The 3rd Northeast Asia Energy Security Forum

- Sustainable Energy, Energy Interconnection and Regional Energy Cooperation -

Renewable Energy Mix and Economics of Northeast Asia Supergrid

17 December 2015, Seoul, Korea

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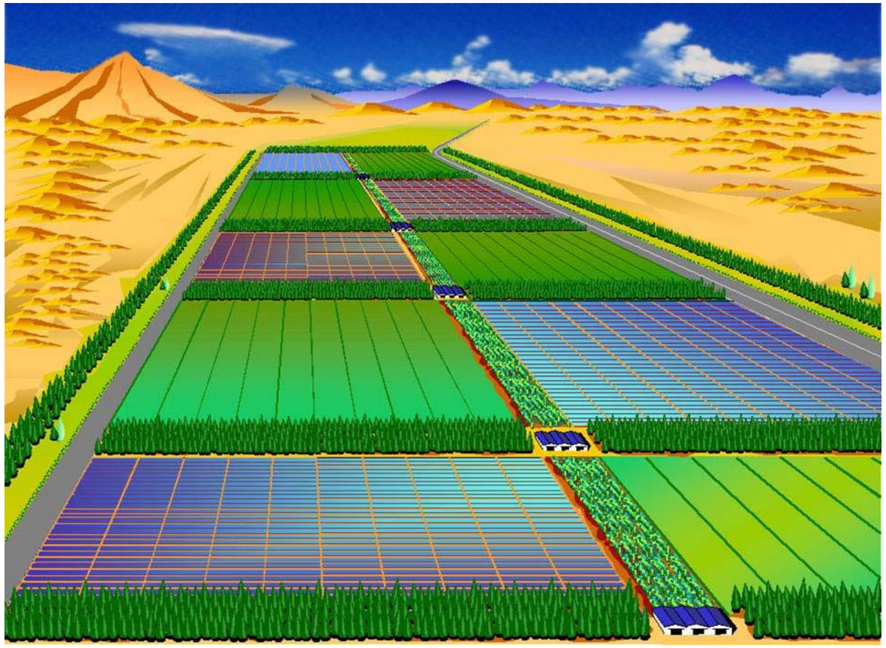
IEA PVPS Task8: Energy from the Desert

Study on Very Large Scale PhotoVoltaic Power Generation (VLS-PV) Systems



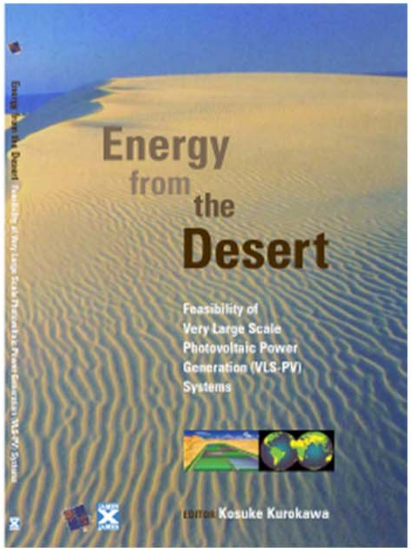
IEA PVPS Task8

- Objectives
  - To examine and evaluate the feasibility of Very Large Scale Photovoltaic Power Generation (VLS-PV) Systems, which have a capacity ranging from over multi-MW to GW
  - To accelerate and implement real VLS-PV projects

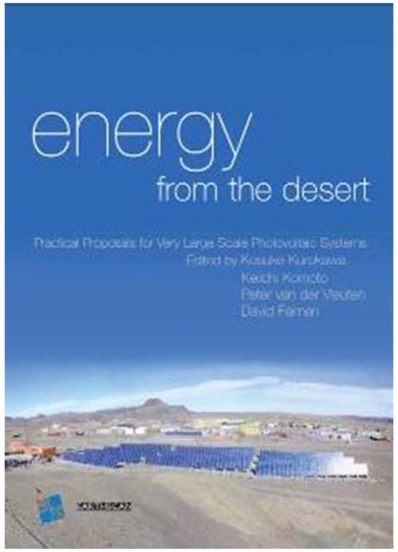
- Activity period
  - 1999 – 2014

Energy from the Desert

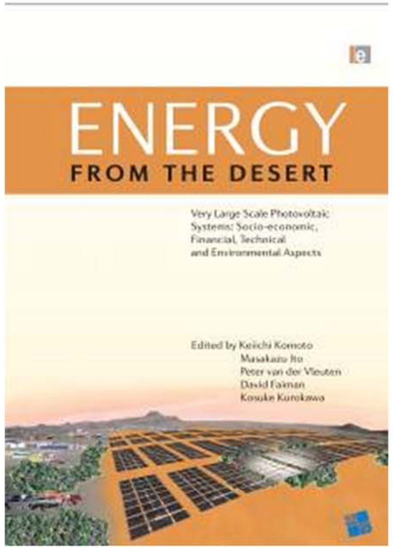
Feasibility of Very Large Scale Photovoltaic Power Generation (VLS-PV) Systems:
Published in 2003



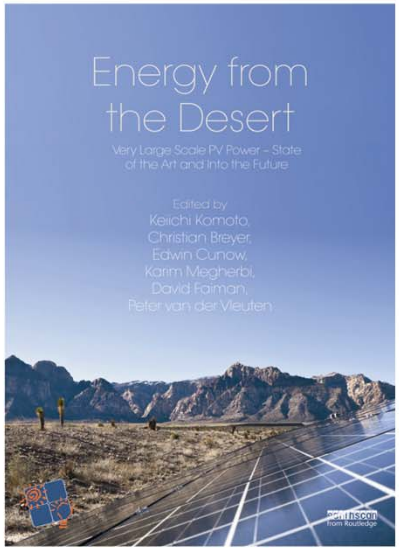
Practical Proposals for Very Large Scale Photovoltaic Systems:
Published in 2007



Very Large Scale Photovoltaic Systems, Socio-Economic, Financial, Technical and Environmental Aspects:
Published in 2009

