Online Meeting
December 03.2020

Multi Criteria planning methodology to decarbonize energy systems

PROSPECT2030 | HSMD | Prof. P. Komarnicki, Dr. P. Lombardi

AGENDA

RES

Status quo in EU and in Germany

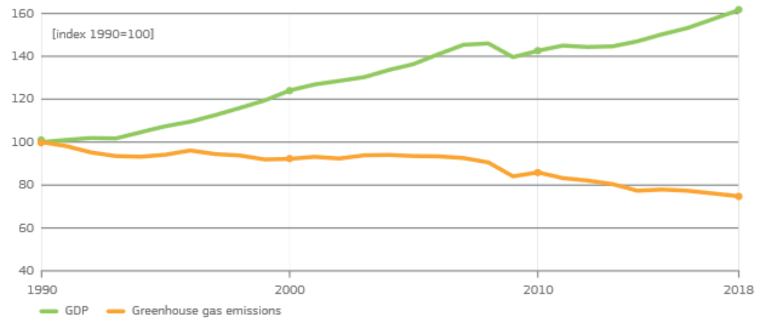
Integrating volatile RES:

Problems and solutions

Multi criteria planning methodology : Analytic Hierarchy Process

Study case: Siberian Isolated Power Systems

EUROPEAN GREEN DEAL STRATEGY



CO_2: - 23%
(in 2018)

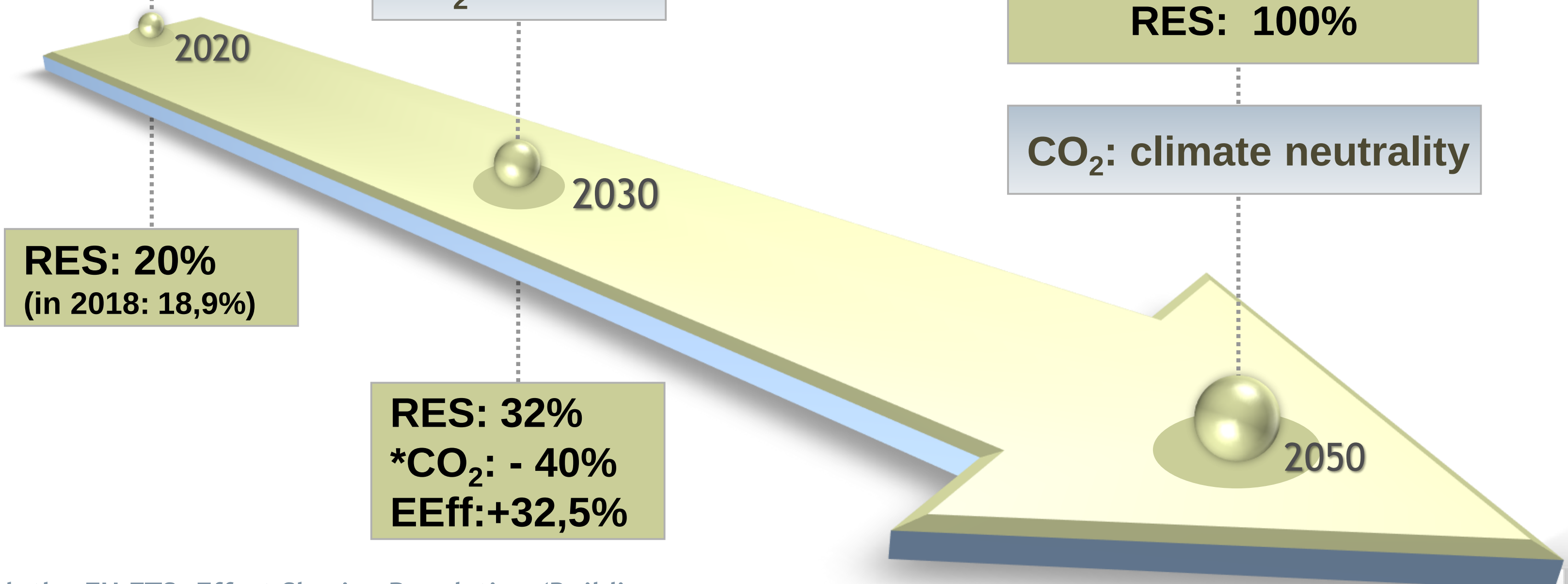
RES: 20%
(in 2018: 18,9%)

