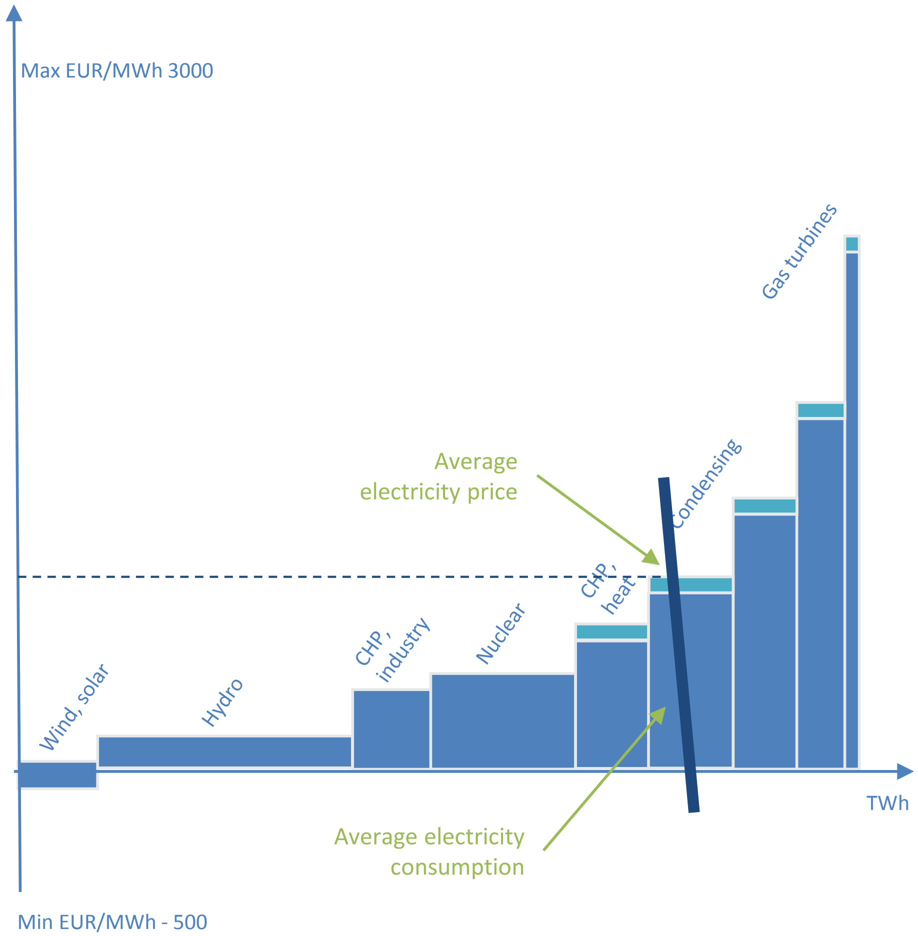
**Always only Nord Pool
as the only
counterparty for all trades!**

Trading at Nord Pool markets Day-Ahead (Elspot) trading schedule

– During morning	Collateral reports sent to members
– Auction Starts	
– Approximately 10:00 CET	Publication of transmission capacities←TSO
– 12:00 CET	Auction closes
– 12:00-12:42 CET	**Calculation of prices and flows ⇔TSO**
– 12:42 CET	Publication of preliminary auction results
– Approximately 12:51	Publication of final auction results
– 14:00 CET	Nord Pool Intraday market for the following day opens (08:00 in Germany)
– Approximately 14:30 CET	Invoice information available

Day-Ahead price formation in theory

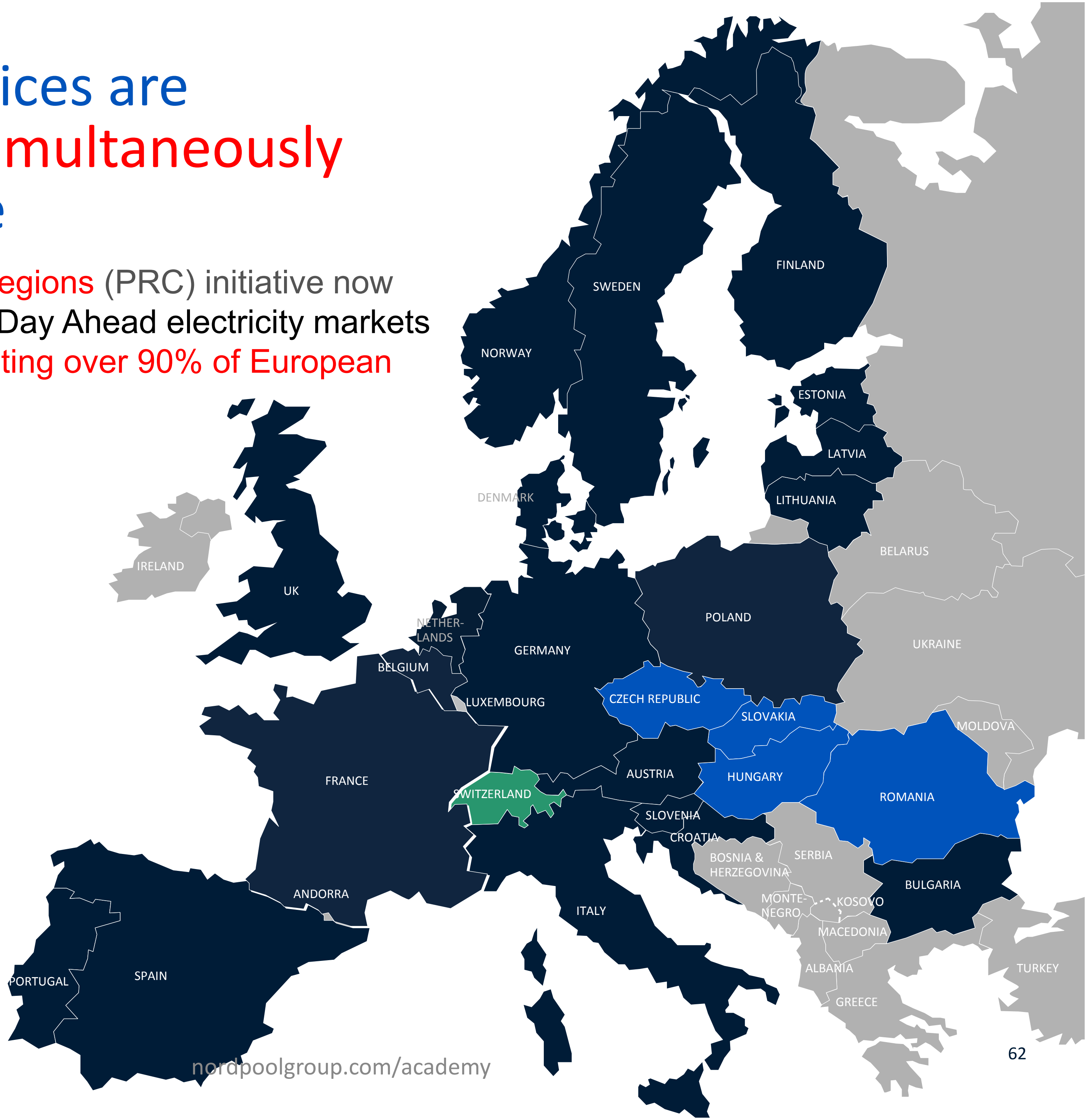
- Day-Ahead prices are calculated using an optimization algorithm called **Euphemia**
- Optimization happens through maximising overall social welfare
- Calculation methodology ensures that, based on the placed sell and buy bids, least-cost generation units are activated first*
- Last activated bid sets the price for all production needed to meet demand