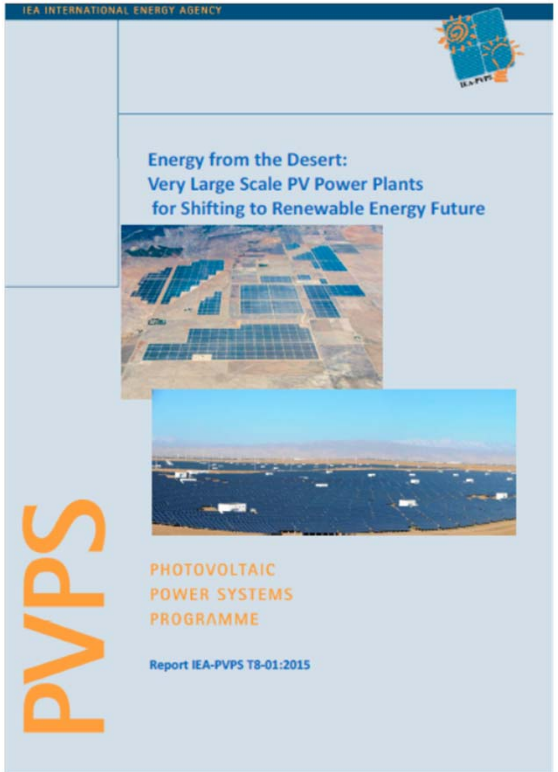


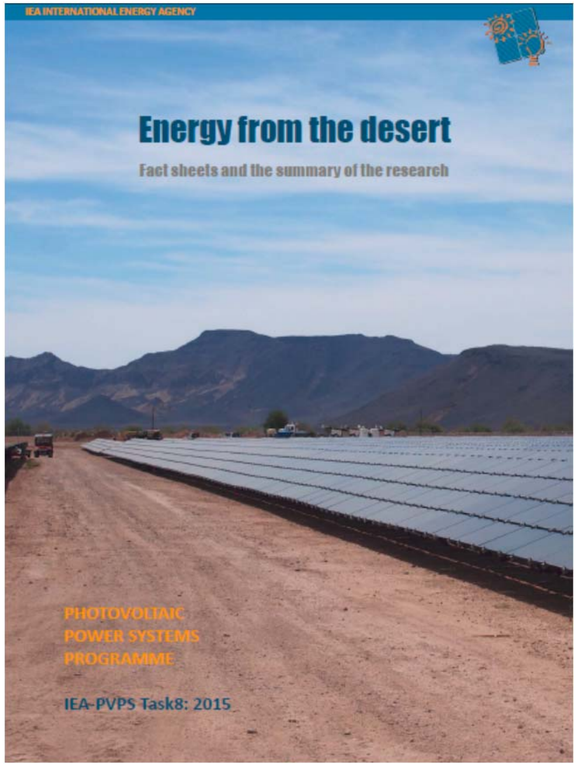
Very Large Scale PV Power- state of the art and into the future
Published in 2013



Energy from the Desert

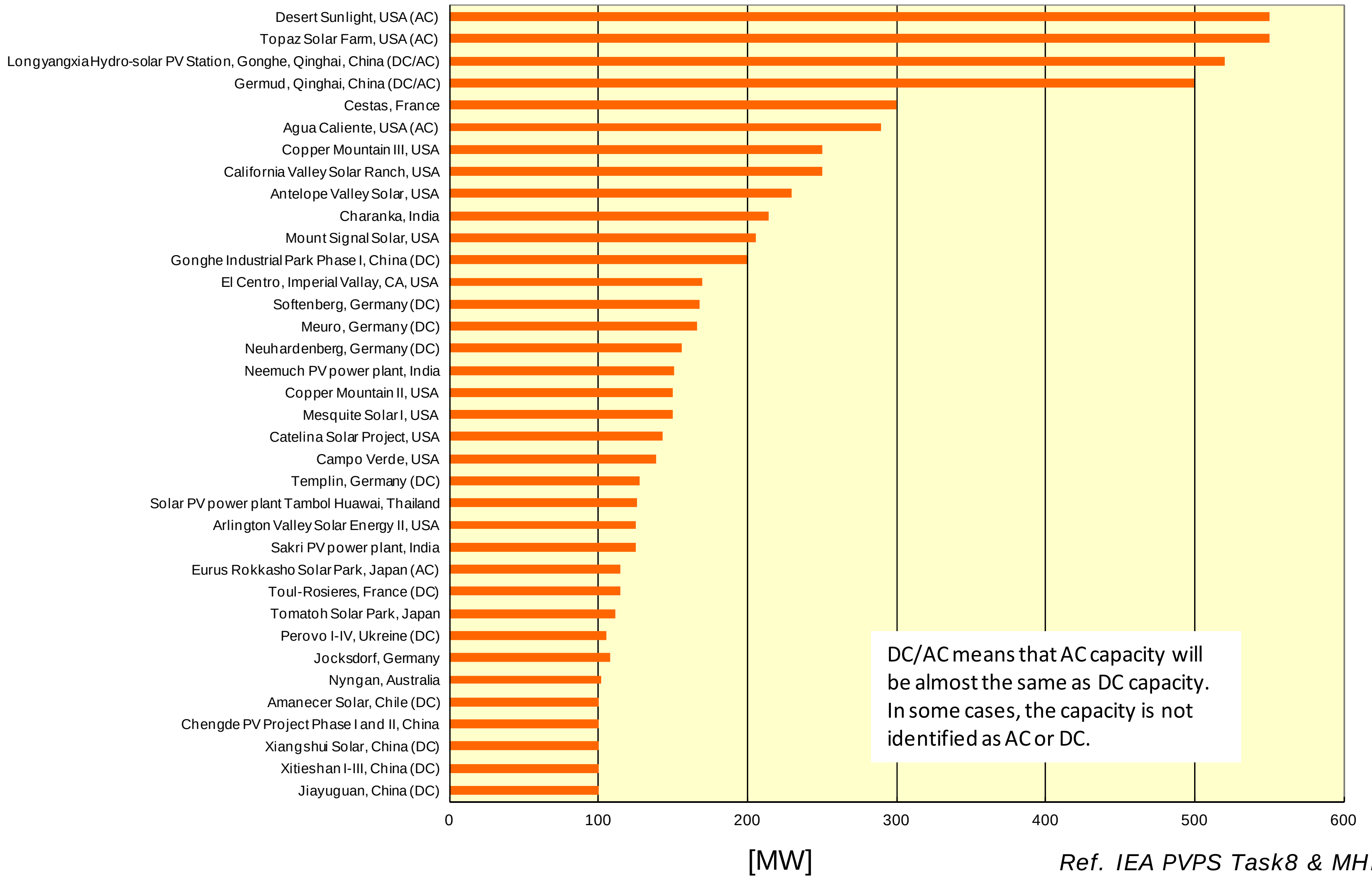
Very Large Scale PV Power Plants for Shifting to Renewable Energy Future *(February 2015)*