CO_2: - 55%

RES: 32%
*CO_2: - 40%
EEff:+32,5%

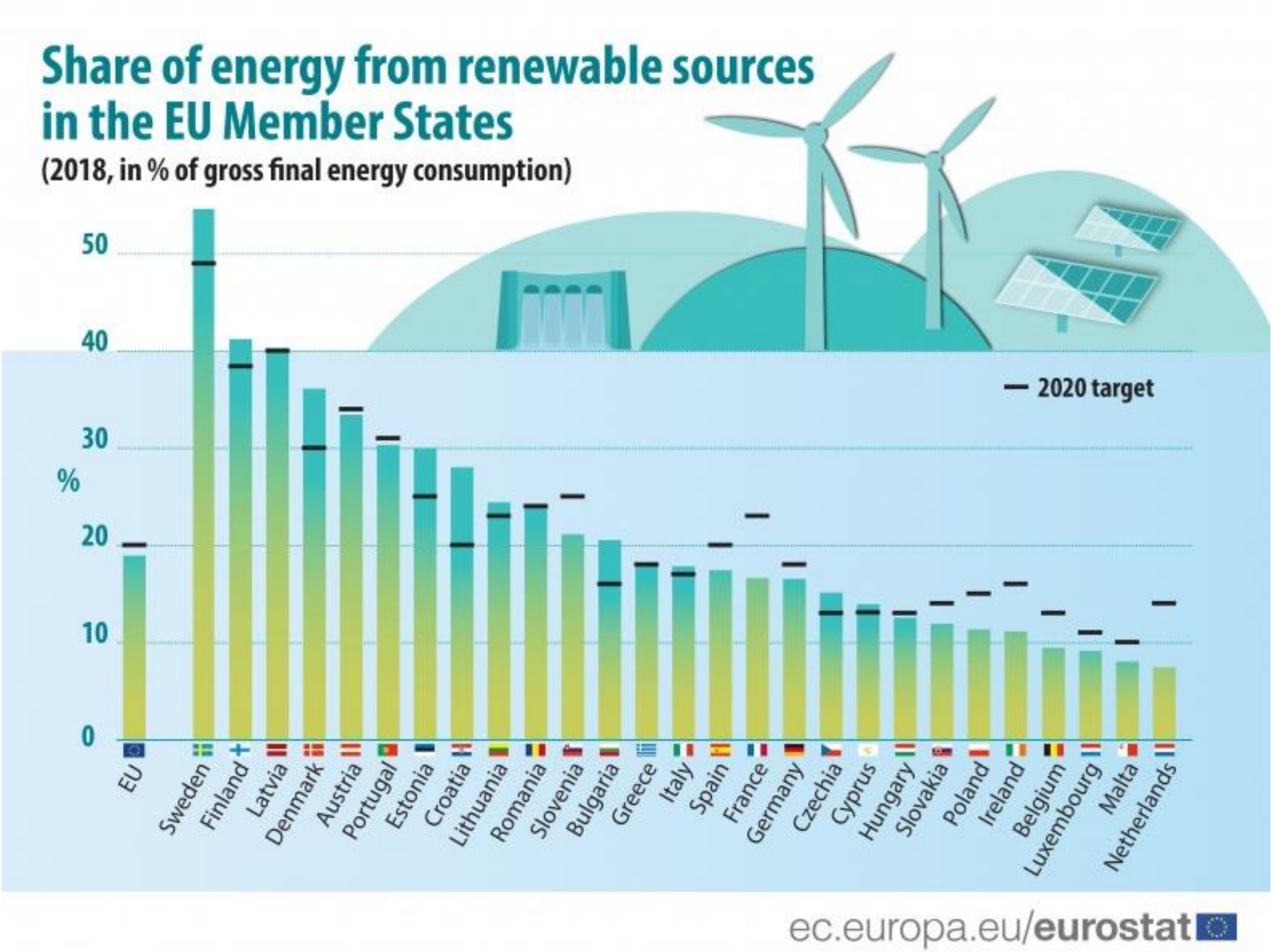
RES: 100%

CO_2: climate neutrality

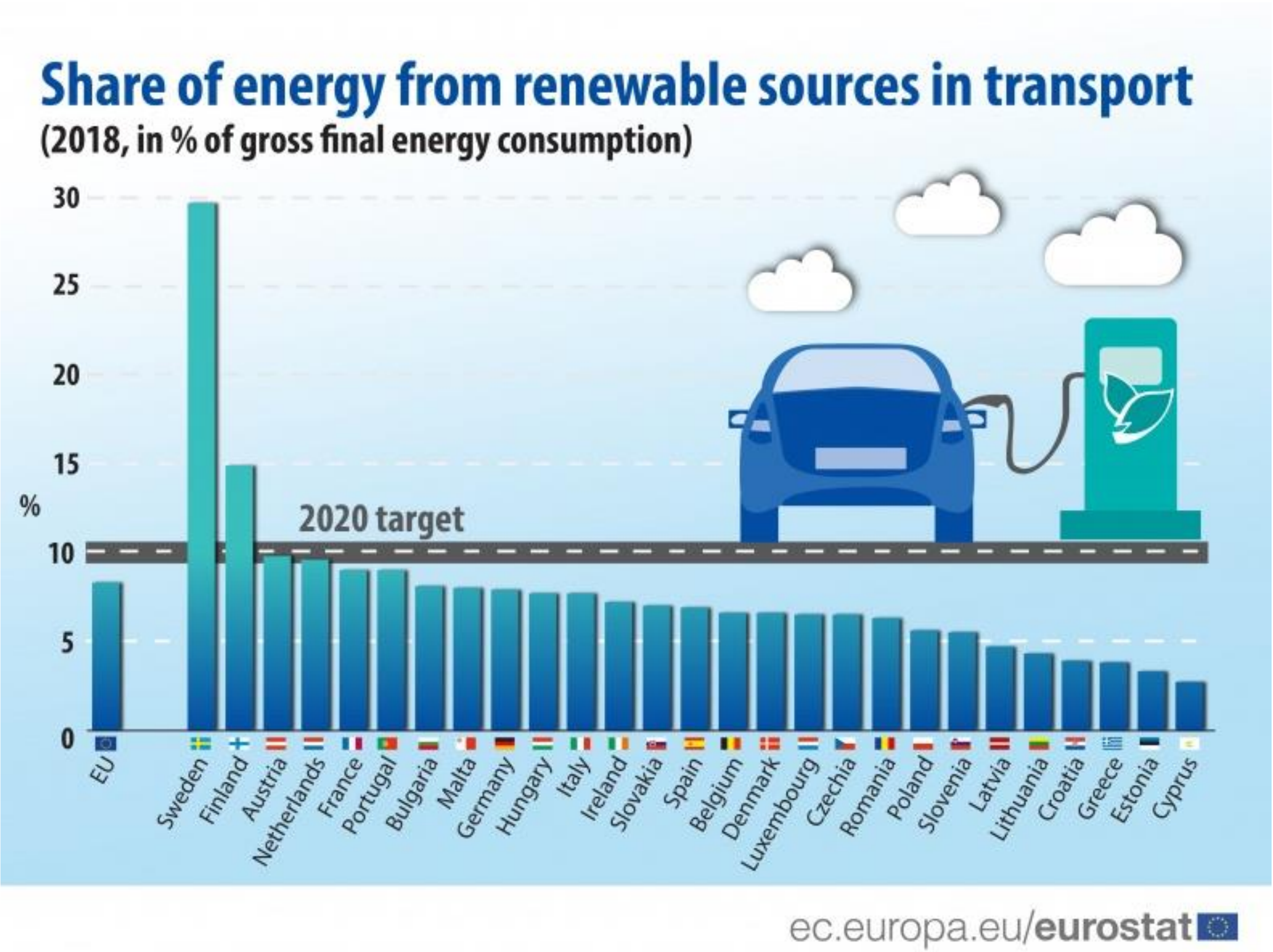


* Through the EU ETS, Effort Sharing Regulation (Building, transport, agriculture and waste) and Land use, forestry regulation