*) The traditional 'merit order' of short-run marginal costs of generation is not fully applicable to intermittent generation as it cannot be dispatched to meet peak demand. Due to zero marginal cost of intermittent generation such as wind and solar, they always become first in the 'merit order': they produce when they produce.

Day-Ahead prices are determined simultaneously across Europe

The Price Coupling of Regions (PRC) initiative now enables the coupling of Day Ahead electricity markets in 23 countries representing over 90% of European power consumption.



- Part of PCR initiative today
- 4 MMC
- Independent

Bidding Zones

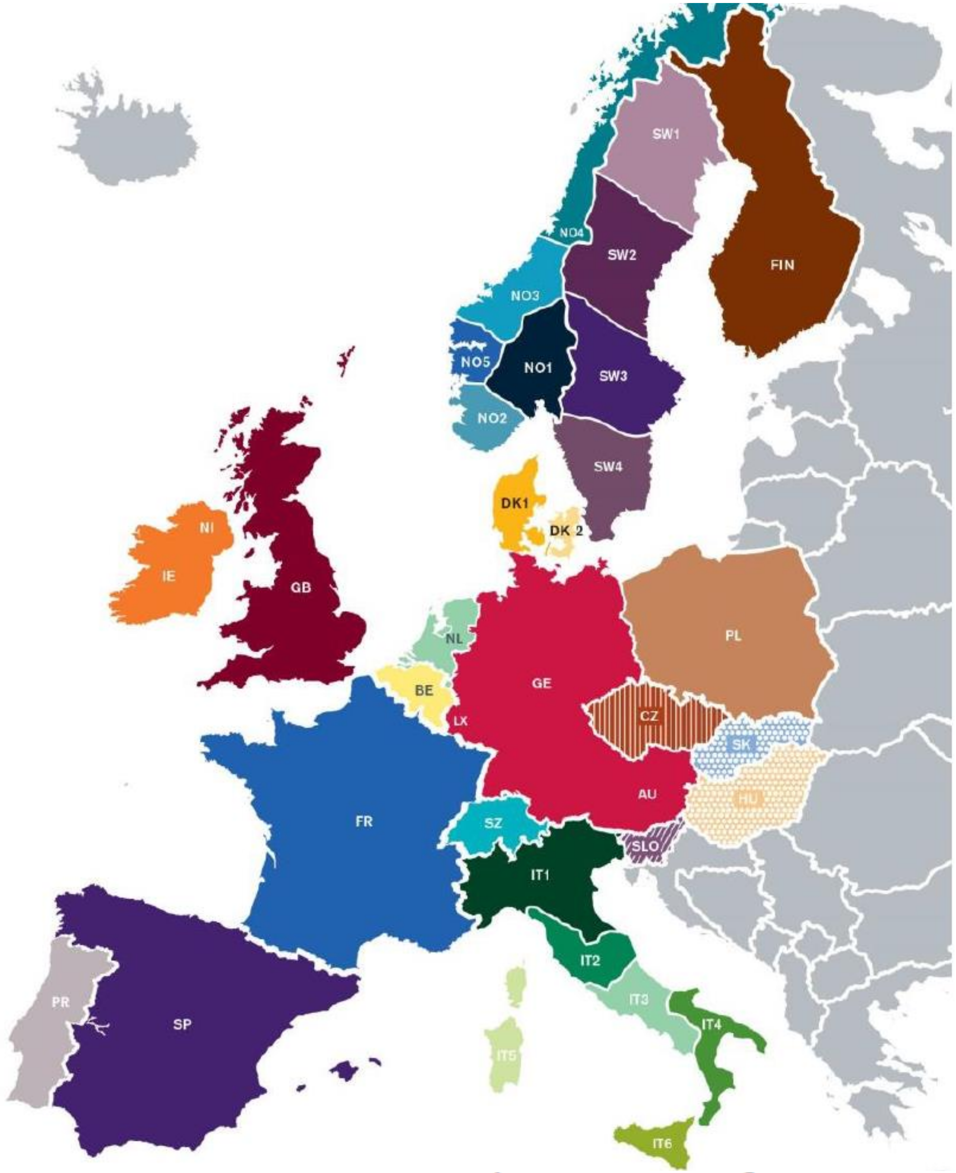
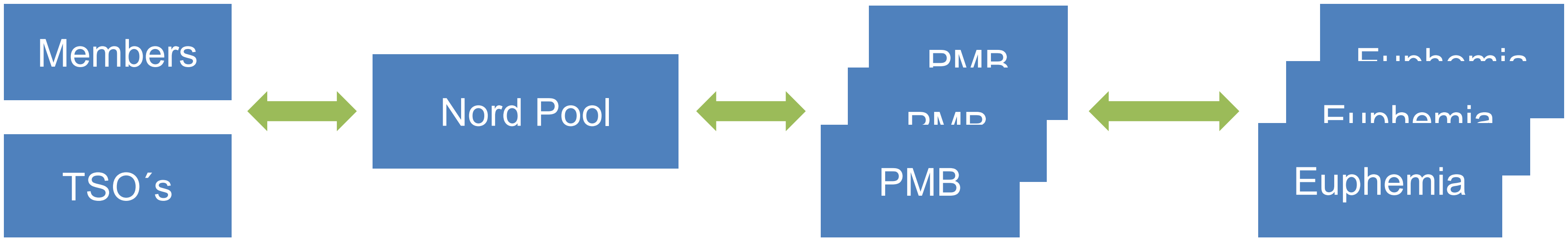