Available at the IEA PVPS website: http://www.iea-pvps.org

>500MW PV power plants are operational



Ref. IEA PVPS Task8 & MHIR

Topaz Solar Farm, AZ, USA

Longyangxia, Qinghai, China

provided by the Yellow River Hydropower Company

VLS-PV is already available!

- Currently, the large scale PV power plants account for at least 10-15 % of cumulative PV installation in the world.
- The largest PV power plants record in the world has been broken every year.
- PV power plants with several hundred MW scales (ex. over 500MW) are already in the commercial stage and technically feasible.
- PV power plants in the desert have to endure the severe environmental conditions. As one of countermeasures for soiling, cleaning option of the PV plants can be justified if the cost for cleaning is lower than the income generated by the solutions.
- When it comes to the PV power plant in the desert environment, the LCOE is already low even with the current module price level.

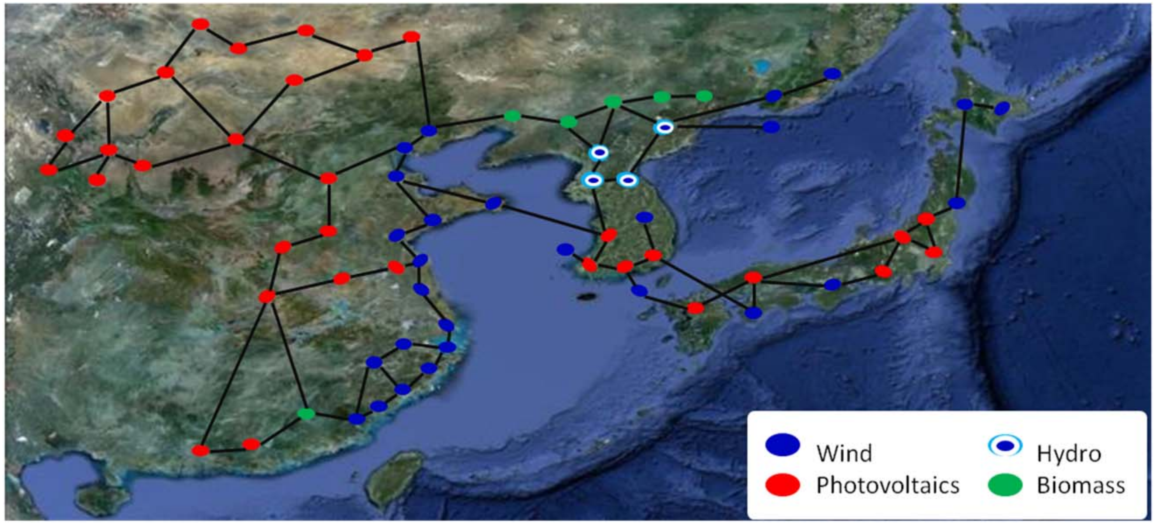
VLS-PV is a key for sustainable environment and social development!

- The EPBT of large scale PV power plants are within ranges of 1 to 3 years. Assuming 30 years lifetime, PV can produce 10 to 30 times more energy than the total energy consumed throughout its life-cycle.
- CO_2 emission rates of large scale PV power plants are very small and one-tenth or one-twentieth of average CO_2 emission rate in China or Africa, coal-based country.
- PV technologies consume water at the production stage to some extent, but little during their operation. Clearly, PV power plants will contribute to saving ground water use by substituting conventional power plants inland.
- GW-scale PV power plant will create substantial and stable demand for PV system components as well as employment for construction, operation and maintenance if such works are managed in an appropriate manner.
- It is ideal to transfer technology as much as possible to the local labours employed to operate by themselves at certain stage. This will contribute to an intrinsic regional development with PV industry.

How VLS-PV can contribute as a major power source?

- In the near future, GW-scale PV power plants will come on the market and PV power plants will become competitive against conventional power plants.
- In order that PV power plants to be one of the major power sources in the future, technology development such as grid integration with energy storage and long-distance electricity transmission including HVDC will be essential.
- One of the most efficient ways to overcome this challenge and to achieve the ambitious goals of increasing the share of renewable energy is to use high capacity transmission grids, called “Supergrid” designed to transfer large amounts of power over the long distances with lower losses.

Study on VLS-PV Supergrid in the North East Asia



Key Objective

- Definition of an optimally structured energy system based on 100% RE supply
  - optimal set of technologies, best adapted to the availability of the regions' resources,
  - optimal mix of capacities for all technologies and every sub-region of North-East Asia,
  - optimal operation modes for every element of the energy system,
  - least cost energy supply for the given constraints

LUT* Energy Model

- key features
  - linear optimization model
  - hourly resolution
  - multi-node approach
  - flexibility and expandability
- Input data
  - historical weather data for: solar irradiation, wind speed and hydro precipitation
  - available sustainable resources for biomass and geothermal energy
  - synthesized power load data
  - gas and water desalination demand
  - efficiency/ yield characteristics of RE plants
  - efficiency of energy conversion processes
  - capex, opex, lifetime for all energy resources
  - min and max capacity limits for all RE resources
  - nodes and interconnections configuration