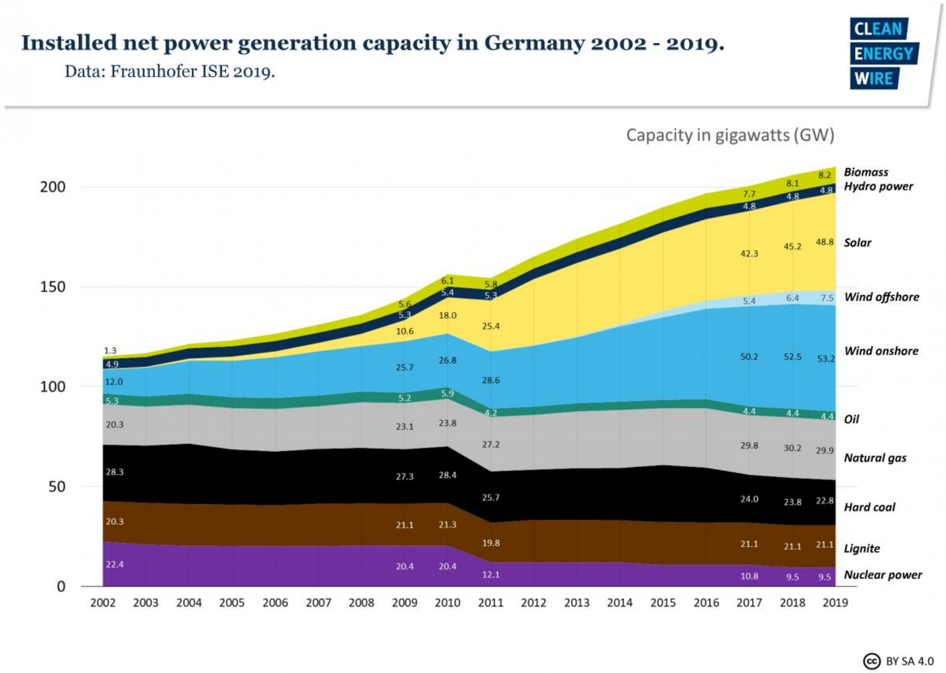
EU28 STATUS QUO FOR SHARE OF RES

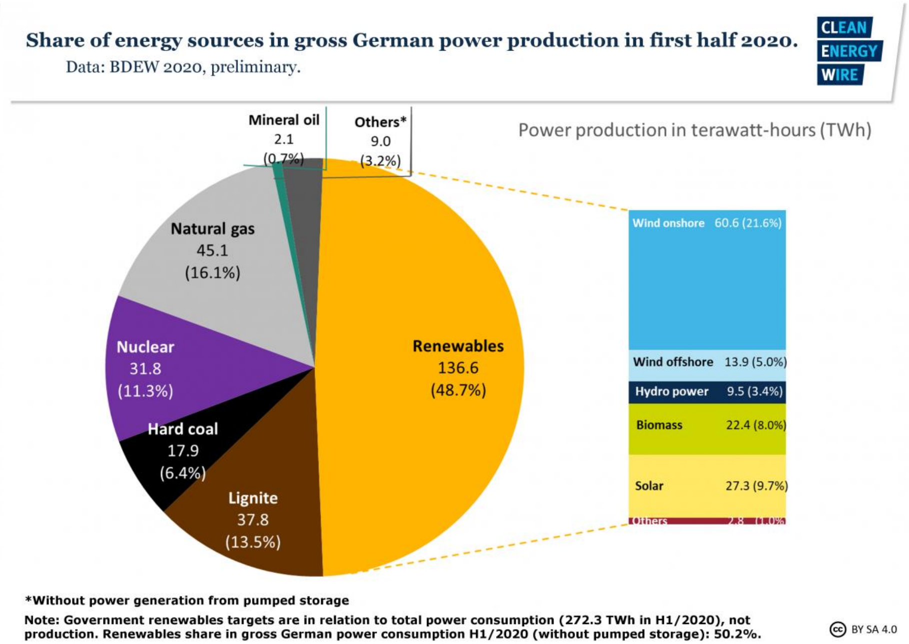


EU28 STATUS QUO FOR SHARE OF RES



GERMANY STATUS QUO FOR SHARE OF RES

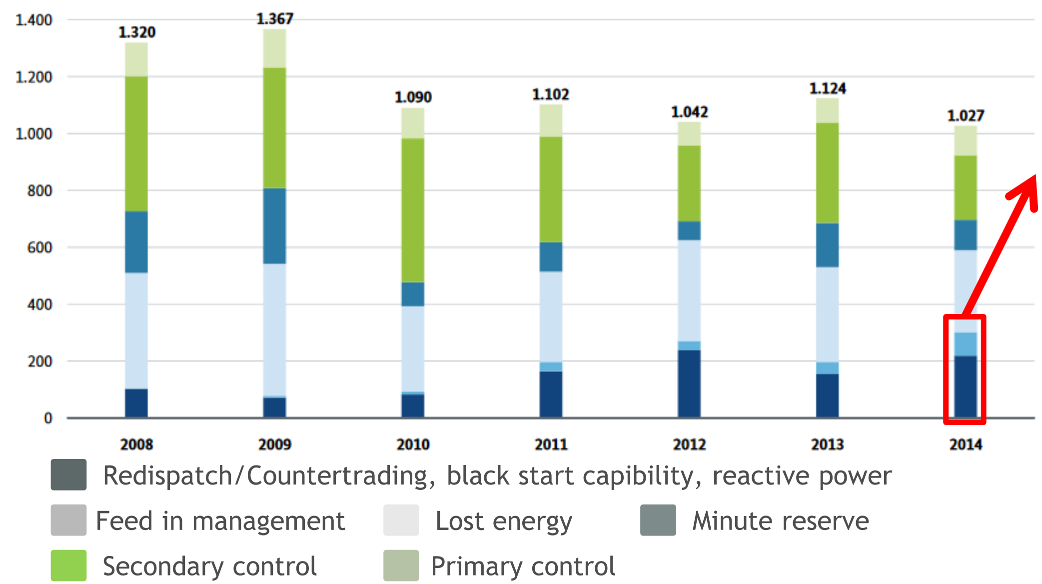




COSTS TO INTEGRATE VOLATILE RES IN GERMANY

- High costs of integrating volatile RES into the electricity system:
- Costs for ancillary services in Germany: more than 1 billion €
  - Costs for feed-in management and redispatch in Germany 2015: 880.5 Mio. € (2014: approx. 368 Mio. €)

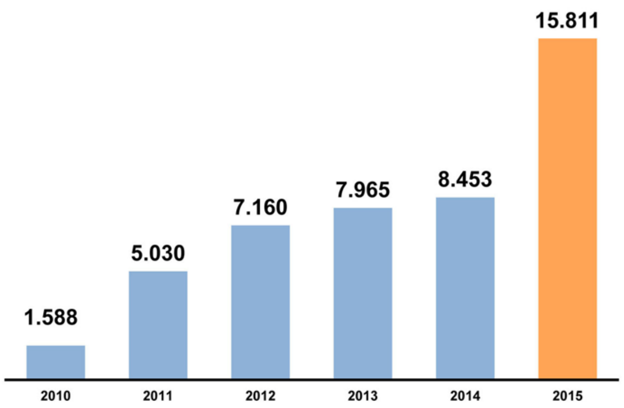
Costs for ancillary services:



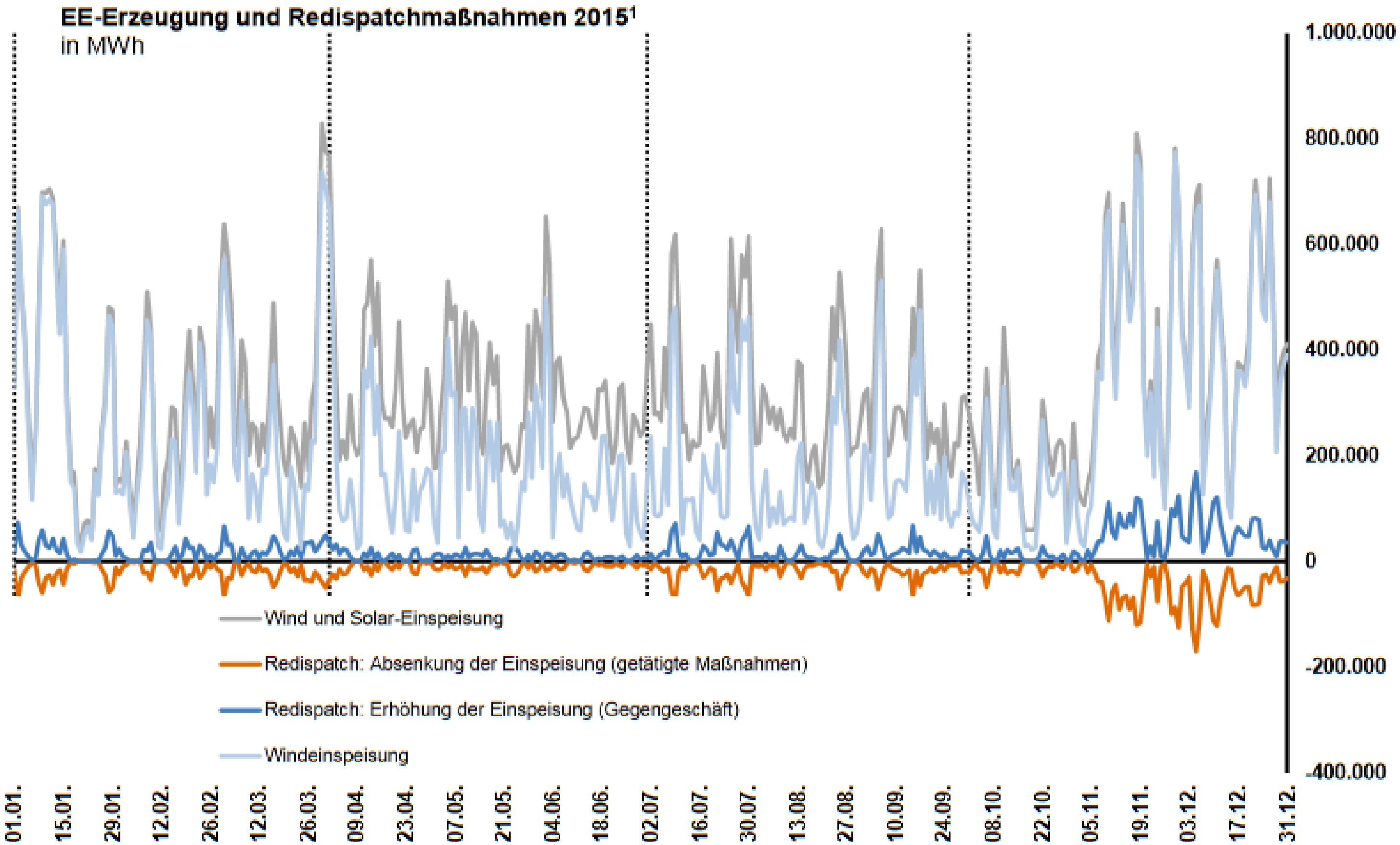
Source: BNetzA

Development of redispatch activities:

Occurences in hours



PROBLEMS DUE TO THE VOLATILITY OR RES



Quelle: Monitoringreferat der Bundesnetzagentur
[1] In dieser Abbildung wird die Korrelation zwischen der Einspeisung Erneuerbarer Energien und Redispatchmaßnahmen dargestellt. Es gibt weitere Ursachen für Redispatchentwicklungen, die unter 3.1.1 genannt sind.

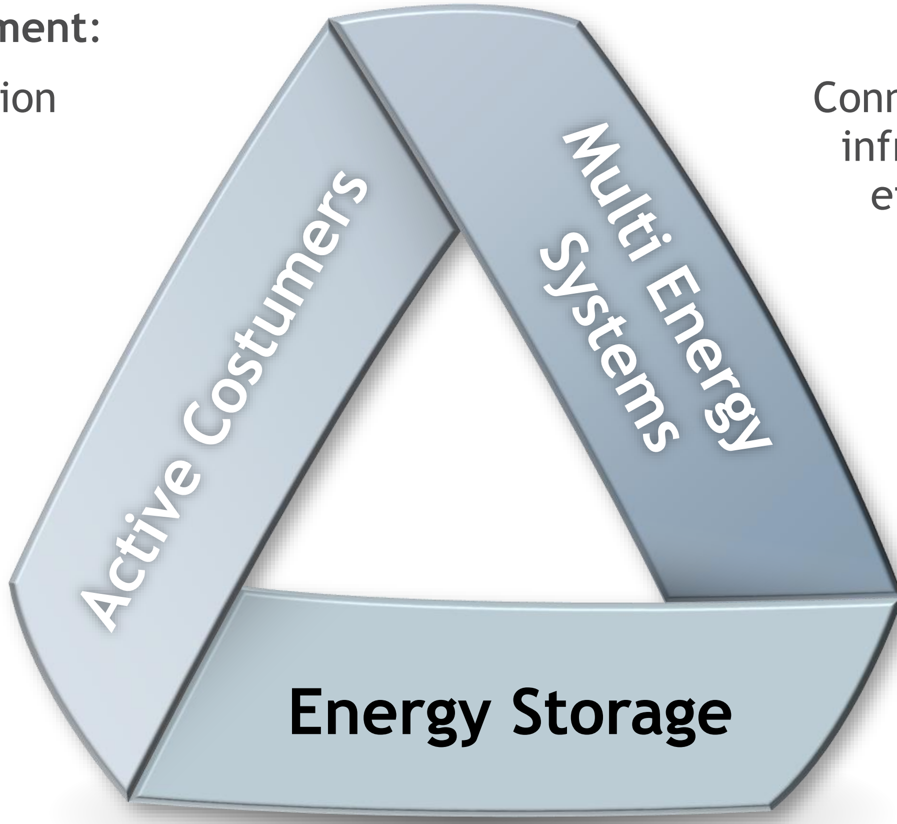
SOLUTION FOR INTEGRATING RES INTO THE ENERGY SYSTEMS: MORE FLEXIBILITY

Demand Side Management:

Align energy consumption with volatile Energy generation

Energy Hubs:

Connect the existing energy infrastructures to increase efficiency, flexibility and synergies