Figure 1

Author	Ofgem, FTA Team
Date	July 2014

Multi-Regional Coupling Day-Ahead Price calculation (Nordic)



Market parties:

- Capacities
- Allocation constraints
- Orders

Nord Pool:

- Receives input from market parties
- Anonymizes block orders
- Aggregates supply and demand curves
- Validates and aggregates network constraints
- Performs portfolio allocation
- Sends results to market parties

PCR Matcher Broker:

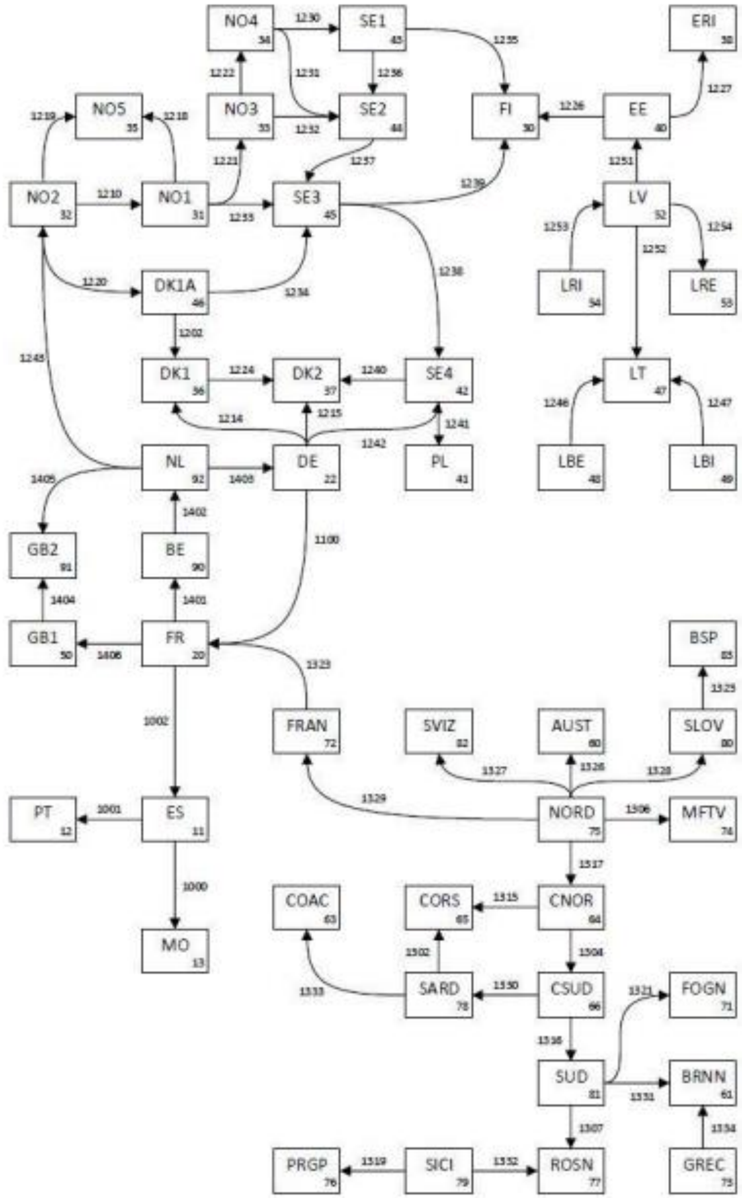
- Is the user interface for the coordinator
- Synchronizes data of all Power Exchanges (PXs)
- Ensures that all information is provided
- Creates input data for Euphemia
- Reads output from Euphemia and sends to PX

Euphemia:

- Matches demand and supply in the different markets
- Optimizes flows
- Calculates prices

Euphemia

- EUPHEMIA: EU + Pan-European Hybrid Electricity Market Integration Algorithm
- It maximizes the welfare of the solution:
  - Most competitive price will arise
  - Overall welfare increases
  - Efficient capacity allocation
- Utilized by six power exchanges (PX) each operating several bidding areas:
  - All bidding areas are matched at the same time
  - Each bidding area can obtain a different price. Price must respect maximum and minimum market price boundaries