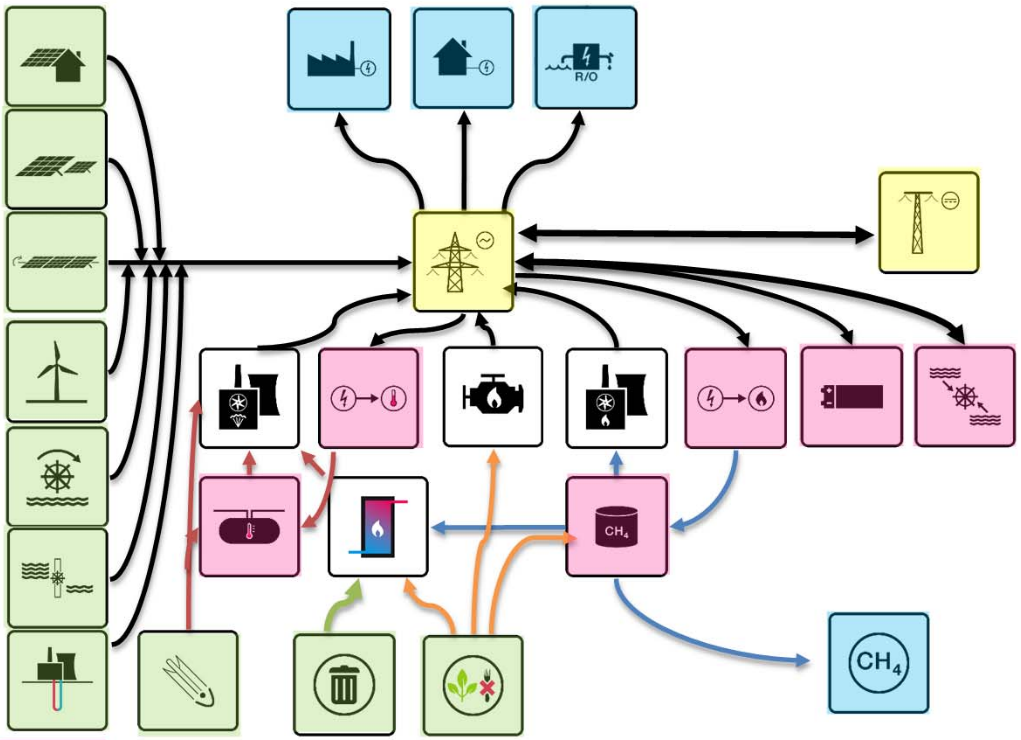
**LUT: Lappeenranta University of Technology, Finland*

Supposed scenario: Components for energy system

Renewable energy sources
- PV ground-mounted (optimally tilted)
- PV rooftop
- Wind onshore
- Hydro run-of-river
- Hydro dam
- Geothermal
- CSP
- Waste
- Biogas
- Biomass

Electricity transmission
- node-internal AC transmission
- interconnected by HVDC lines

Storage options
- Batteries
- Pumped hydro storages
- Thermal energy storage, Power-to-Heat
- Gas storage based on Power-to-Gas
  - Water electrolysis
  - Methanation
  - CO_2 from air
  - Gas storage



Energy Demand
- Electricity
- Water Desalination
- Industrial Gas

Ref. D. Bogdanpv, C. Breyer, et al., 31st EU-PVSEC, Sep. 2015, Hamburg, Germany

Supposed scenarios: Regions and grid configurations

15 regions

- West and East Japan (divided by 50/60 Hz border)
- South and North Korea
- 8 regions in China (based on State Grid Corporation of China grid)
- Mongolia
- Russian regions: East Siberian and Far East economy districts

- Regional-wide open trade (no interconnections between regions)
- Country-wide open trade (no interconnections between countries)
- Area-wide open trade (interconnections by country-wide HVDC grids)
- Area-wide open trade with water desalination and industrial gas production

Ref. D. Bogdanpv, C. Breyer, et al., 31st EU-PVSEC, Sep. 2015, Hamburg, Germany

Supposed scenarios: Financial assumptions (year 2030)

Technology	Capex [€/kW]	Opex fix [€/kW]	Opex var [€/kWh]	Lifetime [a]
PV fixed-tilted	550	8	0	35
PV rooftop	813	12	0	35
PV 1-axis	620	9	0	35
Wind onshore	1000	20	0	25
Hydro Run-of-River	2560	115.2	0.005	60
Hydro Dam	1650	66	0.003	60
Geothermal	4860	87	0	30
Water electrolysis	380	13	0.001	30
Methanation	234	5	0	30
CO_2 scrubbing	356	14	0.0013	30
CCGT	775	19	0.002	30
OCGT	475	14	0.011	30
Biomass PP	2500	175	0.001	30
Wood gasifier CHP	1500	20	0.001	40
Biogas CHP	370	14.8	0.001	20
Steam Turbine	700	14	0	30
Technology	**Capex [€/(m^3·h)]**	**Opex fix [€/(m^3·h)]**	**Opex var [€/(m^3·h)]**	**Lifetime [a]**
Water Desalination	815	35	0	30

Technology	Energy/Power Ratio [h]
Battery	6
PHS	8
Gas Storage	80*24

	Efficiency [%]
Battery	90
PHS	92
Gas Storage	100
Water Electrolysis	84
CO_2 Scrubbing	78
Methanisation	77
CCGT	58
OCGT	43
Geothermal	24
MSW Incinerator	34
Biogas CHP	40
Steam Turbine	42
CSP collector	51

WACC = 7%

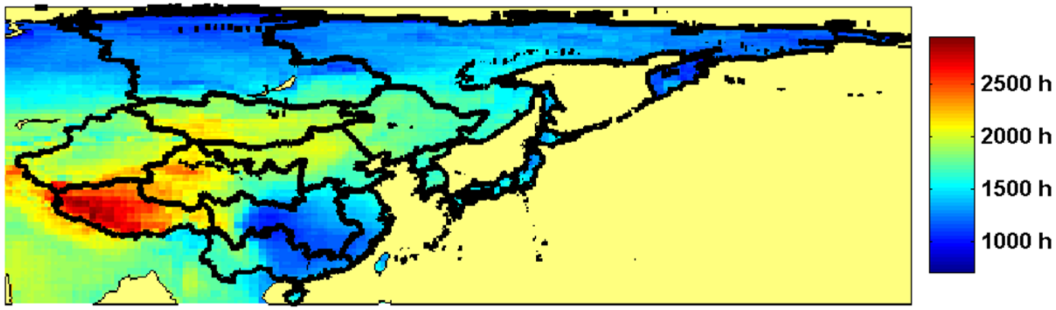
Ref. D. Bogdanpv, C. Breyer, et al., 31st EU-PVSEC, Sep. 2015, Hamburg, Germany

