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Vulnerability of renewable energy sources to climate change

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The Abdus Salam
International Centre for Theoretical Physics

Workshop on Vulnerability of Energy Systems to Climate Change and Extreme Events

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VULNERABILITY OF RENEWABLE ENERGY PRODUCTION TO CLIMATE CHANGE

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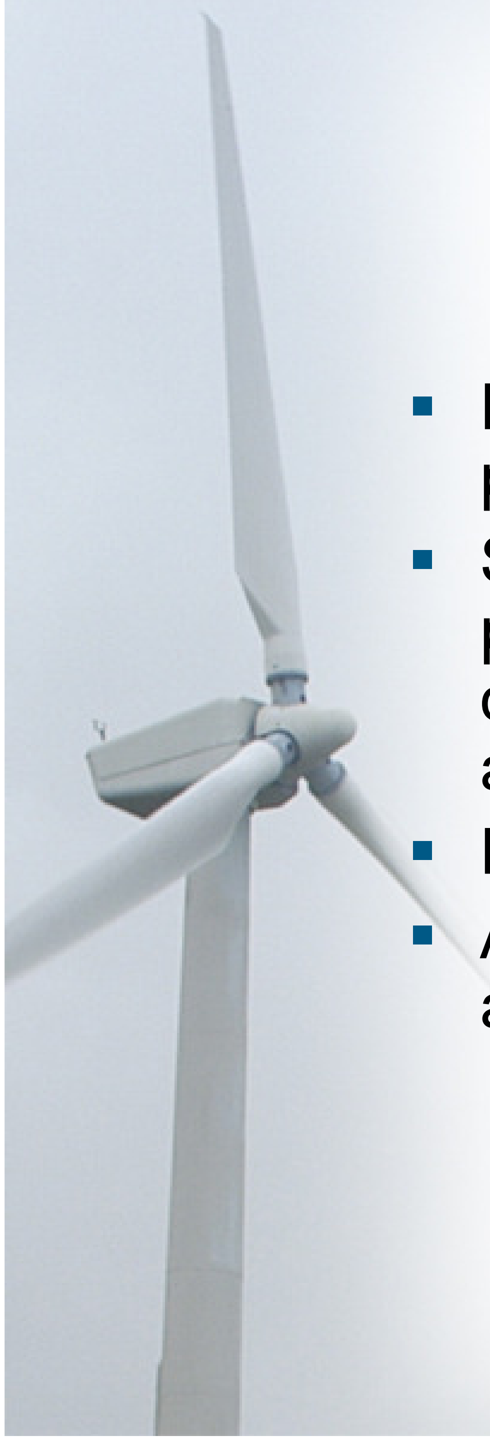
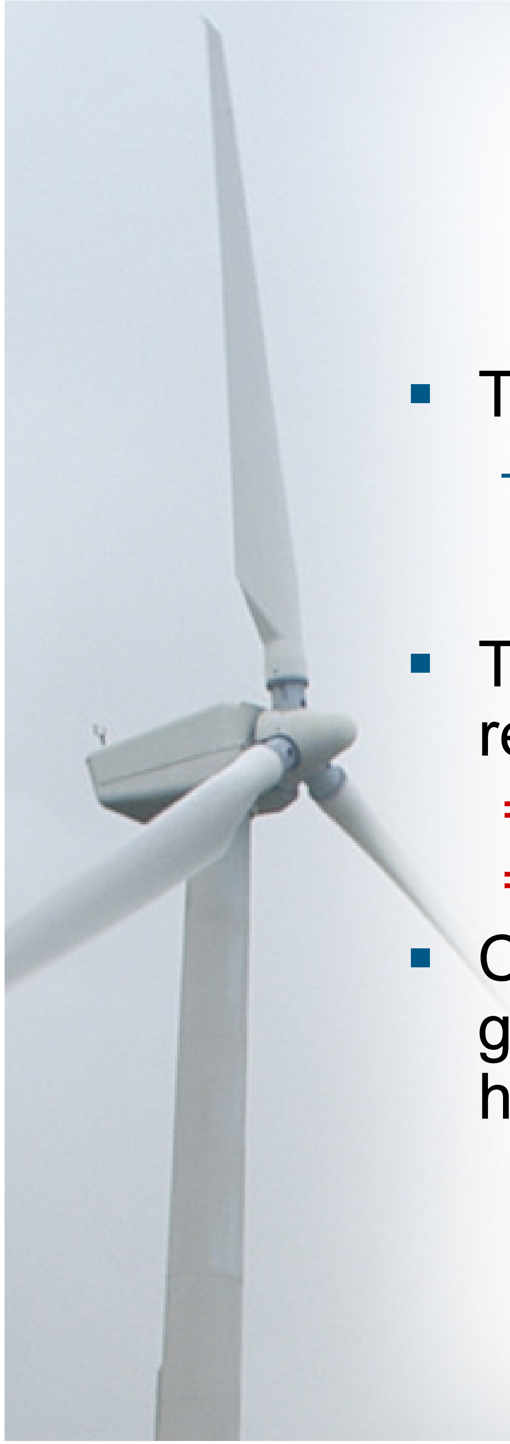
1. INTRODUCTION