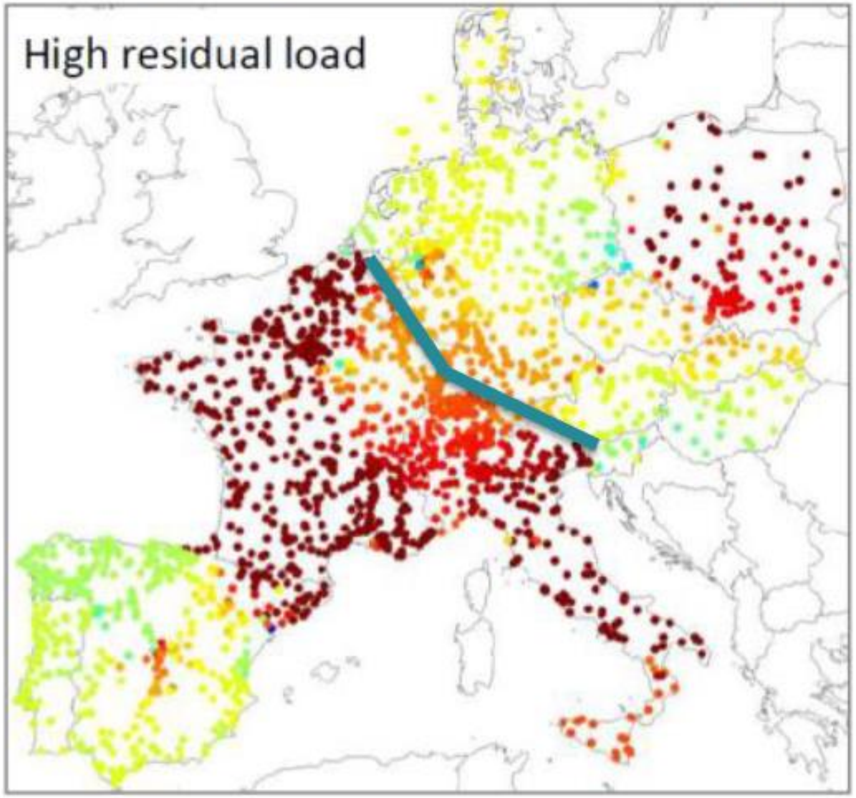


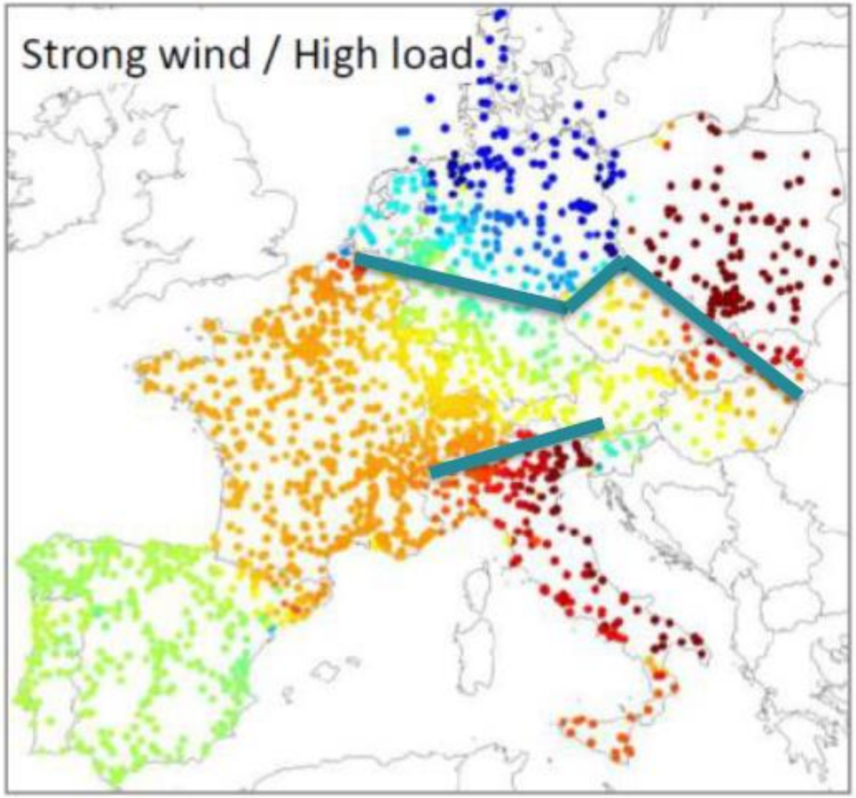
nordpoolgroup.com/academy

Source: EUPHEMIA description and functioning, January 2016

Potential bidding areas in Europe

Nodal pricing simulation indicating potential design of bidding areas





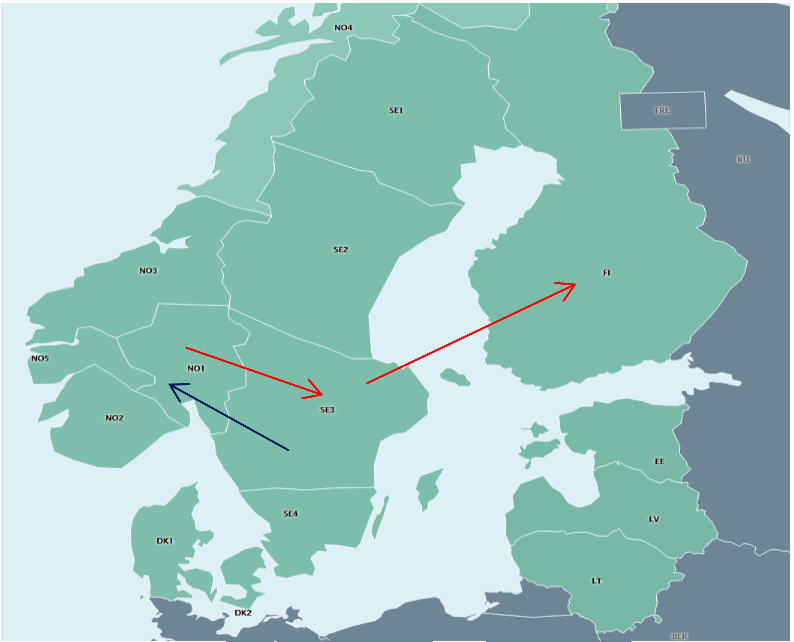
Source: Dissertation C.Breuer (2014), IAEW,

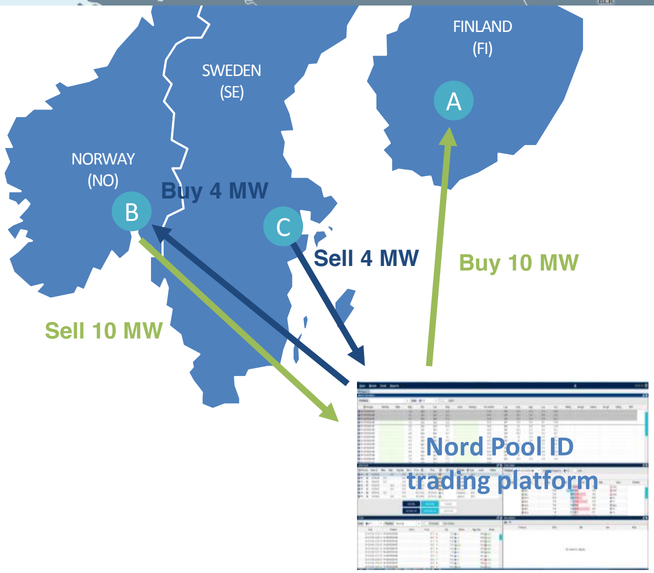
- While the theoretical optimum is either nodal pricing or one single bidding area, practice means compromising between low redispatch volumes and high liquidity.