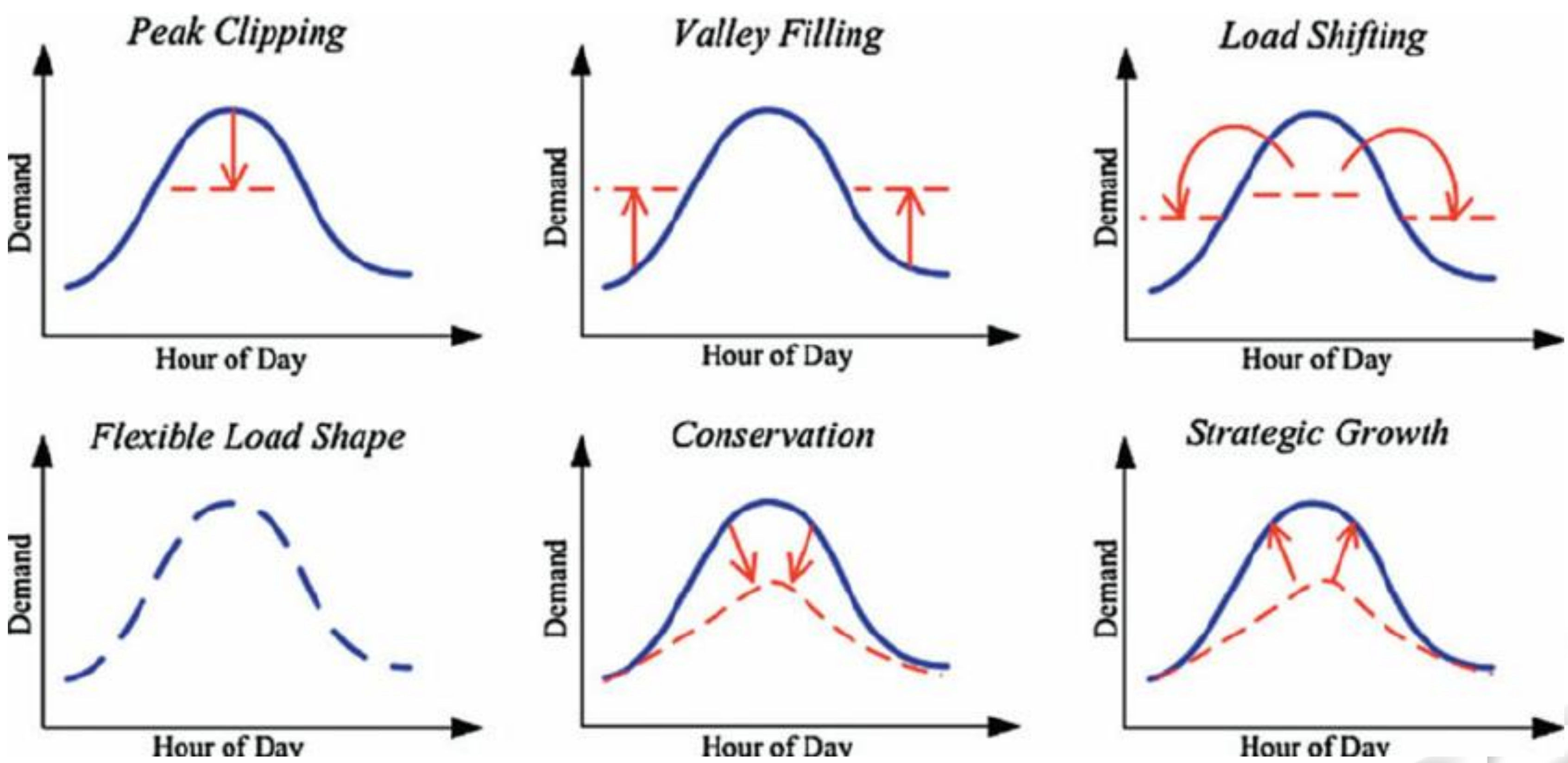


Energy Buffering:

Store surplus energy for times with high demand

SOLUTION I: DEMAND SIDE MANAGMENT

- Limited potential of total energy consumption (approx. 10%)



SOLUTION II: ENERGY STORAGE SYSTEMS

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Technology | **Main Issues**

Pumped Hydro Storage (PHS)

- Geographically limited

Compressed Air Energy Storage (CAES)

- Geographically limited
- Expensive

Batteries

- mature but still expensive
- Limited natural resources
- No capacity for long term storage

Power to Gas

- Expensive
- Low efficiency

Also: Thermal Energy Storage, Flywheels, Capacitors

SOLUTION III: MULTI-ENERGY SYSTEMS

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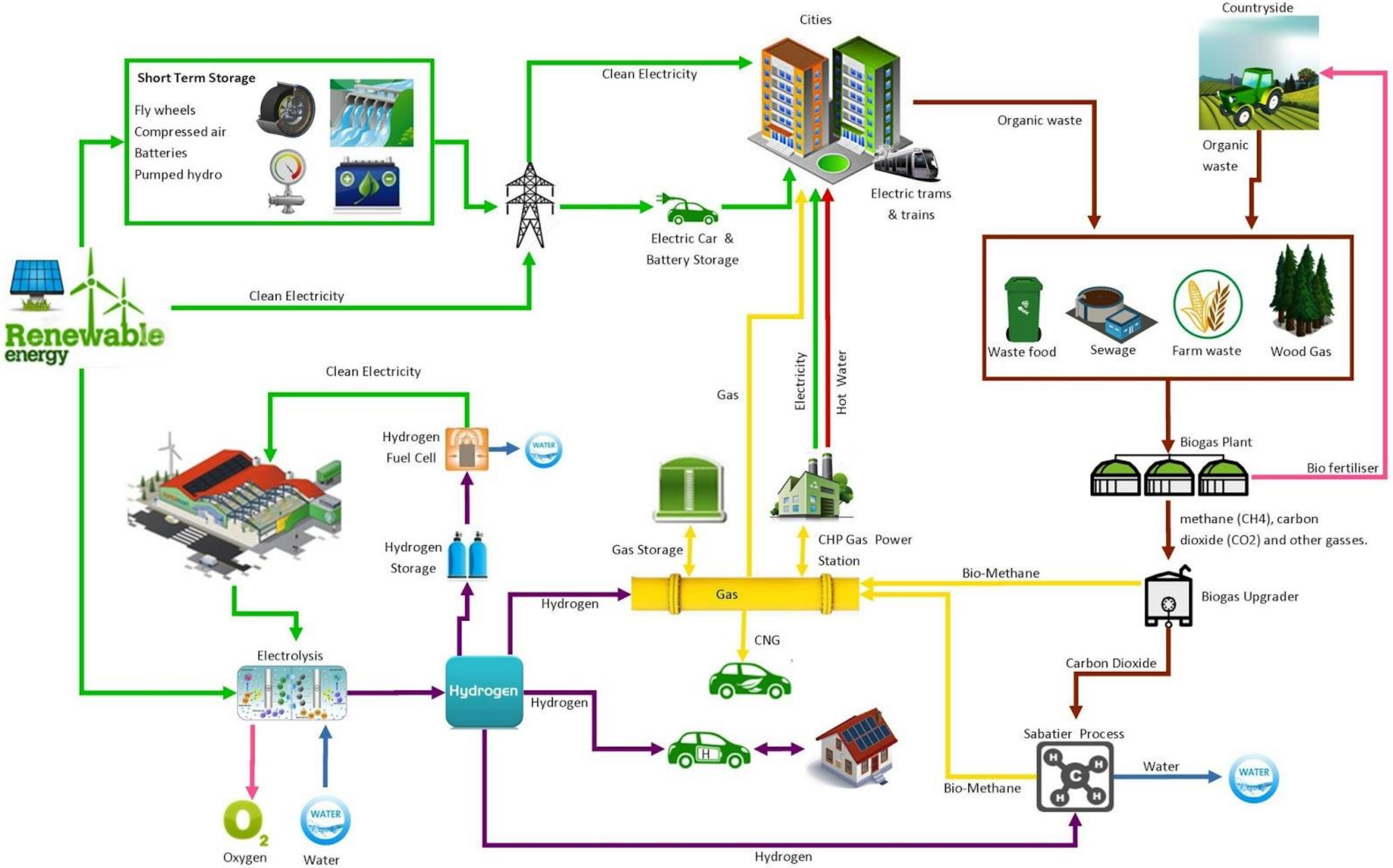
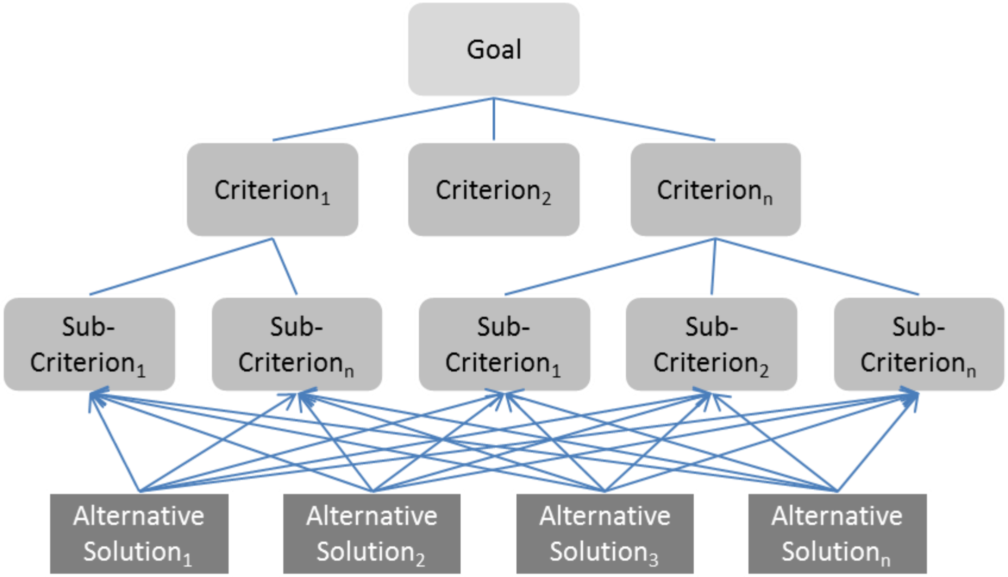