Supposed scenarios: Full load hours & LCOE (PV / wind)

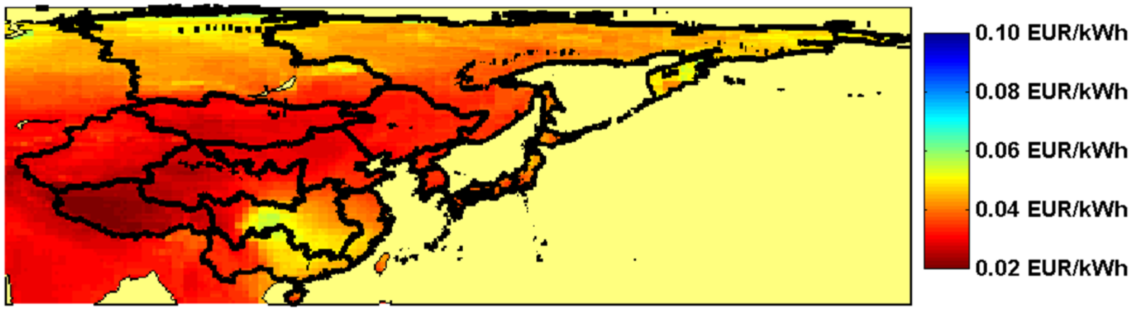
Region	PV fixed-tilted FLH	PV 1-axis FLH	CSP FLH	Wind FLH
East Japan	1316	1536	1230	3362
West Japan	1365	1604	1288	3204
South Korea	1467	1733	1486	2946
North Korea	1469	1749	1495	2890
Northeast China	1457	1832	1706	3519
North China	1592	2011	1844	3541
East China	1340	1549	1228	2083
Central China	1471	1726	1284	2608
South China	1435	1678	1208	2310
Tibet	1983	2719	2417	5208
Northwest China	1739	2221	1963	3703
Uygur	1666	2124	1957	2724
Mongolia	1572	2062	1975	3288
Russia Siberia	1158	1476	1380	3082
Russia Far East	1136	1477	1397	2712

(weather year 2005, cost year 2030)

PV (1-axis tracking) full load hours



PV (1-axis tracking) LCOE



FLH of region computed as weighed average of regional sub-areas (about 50 km x 50 km each):

0%-10% best “sub-areas” of region – 0.3
10%-20% best “sub-areas” of region – 0.3
20%-30% best “sub-areas” of region – 0.2
30%-40% best “sub-areas” of region – 0.1
40%-50% best “sub-areas” of region – 0.1

Ref. D. Bogdanpv, C. Breyer, et al., 31st EU-PVSEC, Sep. 2015, Hamburg, Germany

Results: Expected Capacity

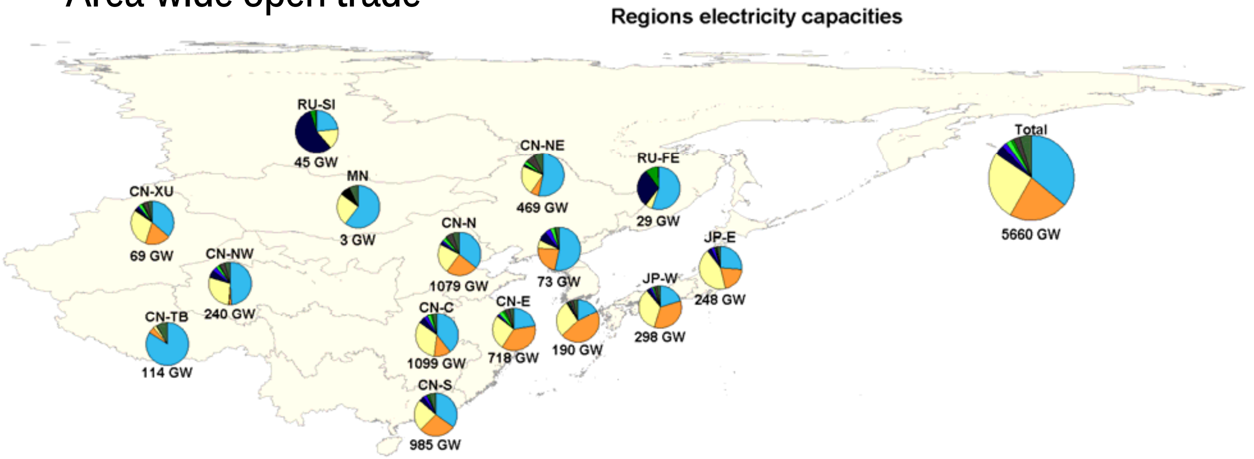
2030 Scenario	Wind [GW]	PV [GW]	Hydro RoR [GW]	Hydro dams [GW]	Biogas [GW]	Biomass [GW]	Waste [GW]	Geothermal [GW]	Battery [GWh]	PHS [GWh]	PtG electrolyzers [GW_{el}]	GT [GW]
Region-wide	1733	3951	115	191	66	80	5	6.5	5423	98	323	540
Country-wide	1930	3093	115	191	99	67	4	6	4270	98	221	433
Area-wide	2034	2750	112	195	110	67	4	6	3734	105	173	381
Area-wide Des-Gas	2435	3929	113	195	54	50	4	5	4060	105	550	294

2030 Scenario	PV 0-axis [GW]	PV 1-axis [GW]	PV prosumers [GW]	PV total [GW]	Battery system [GWh]	Battery prosumers [GWh]	Battery total [GWh]
Region-wide	481	1977	1493	3951	3485	1938	5423
Country-wide	72	1528	1493	3093	2332	1938	4270
Area-wide	1	1256	1493	2750	1796	1938	3734
Area-wide Des-Gas	1	2435	1493	3929	2122	1938	4060