Management of transmission capacities

- TSOs confirm the capacities available for Intraday (Elbas) trading:
  - Available transmission capacities depend on the Day Ahead auction results
  - Initial Intraday capacities for all Nordic and Baltic bidding areas are published simultaneously on Nord Pool website at approximately 14:00 CET
  - TSOs can adjust capacities if the status of the transmission system network changes
  - Otherwise, Nord Pool's Intraday trading system automatically calculates and updates the capacity information, based on realised Intraday trades
- All Intraday trades are fixed deliveries:
  - Changes in the status of the transmission system infrastructure cannot lead to cancellation of Intraday trades
- It is not possible to exceed the Available Transmission Capacity
  - Trading system only displays orders that can be filled in each area, taking into account the available cross-border transmission capacities (Automated Market Splitting)
  - For example, if there is a bottleneck between Finland and Sweden, traders in Sweden don't see any Finnish sales orders. If there are no bottlenecks, traders in all areas will see all existing orders

Example: Automatic transmission capacity management





Direction	Initial intraday capacity	Intraday capacity after 1. trade	Intraday capacity after 2. trade
FI → SE3	2 300	**2 310** (+10)	**2 310** (0)
SE3 → FI	1 100	**1 090** (-10)	**1 090** (0)
NO1 → SE3	2 000	**1 990** (-10)	**1 994** (+4)
SE3 → NO1	0	**10** (+10)	**6** (-4)

Intraday trades:

1. B from NO1 sells 10 MW to A in FI
   - Decreases the ID capacity from SE3 to FI by 10 MW
   - Opens 10 MW from SE3 to NO1 for trading
2. C from SE3 sells 4 MW to B in NO1
   - Does not affect capacity between SE3 and FI
   - Decreases the ID capacity from SE3 to NO2 by 4 MW

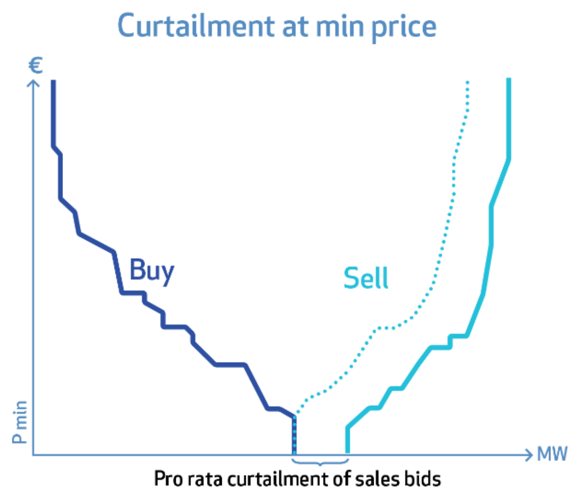
Illustrative example without actual bidding areas being displayed

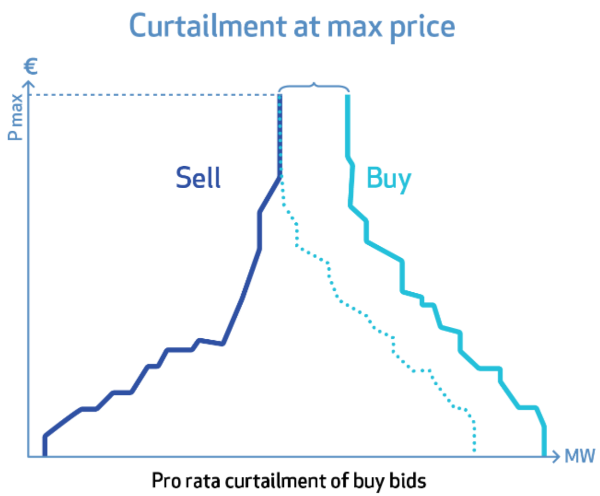
Curtailment

– Having significant oversupply or undersupply in an area incurs the risk of buy and sell curves not matching. This prevents price from being calculated

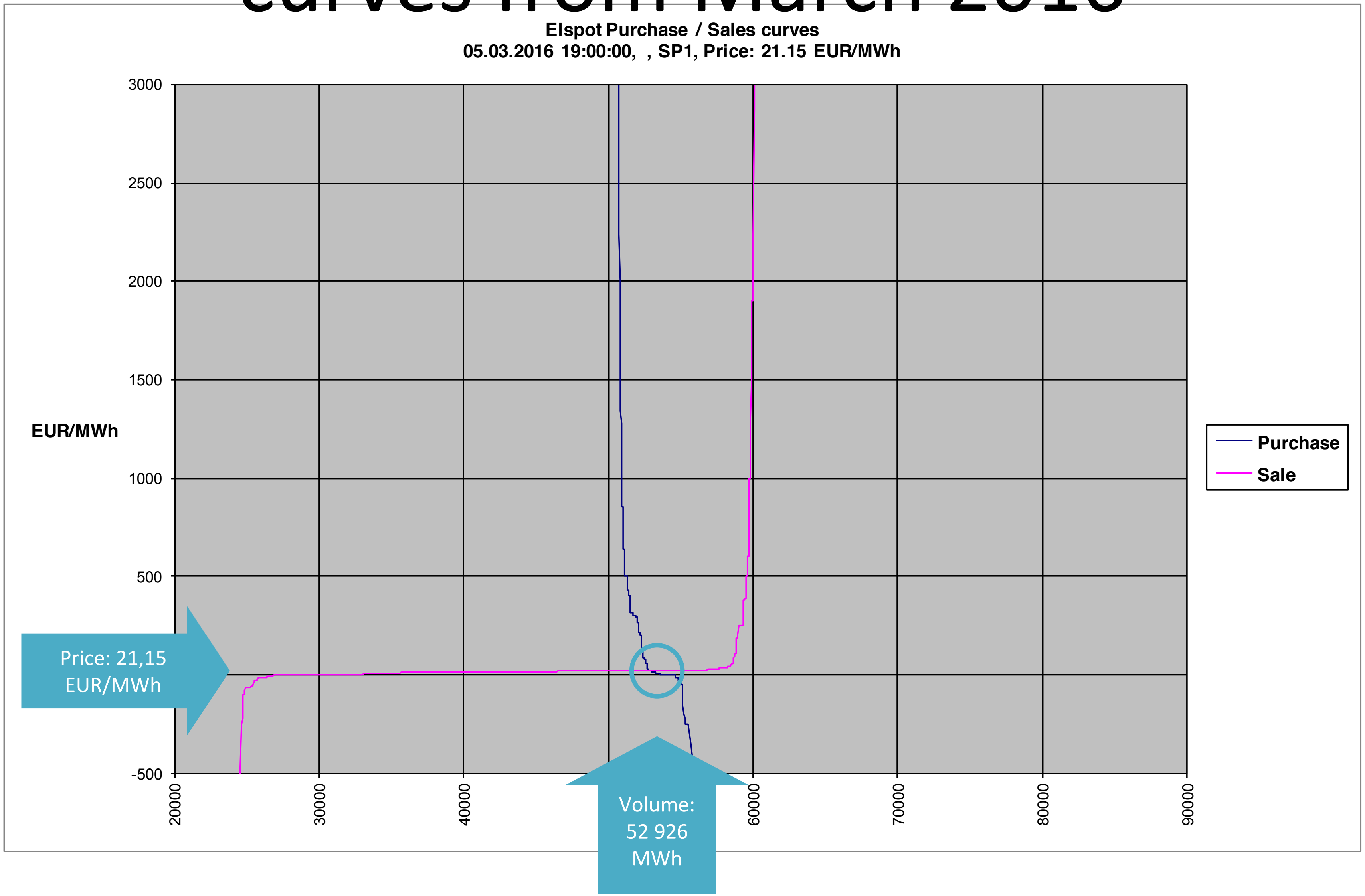
– In such situation, bid curves will be curtailed on a *pro rata* basis:
  - In an area with oversupply, sales bids are curtailed so that the supply curve intersects with the demand curve at minimum price
  - In an area with undersupply, purchase bird are curtailed so that the demand curve intersects with the supply curve at maximum price