MULTI CRITERIA PLANNING TOOL: ANALYTIC HIERARCHY PROCESS (AHP)

- Multi criteria decision analysis weidely used for planning and upgrading energetic infrastructures
- AHP belongs to the Multi Attribute Decision Making (MADM)
    - Hieararchical structure
    - Aim of the problem is set at the top level, the criteria and the sub criteria are set at the midle levels, the alternative solution are set at the bottom level



MULTI CRITERIA PLANNING TOOL: ANALYTIC HIERARCHY PROCESS (AHP)

- AHP composed of six steps
  1. Set of goal of the problem and criteria to be considered
  2. Organization of the problem in a hierarchical structure
  3. Comparison of all criteria and sub criteria in a pair-wise fashion
  4. Set of a *n x n* reciprocal judgment matrix *A* and evaluation of the largest positive real eigenvalue λ_{max} and the corresponding eigenvector *w*
  5. Consistency check
  6. Evaluation of all the local priority vector (rank of the alternative solutions)

ANALYTIC HIERARCHY PROCESS: SAATY SCALE PAIR WISE COMPARISON

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Intensity	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
2	Weak	
3	Moderate importance	Experience and judgment slightly favour one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgment strongly favour one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
8	Very. very strong	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation

ANALYTIC HIERARCHY PROCESS: JUDMENT MATRIX

$$\begin{bmatrix} 1 & a_{12} & a_{13} & \dots & a_{1n} \\ 1/a_{12} & 1 & a_{23} & \dots & a_{2n} \\ 1/a_{13} & 1/a_{23} & 1 & \dots & a_{3n} \\ \dots & \dots & \dots & \dots & \dots \\ 1/a_{1n} & 1/a_{2n} & 1/a_{3n} & \dots & 1 \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ w_3 \\ \dots \\ w_n \end{bmatrix} = \lambda \begin{bmatrix} w_1 \\ w_2 \\ w_3 \\ \dots \\ w_n \end{bmatrix}$$

Set of a *n x n* reciprocal judgment matrix *A* and evaluation of the largest positive real eigenvaleu λ_{max} and the corresponding eigenvector *w*

$$C_i = \frac{(\lambda_{max} - n)}{(n-1)}$$

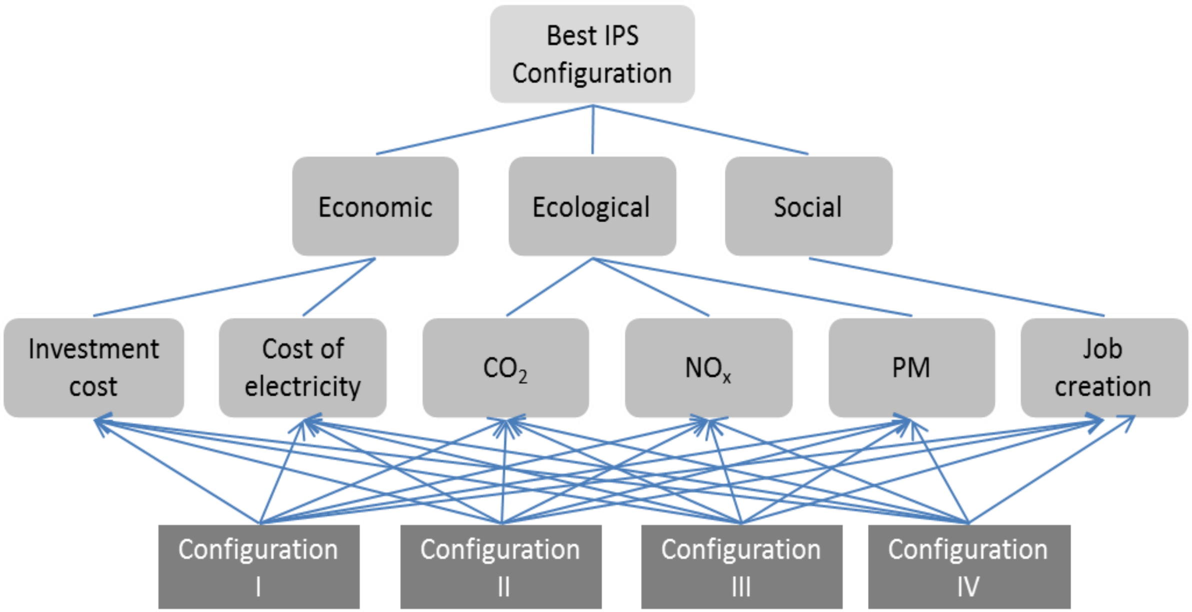
Consistency index

$$C_R = \frac{C_i}{R_i}$$

Consistency Ratio

Matrix size	1	2	3	4	5	6	7	8	9	10
Random index	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