- Most of renewable energy sources (RES) are potentially vulnerable to climate changes
- The energy production and efficiency of most of RES are constrained by environmental conditions
- Increasing renewable energy production
  - reducing greenhouse gas emissions from energy sector
  - mitigating the impacts of potential climate change
- Solar energy is vulnerable to variations in cloud cover and atmospheric turbidity



1. INTRODUCTION

- Hydroelectric power - vulnerable to weather patterns and local hydrology
- Sensitive to the quantity, timing, and spatial pattern of precipitation as well as the influence of temperature on evaporation and the accumulation
- Hydropower operations - affected indirectly
- Air temperatures, humidity, or wind patterns are affected by climate changes
  => changes in reservoir dynamics and water quality



1. INTRODUCTION

- The hydrologic vulnerabilities to climate are:
  - extreme events, particularly drought and flood, seasonal variability of flow, and seasonal changes in demand (load pattern and peak flood)
- The unpredictable high water levels when reservoirs are full can cause flooding

  => economic loss

  => safety issues are needed
- Changes in flow regimes and hydrology are of great importance to determine the variations in hydro power generation

1. INTRODUCTION

- Wind power generation - susceptible to variations in atmospheric pressure, ambient temperatures, humidity, air density and wind velocity
- The cubic relationship between available wind power and wind speed
- change in wind speed => change in the wind turbine power output
- wind power production depend on wind direction
- wind direction impact on wake interactions between individual turbines in an array

1. INTRODUCTION

- Air density - another factor that affect on wind power
- As density is inversely proportional to temperature, power levels will vary with temperature
- Temperature and rainfall are important determinants of blade fouling which reduce aerodynamic efficiency although the extent of icing appears to be less significant in a warmer climate
- So, the changes in wind speed are the most important in examining climate impacts

1. INTRODUCTION

- Need for more accurate models for climate change predictions and changes in meteorological variables
- To assess the impact of a new climate condition on the electricity generation from RES power plant (WPP, SHPP) it is necessary
  1. first to project how it would affect the incoming flow/wind speed at each power plant
  2. the projected water flow/wind speed series are used to calculate the impacts on energy generation

1. INTRODUCTION

- Changes in production levels - affect on the earned revenue, particularly when changes concur with high price periods
- If the effects of climate change are such as reduced wind speeds or reduced river flows

  ⇒reduction of financial benefits

  ⇒making hydro power and wind power less competitive
- Additional resource uncertainty that stems from potential climate change might appear to increase the potential risk for investors

2. *HYDRO ENERGY POTENTIAL IN MACEDONIA*

- Hydro potential of Macedonia is mainly dominated as the renewable resource
- The existing HPPs in Macedonia - cover 10% to 20% of the whole demand, depending on hydrology - around 1400 GWh (yearly production)
- The rest of the demand is covered with lignite fired TPP (Bitola and Oslomej) - yearly production of around 5000 GWh.
- The main HPPs in Macedonia - storage PP with reservoir and operate in flexible mode covering the peaks of the load in Macedonian Power System
- small HPP - fill about 5% of the whole hydro energy

2. *HYDRO ENERGY POTENTIAL IN MACEDONIA*

Tab. 2.1.The planned HPP in Macedonia

	River basin	**$P_{inst.}$ (MW)**	**W_{year} (GWh)**	**Year of Commissioning**
				Year
Sveta Petka	r. Treska	36	60	2011
Boskov Most	r. Radika	68.2	134	2014
Luk. Pole + HPP Crn Kamen**	Mavrovo	8	140	2014
Galiste*	r. Crna	193.5	264	2016-2020
Cebren*	r. Crna	333	340	2016-2020
Gredec	r. Vardar	54.6	252	2020-2025
Veles	r. Vardar	93	300	2025-2030
10 HPP Vardar Valley	r. Vardar	176.8	784	2030
Small HPP		72.5	200	2010-2020
TOTAL		**1035.6**	**2474**	