– The total curtailment in a price area is divided among the affected members based on their sell or purchase bids at minimum or maximum price (respectively)





An example of System Price bidding curves from March 2016

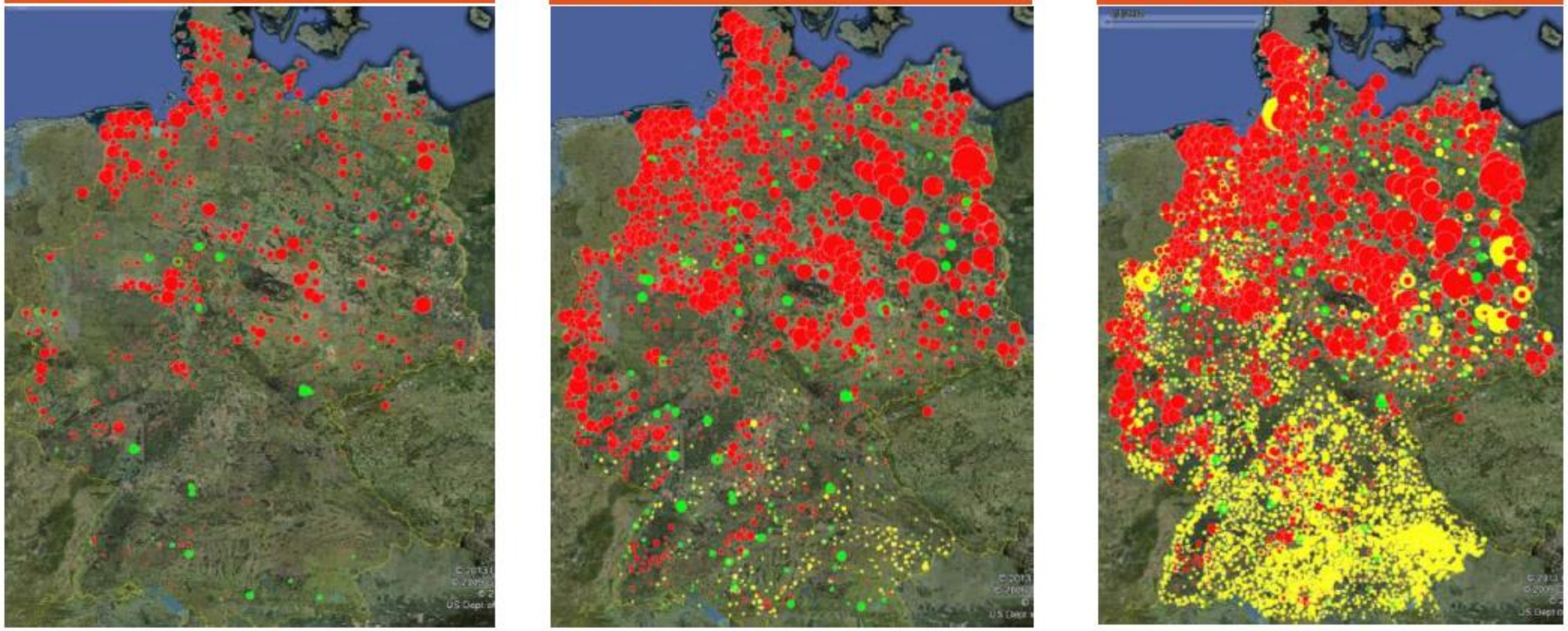


nordpoolgroup.com/academy

Source: Nord Pool

５０Hertzのグリッド増強計画の策定

RES development in Germany



2000	2006	2015
~ 30,000 plants	~ 221,000 plants	> 1,600,000 plants

Solar PV Wind Biomass

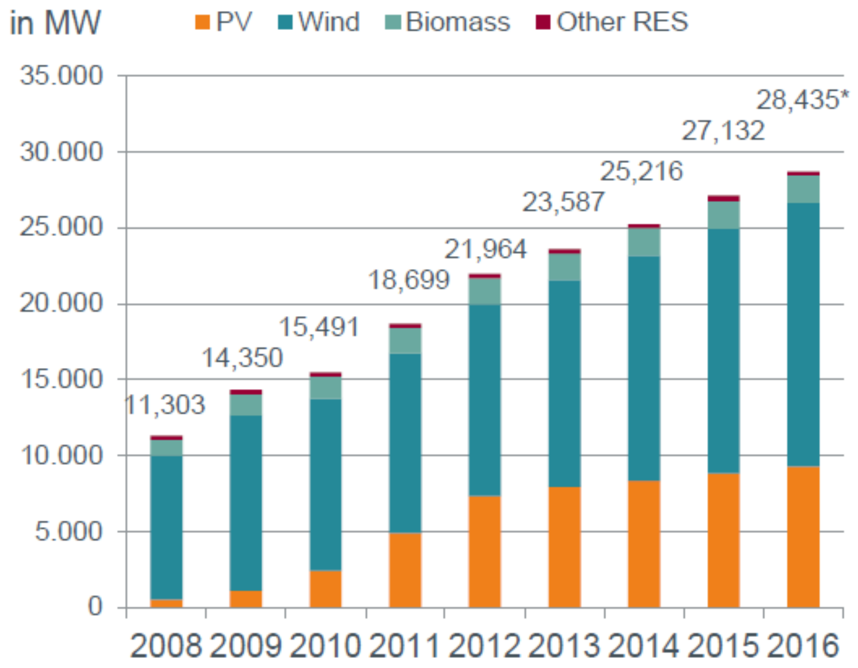
Area proportional to installed capacity

With the introduction of the Renewables Energy Law (EEG) in Germany in 2000 the RES share started to grow massively