STUDY CASE:
SIBERIAN ISOLATED POWER SYSTEM



	Diesel generator	Photovoltaic plant	Battery	Wind turbine(s)
Configuration I	√			
Configuration II	√	√		
Configuration III	√	√	√	
Configuration IV	√	√	√	√

Source: P. Lombardi, T. Sokolnikova, K. Suslov, N. Voropai, Z. Styczynski, "Isolated Power System in Russia. A chance for renewable energies?" Renewable Energy, 90, 532-541, 2016

STUDY CASE:
SIBERIAN ISOLATED POWER SYSTEM

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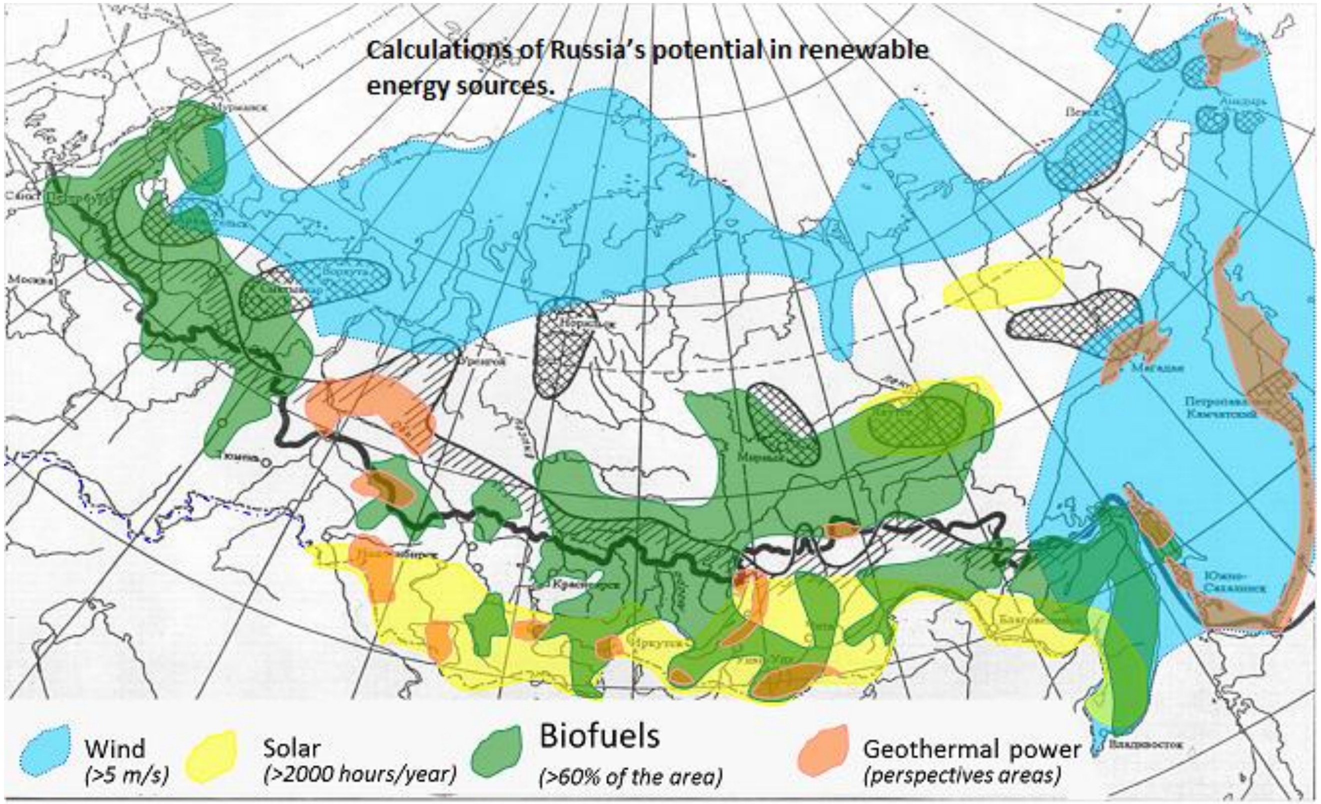

Source: P. Lombardi, T. Sokolnikova, K. Suslov, N. Voropai, Z. Styczynski, "Isolated Power System in Russia. A chance for renewable energies?" Renewable Energy, 90, 532-541, 2016

STUDY CASE:
SIBERIAN ISOLATED POWER SYSTEM

	Diesel generator	Photovoltaic plant	Wind turbine (Enercon E33)	Energy storage system (Battery)	Inverter
Nominal power [kW] - Storage capacity [kWh]	Up to 3200 [kW]	Up to 3200 [kW]	330 [kW] Up to 10 turbines	1000 [kW] 1000 [kWh]	3200 [kW]
Investment costs [€/kW]	700	2500	1515	1630	400
Maintenance & Operation costs	0.1 [€/h]	100 [€/years]	2000 [€/years]	9200 [€/years]	
Lifetime	15000 [h]	20 [years]	15 [years]	15 [years]	
Hub high [m]			25		
Round trip efficiency [%]				80	
Minimal state of charge [%]				20	

Source: P. Lombardi, T. Sokolnikova, K. Suslov, N. Voropai, Z. Styczynski, "Isolated Power System in Russia. A chance for renewable energies?" Renewable Energy, 90, 532-541, 2016

STUDY CASE: SIBERIAN ISOLATED POWER SYSTEM ECONOMICAL ANALYSIS

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Diesel price [€/litre]	Investment cost [k€]				Cost of electricity [€/kWh]			
	Conf. I	Conf. II	Conf. III	Conf. IV	Conf. I	Conf. II	Conf. III	Conf. IV
0.1	2100	3380	3380	3380	0.293	0.302	0.302	0.302
0.2	2100	3380	3380	3380	0.337	0.346	0.346	0.346
0.3	2100	3380	3380	3380	0.38	0.389	0.389	0.389
0.4	2100	3380	3380	3380	0.424	0.433	0.433	0.433
0.5	2100	3380	3380	3380	0.468	0.477	0.477	0.477
0.6	2100	3380	3380	3380	0.512	0.521	0.521	0.521
0.7	2100	3380	13013	13013	0.555	0.564	0.56	0.56
0.8	2100	3380	13013	13013	0.599	0.608	0.594	0.594
0.9	2100	3380	13013	18013	0.643	0.652	0.627	0.625
1.0	2100	3380	13013	18013	0.687	0.696	0.661	0.655
1.1	2100	4880	13013	18013	0.73	0.738	0.695	0.684
1.2	2100	4880	13013	18013	0.774	0.781	0.729	0.714
1.3	2100	4880	13013	18013	0.818	0.823	0.762	0.743
1.4	2100	4880	13013	18013	0.862	0.865	0.796	0.773
1.5	2100	4880	13013	18013	0.906	0.907	0.83	0.802
1.6	2100	4880	13013	18013	0.949	0.949	0.864	0.83
1.7	2100	4880	13013	18013	0.993	0.992	0.897	0.859
1.8	2100	4880	13013	18013	1.037	1.034	0.931	0.888
1.9	2100	4880	13013	18013	1.081	1.076	0.965	0.917
2.0	2100	4880	13013	18013	1.124	1.118	0.998	0.946