** Cebren and Galiste can operate as the reversible HPP in pumping and generating mode.*

*** Crn Kamen is additional HPP between storage Lukovo pole and HPP Vrben*

2. HYDRO ENERGY POTENTIAL IN MACEDONIA

Installed power and yearly generation for the existing and planned HPP

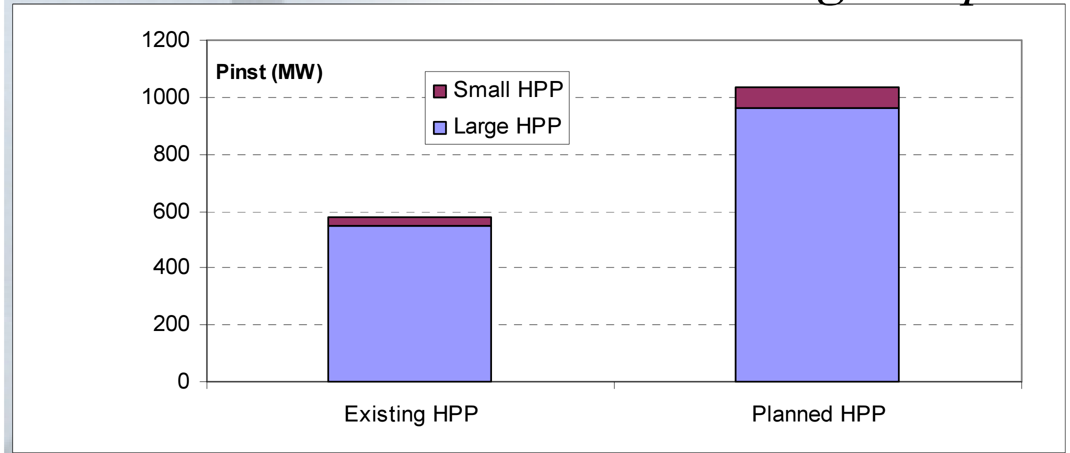
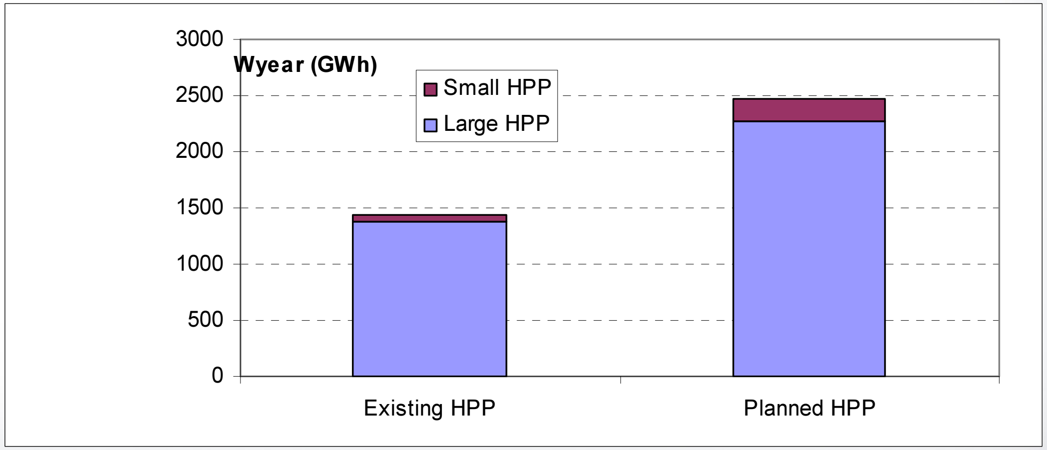


Fig. 2.1.

Fig. 2.2.