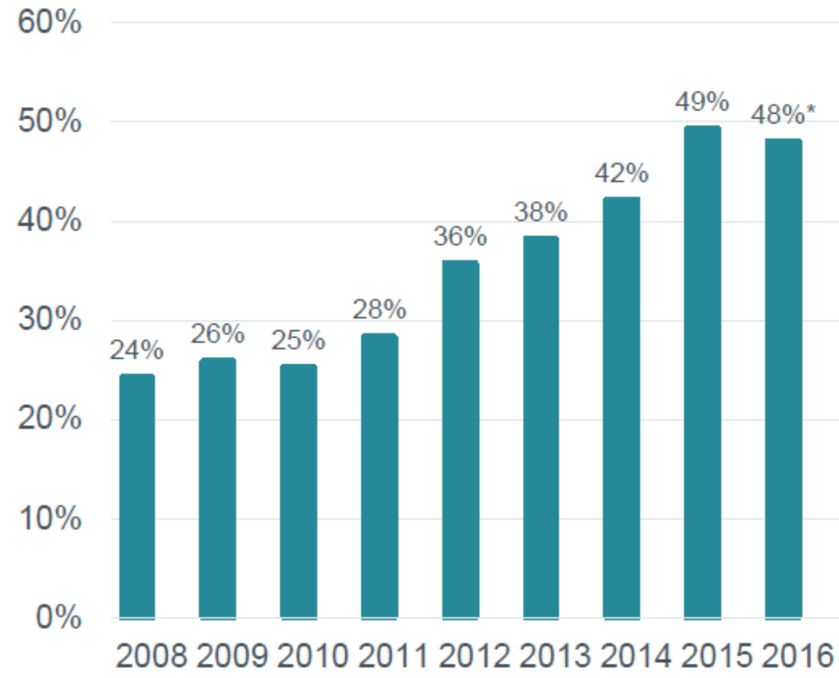
Source: 50Hertz, TenneT, Amprion, TransnetBW, Google Earth

RES have become a major player in the 50Hertz grid area

Installed RES capacity (MW) 50Hertz grid area



RES share in energy consumption 50Hertz grid area (%)



*preliminary data as of January 2017; Source: 50Hertz

50Hertz managed to integrate as much as a ~48% mostly volatile RES share into the grid (with respect to approx. 30% in Germany) in 2016.

Connection of offshore wind farms in responsibility of TSOs

North Sea – in responsibility of TenneT

Baltic Sea - in responsibility of 50Hertz

Grid load in the 50Hertz area

Asynchronous line load > 5h/a

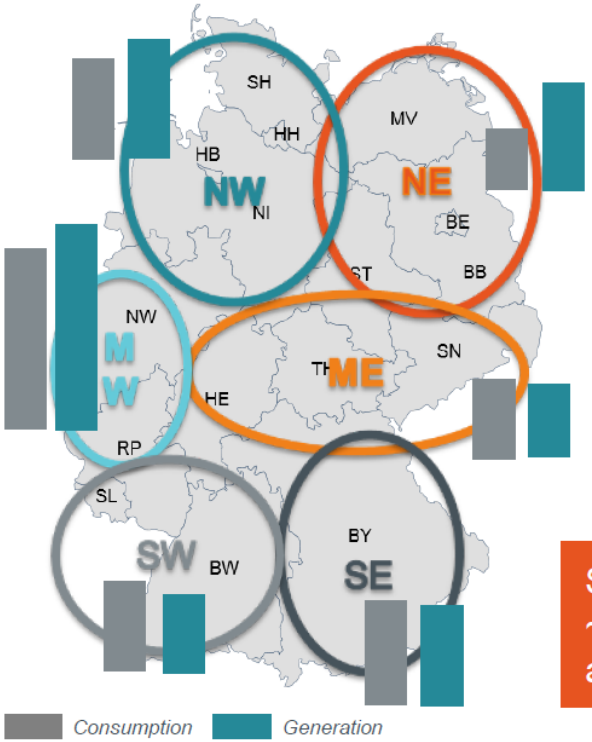
2009

2016

Grid load increases dramatically due to the changing generation infrastructure

Load ≤ 50% — *50% < Load < 70%* — *Load ≥ 70%* — *No values*

Energy balance in 2013 (Volumes in TWh)
acc. to Federal Statistical Office



2013		
	Consumption [TWh]	Generation [TWh]
NW	87,0	102,0
NE	52,0	91,9
MW	155,8	186,8
ME	68,9	62,4
SW	77,6	67,9
SE	89,0	86,4

B 2030		
	Consumption [TWh]	Generation [TWh]
NW	88,2	150,8
NE	49,0	105,5
MW	170,1	129,5
ME	74,7	72,9
SW	88,0	49,7
SE	93,8	55,2

Southern Germany imported
~12 TWh electricity for industry, commerce
and households in 2013.

Congestions and Grid Extension Area

Grid utilization at 50Hertz 2015*

Non-simultaneous grid utilization >5h/a

utilization ≤ 50 %
utilization ≥ 70 %
50 % < utilization < 70 %
no value

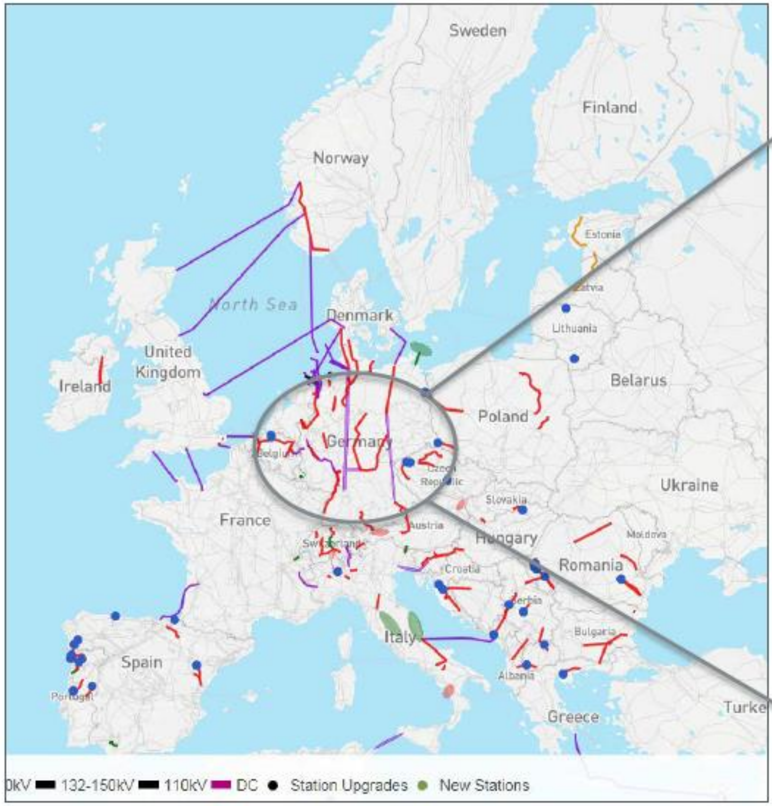
"Grid Extension Area" until 2019

Grid Extension Area

- Aim of the Grid Extension Area: Synchronisation of grid extension and RES installation by limiting RES installations in North of Germany.