Source: P. Lombardi, T. Sokolnikova, K. Suslov, N. Voropai, Z. Styczynski, “Isolated Power System in Russia. A chance for renewable energies?” Renewable Energy, 90, 532-541, 2016

STUDY CASE: SIBERIAN ISOLATED POWER SYSTEM ECOLOGICAL AND SOCIAL ANALYSIS

	Configuration I	Configuration II	Configuration III	Configuration IV
CO_2 [tons/yr]	12914	12460	9959	8697
NO_x [tons/yr]	284	274	219	191
PM [tons/yr]	2.43	2.31	1.85	1.618

Social aspect:

For each MW of installed PV or Wind Turbine operating as isolated power system in rudal area, 30 and 22 new jobs are created (source: IRENA)

Source: P. Lombardi, T. Sokolnikova, K. Suslov, N. Voropai, Z. Styczynski, "Isolated Power System in Russia. A chance for renewable energies?" Renewable Energy, 90, 532-541, 2016

STUDY CASE:
SIBERIAN ISOLATED POWER SYSTEM
MATRIX OF JUDGMENT

$$\begin{bmatrix} 1 & a_{12} & a_{13} & \dots & a_{1n} \\ 1/a_{12} & 1 & a_{23} & \dots & a_{2n} \\ 1/a_{13} & 1/a_{23} & 1 & \dots & a_{3n} \\ \dots & \dots & \dots & \dots & \dots \\ 1/a_{1n} & 1/a_{2n} & 1/a_{3n} & \dots & 1 \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ w_3 \\ \dots \\ w_n \end{bmatrix} = \lambda \begin{bmatrix} w_1 \\ w_2 \\ w_3 \\ \dots \\ w_n \end{bmatrix}$$

	IC	COE	CO_2	NO_x	PM	JC
IC	1	1/3	5	9	4	1
COE	3	1	3	9	3	1
CO_2	1/5	1/3	1	9	3	1/5
NO_x	1/9	1/9	1/9	1	1/3	1/9
PM	1/4	1/3	1/3	3	1	1/9
JC	1	1	5	9	9	1
$\lambda_{max} = 6.597$;CR=0.092						

STUDY CASE: SIBERIAN ISOLATED POWER SYSTEM PAIR WISE COMPARISON

PAIR WISE COMPARISON OF THE IPS CONFIGURATION TO THE INVESTMENT COST SUB CRITERION

	Conf. I	Conf. II	Conf. III	Conf. IV	**Priority Vector**
Conf. I		3	5	9	**0.583**
Conf. II	1/3		5	7	**0.29**
Conf. III	1/5	1/5		3	**0.085**
Conf. IV	1/9	1/7	1/3		**0.042**
λ_{max} = 4.165;CR=0.06					

PAIR WISE COMPARISON OF THE IPS CONFIGURATION TO THE COST OF ELECTRICITY SUB CRITERION

	Conf. I	Conf. II	Conf. III	Conf. IV	**Priority Vector**
Conf. I		3	1/5	1/8	**0.0914**
Conf. II	1/3		1/3	1/8	**0.0579**
Conf. III	5	3		1/3	**0.2535**
Conf. IV	8	8	3		**0.5972**
λ_{max} = 4.273;CR=0.1					

PAIR WISE COMPARISON OF THE IPS CONFIGURATION TO CO_2 SUB CRITERION

	Conf. I	Conf. II	Conf. III	Conf. IV	**Priority Vector**
Conf. I		1/3	1/5	1/8	**0.0503**
Conf. II	3		1/3	1/8	**0.0984**
Conf. III	5	3		1/3	**0.2401**
Conf. IV	8	8	3		**0.6112**
λ_{max} = 4.125;CR=0.046					

PAIR WISE COMPARISON OF THE IPS CONFIGURATION TO NO_2 SUB CRITERION

	Conf. I	Conf. II	Conf. III	Conf. IV	**Priority Vector**
Conf. I		1/3	1/5	1/8	**0.0503**
Conf. II	3		1/3	1/8	**0.0984**
Conf. III	5	3		1/3	**0.2401**
Conf. IV	8	8	3		**0.6112**
λ_{max} = 4.125;CR=0.046					

PAIR WISE COMPARISON OF THE IPS CONFIGURATION TO PM SUB CRITERION

	Conf. I	Conf. II	Conf. III	Conf. IV	**Priority Vector**
Conf. I		1/3	1/5	1/8	**0.0503**
Conf. II	3		1/3	1/8	**0.0984**
Conf. III	5	3		1/3	**0.2401**
Conf. IV	8	8	3		**0.6112**
λ_{max} = 4.125;CR=0.046					

PAIR WISE COMPARISON OF THE IPS CONFIGURATION TO JOB CREATION SUB CRITERION

	Conf. I	Conf. II	Conf. III	Conf. IV	**Priority Vector**
Conf. I		1/3	1/5	1/8	**0.0491**
Conf. II	3		1/3	1/8	**0.0778**
Conf. III	5	3		1/3	**0.2175**
Conf. IV	8	8	3		**0.6556**
λ_{max} = 4.163;CR=0.06					

Source: P. Lombardi, T. Sokolnikova, K. Suslov, N. Voropai, Z. Styczynski, "Isolated Power System in Russia. A chance for renewable energies?" Renewable Energy, 90, 532-541, 2016

STUDY CASE: SIBERIAN ISOLATED POWER SYSTEM RESULT

$$\begin{bmatrix} 0.583 & 0.0914 & 0.0503 & 0.0503 & 0.0503 & 0.0491 \\ 0.29 & 0.0579 & 0.0984 & 0.0984 & 0.0984 & 0.0778 \\ 0.085 & 0.2535 & 0.2401 & 0.2401 & 0.2401 & 0.2175 \\ 0.042 & 0.5972 & 0.6112 & 0.6112 & 0.6112 & 0.6556 \end{bmatrix} \begin{bmatrix} 0.2321 \\ 0.2946 \\ 0.0992 \\ 0.0215 \\ 0.0515 \\ 0.3011 \end{bmatrix} = \begin{bmatrix} 0.1752 \\ 0.1247 \\ 0.2012 \\ 0.4883 \end{bmatrix} \begin{matrix} \text{Configuration I} \\ \text{Configuration II} \\ \text{Configuration III} \\ \text{Configuration IV} \end{matrix}$$

	Diesel generator	Photovoltaic plant	Battery	Wind turbine(s)
Configuration I	√			
Configuration II	√	√		
Configuration III	√	√	√	
Configuration IV	√	√	√	√

Source: P. Lombardi, T. Sokolnikova, K. Suslov, N. Voropai, Z. Styczynski, “Isolated Power System in Russia. A chance for renewable energies?” Renewable Energy, 90, 532-541, 2016

THANK YOU FOR YOUR ATTENTION