2. HYDRO ENERGY POTENTIAL IN MACEDONIA

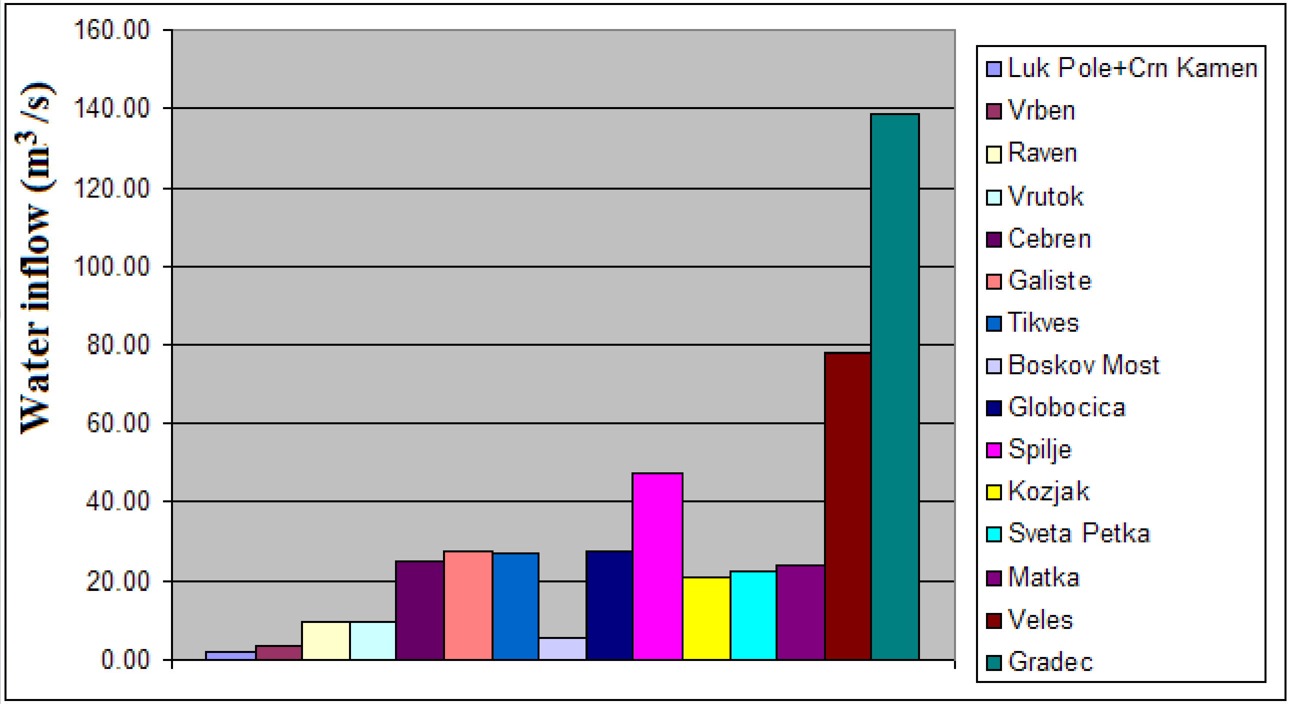


Fig. 2.3. The water inflow for average hydrology for planned and existing HPP

2. *HYDRO ENERGY POTENTIAL IN MACEDONIA*

If the water inflow change to the following

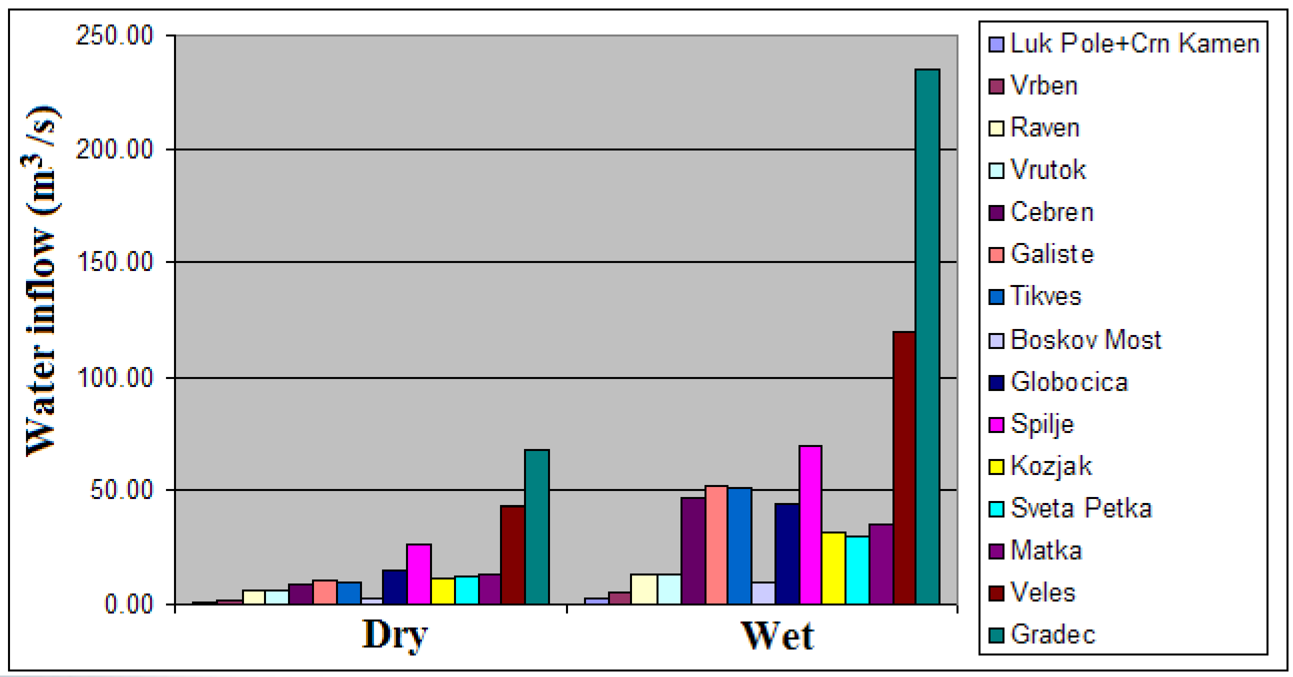


Fig. 2.4. The water inflow for dry and wet hydrology for planned and existing HPP

Tab. 2.2.Electricity generation for dry, average and wet hydrology of planned and existing HPP

	W year (GWh)		
HPP	**Dry**	**Ave**	**Wet**
Lukovo Pole + Crn Kamen	74.34	120.00	175.58
Vrben	26.73	46.29	65.41
Raven	28.15	45.12	61.44