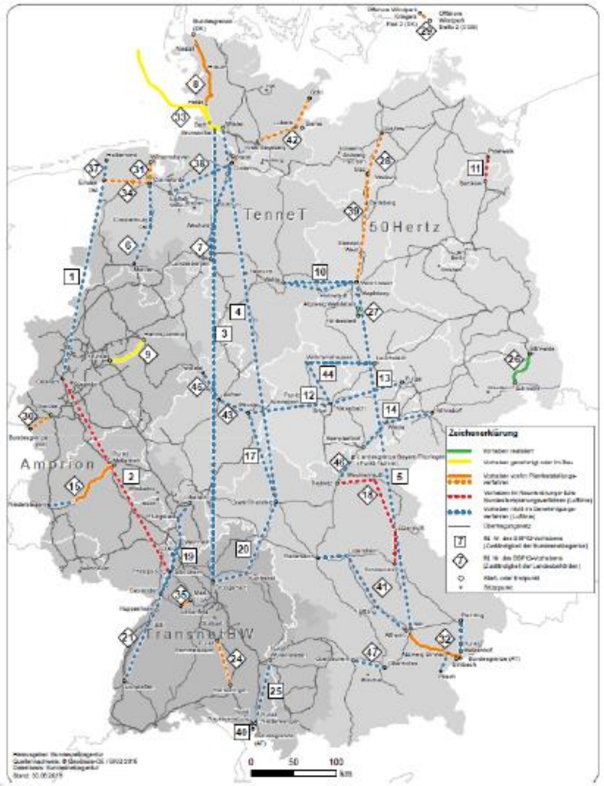
Grid development in Germany in the EU context

2016 - 10 years EU Grid Development Plan



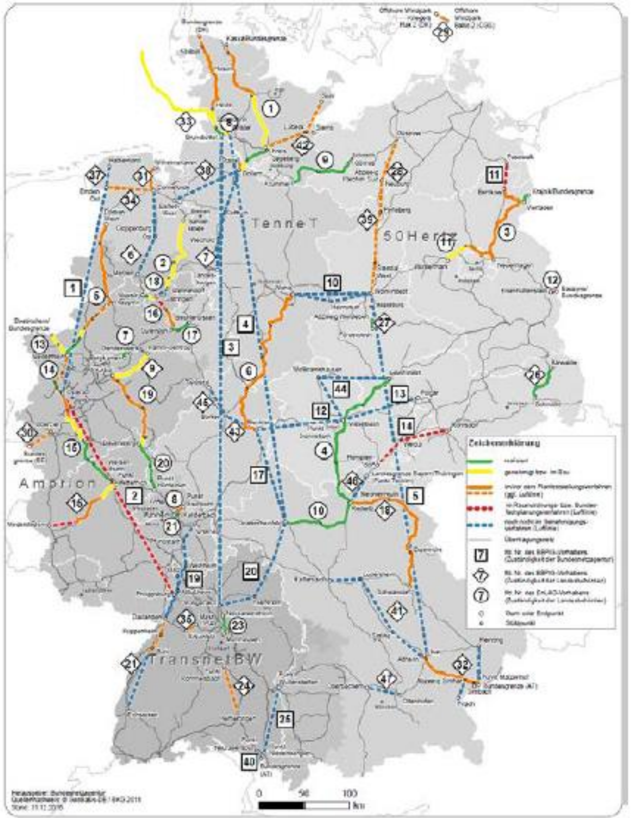
Expected investment needs: approx. **150 bn. €**

German Federal Requirement Plan 2016



Expected investment needs: approx. **50 bn. €**

Status grid extension Germany Q1 2016



Energy Line Extension Act from 2009:

36 %

50Hertz	264 km of 436 km (rd. 61 %)
Amprion	204 km of 713 km (rd. 29 %)
TenneT	162 km of 643 km (rd. 25 %)
TransnetBW	25 km of 25 km (100 %)

Federal Grid Requirement Plan Act from 2014 (only AC extensions):

4 %

50Hertz	59 km of 781 km (rd. 8 %)
Amprion	38 km of 185 km (rd. 21 %)
TenneT	14 km of 1667 km (< 1 %)
TransnetBW	0 km of 330 km (0 %)

Currently, grid extension at 50Hertz and in Germany is well performing.

Approach to Strategic Grid Development and Market Modelling

Scenario Building

- Basic data: Power plants, RE, Consumption in Germany and EU (…)
- LT renewables outlook
- Setting the basic scenario framework within the NEP-process / Consultation
- Adoption of scenarios for special purposes

Market Modelling

- Setup of Data
- Modelling of different scenarios
- Crosscheck of the Modelling Output
- Interfacing with the Grid Modell
- …

Network Analysis

- Network analysis: Load flow calculations (around the year runs, special situations)
- Contingency Analysis
- short circuit calculations, stability calculations, etc.
- Redispatch
- …

Analysis Criteria Applied in the GDP (1/2)

- **Contingency Analysis based on year round simulations:**
  - Ability of the project to redu

$$Score = \sum_{i=1}^{\text{Anzahl Zweige}} \sum_{j=1}^{\text{Anzahl Ausfallelemente}} \sum_{t=1}^{8760} \left[(\alpha_{i,j,t})_{(m-1)} - (\alpha_{i,j,t})_{(m)} \right],$$

$$\forall (\alpha_{i,j,t})_{(m-1)} > 100\% \wedge (\alpha_{i,j,t})_{(m)} \leq 100\%$$

- **Avoided Redispatch (in year round simulations)**

Base Grid → Redispatch Calculation for Base Grid → Redispatch Calcuation for Base Grid + Project X

Sorting of the Projects according to avoided Redispach → Inclusion of the most effective measures in the Base Grid → New Base Grid

御静聴ありがとうございました。