Ref. D. Bogdanpv, C. Breyer, et al., 31st EU-PVSEC, Sep. 2015, Hamburg, Germany

Results:
Regions electricity capacity

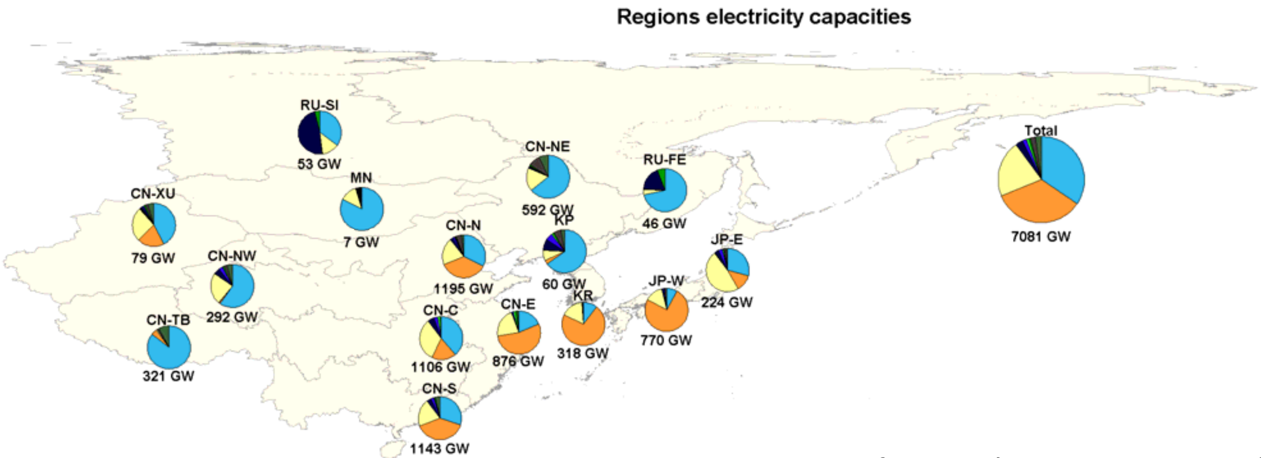
Area-wide open trade



Key insights:

- Area-wide scenario shows high PV capacities due to (prosumer) LCOE competitiveness in majority of the regions
- Importing regions generate economic benefit from significant local PV self-consumption share

Area-wide open trade desalination gas



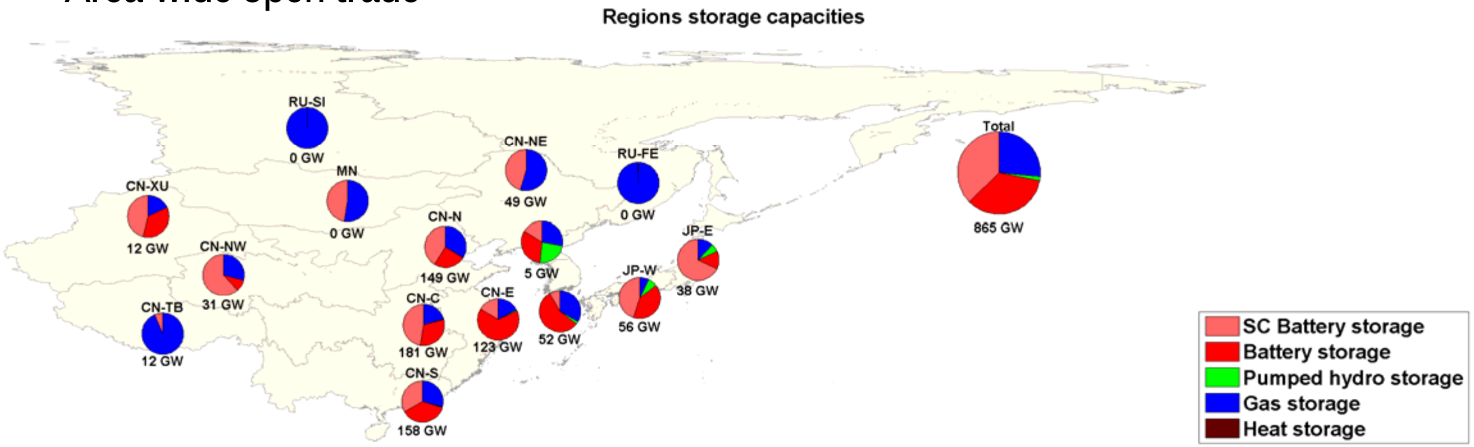
Key insights:

- Area-wide desalination gas scenario is dominated by PV
- PV 1-axis and wind are the main sources of electricity for water desalination and industrial gas production, especially for importing regions

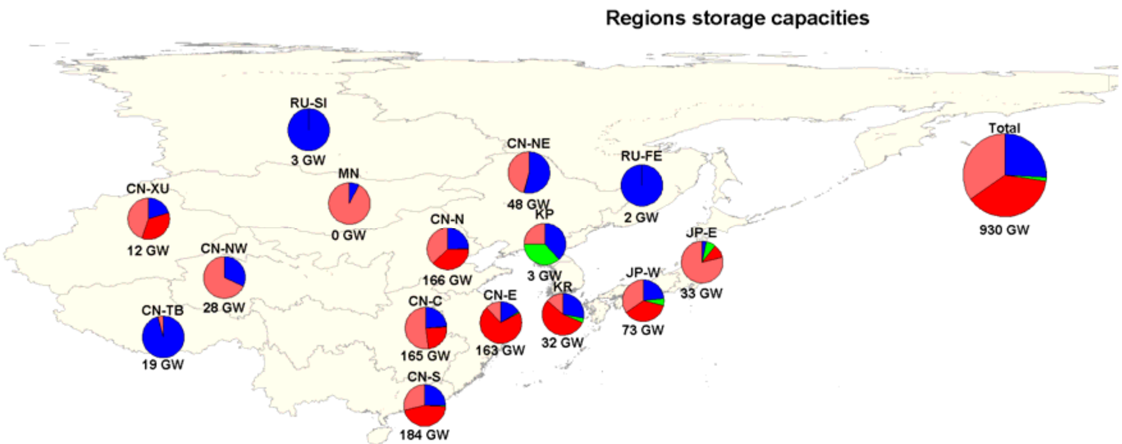
Ref. D. Bogdanpv, C. Breyer, et al., 31st EU-PVSEC, Sep. 2015, Hamburg, Germany

Results: Regions storage capacity

Area-wide open trade



Area-wide open trade desalination gas



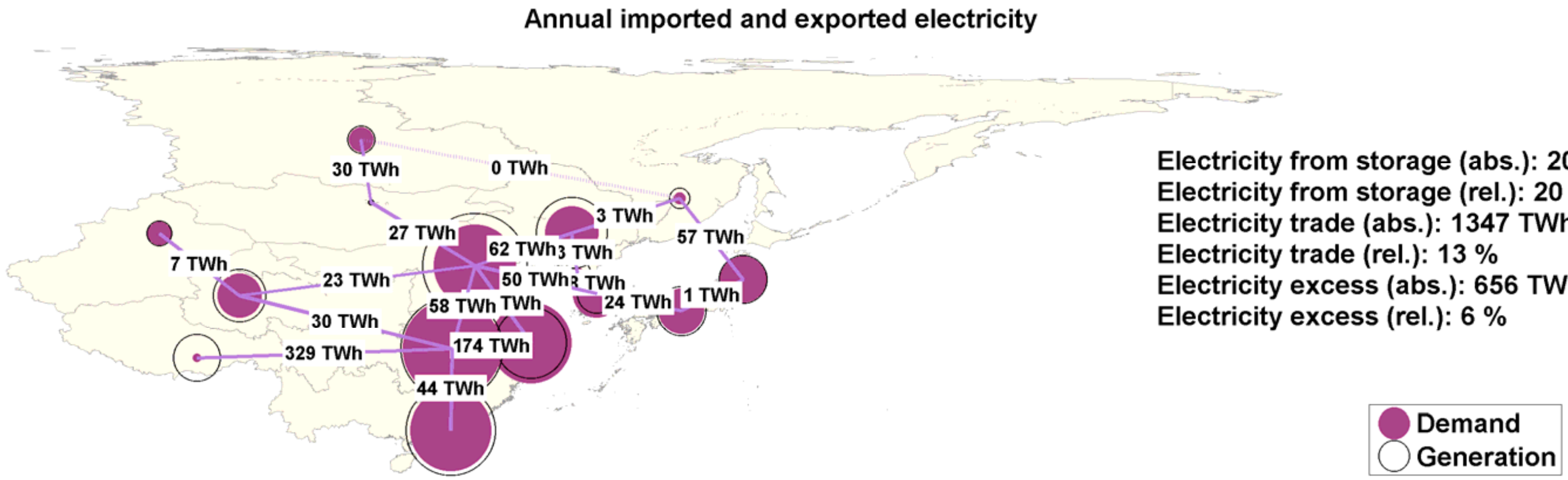
Key insights:

- Excess energy for area-wide open trade desalination gas: higher in absolute numbers, but lower in relative ones (from 6.5% to 5.9% of total generation).
- Hydro dams as virtual battery very important, batteries in a key role for prosumers but also on the grid level and gas storages for balancing periods of wind and solar shortages

Ref. D. Bogdanpv, C. Breyer, et al., 31st EU-PVSEC, Sep. 2015, Hamburg, Germany

Results: Import / export electricity

Area-wide open trade



Key insights:
- Net Importers: Japan, South Korea, East China
- Net Exporters: Russia, Tibet, North and Northwest China

Ref. D. Bogdanpv, C. Breyer, et al., 31st EU-PVSEC, Sep. 2015, Hamburg, Germany

Results: Expected LCOE

2030 Scenario	Total LCOE [€/kWh]	LCOE primary [€/kWh]	LCOC [€/kWh]	LCOS [€/kWh]	LCOT [€/kWh]	Total ann. cost [bn €]	Total CAPEX [bn €]	RE capacities [GW]	Generated electricity [TWh]
Region-wide	0.077	0.042	0.003	0.032	0.000	790	6722	6642	12447
Country-wide	0.072	0.041	0.003	0.025	0.003	724	6326	5891	11993
Area-wide	0.068	0.041	0.002	0.021	0.004	697	6171	5609	11753
Area-wide Des-Gas*,**	0.058	0.038	0.002	0.013	0.005	876	7939	7057	15322

Total LCOE*** prosumer [€/kWh]	LCOE primary prosumer [€/kWh]	LCOS prosumer [€/kWh]	Total ann. Cost prosumer [bn €]	Total CAPEX prosumer [bn €]	RE capacities prosumer [GW]	Generated electricity prosumer [TWh]
0.092	0.052	0.040	142	1290	1492	2184

LCOW: 0.98 €/m^3

LCOG: 0.142 €/kWh,gas

* additional demand 82% gas and 18% desalination

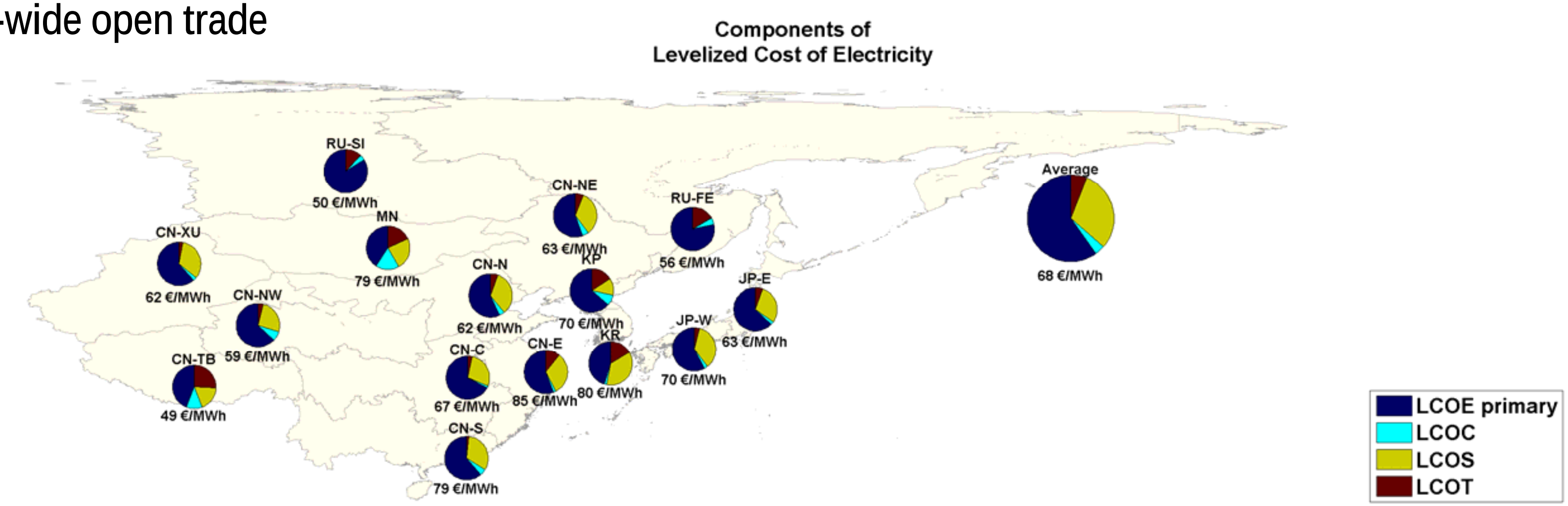
** LCOS does not include the cost for the industrial gas (LCOG)

*** fully included in table above

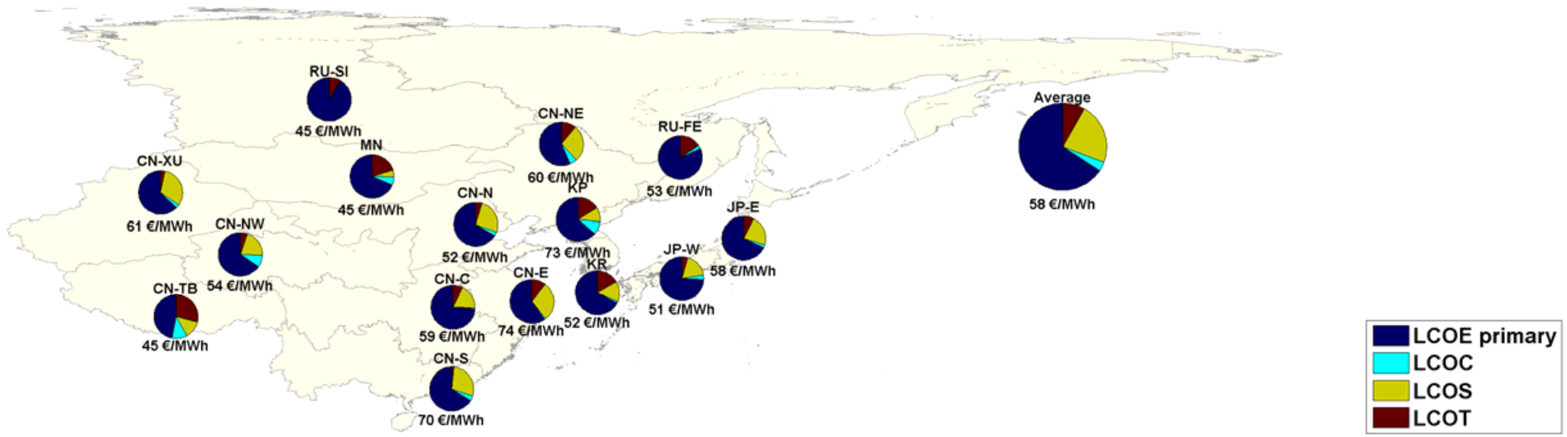
Ref. D. Bogdanpv, C. Breyer, et al., 31st EU-PVSEC, Sep. 2015, Hamburg, Germany

Results:
Components of LCOE

Area-wide open trade



Area-wide open trade desalination gas



Ref. D. Bogdanpv, C. Breyer, et al., 31st EU-PVSEC, Sep. 2015, Hamburg, Germany

Understanding

- 100% Renewable Energy system in North-East Asia reachable!
- Super grid interconnection decrease average cost of electricity to 0.068 EUR/kWh of the total area from 0.072 EUR/kWh (country-only) and 0.077 EUR/kWh (region-only)
- Integration benefit of gas and desalination is about 4-6% (generation and cost) due more efficient usage of storage and flexibility options
- In 2030, for region scenario PV technologies dominate in the electricity sector in most regions of North-East Asia, however for country and area-wide open trade scenarios wind starts to play the most important role
- Hydro dams can be used as a virtual battery for solar and wind electricity storage, in the same time RoR hydro is not cost competitive to PV and Wind
- The shift to power in the gas, desalination, heat and mobility sector will be driven by higher supply of least cost solar PV and wind sites
- Despite an upper limit 50% higher than the current capacity for hydro dams and RoR, in all the considered scenarios PV and wind are more profitable technologies according to the availability of the regions' resources
- 100% RE system is more cost competitive than nuclear-fossil option!

Concluding remarks

Direction for accelerating PV power plants

- It will be reasonable to expect that GW-scale PV power plants will come on the market in near future.
- Global deployment of PV power plants will be accelerated by developing energy supplying system combined with other renewables and energy storage technologies.
- Our precise study has revealed that 100% Renewable Energy system in North-East Asia reachable. PV will play important role although wind may dominates the region.
- The renewable energy can also be used to produce liquid fuel when the power supply surpasses the demand.
- Although there are technical and economic barriers to be solved for the renewable-based liquid fuel production system, low carbon energy system with 100 % renewable energy is certainly possible in the future.


Thank you for your attention!
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K. Komoto, 3rd Northeast Asia Energy Security Forum. Seoul, Korea, December 2015