Vrutok	255.13	408.97	556.88
Cebren	112.04	311.35	583.04
Galiste	101.41	272.72	507.61
Tikves	64.89	185.78	354.61
Boskov Most	80.20	151.44	280.97
Globocica	108.57	201.10	316.70
Spilje	176.56	319.24	470.00
Kozjak	85.17	163.17	244.51
Sveta Petka	34.05	62.09	82.05
Matka	22.55	40.58	59.82
Veles	175.60	318.93	491.72
Gradec	124.63	254.35	432.53
Total Large HPP	**1470.02**	**2901.14**	**4682.86**
Existing Small HPP	35	70	105
Planned Small HPP	100	200	300
Vardar Valley HPP	400	700	1150
TOTAL	**2005.02**	**3871.14**	**6237.86**

2. HYDRO ENERGY POTENTIAL IN MACEDONIA

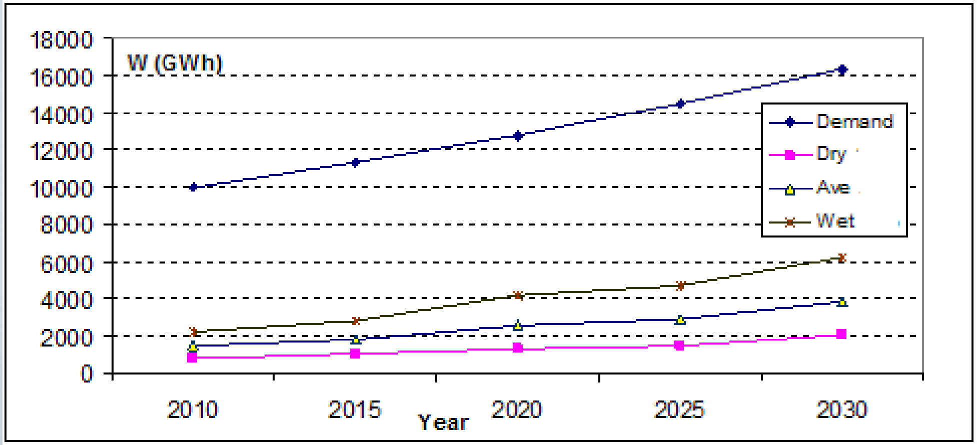
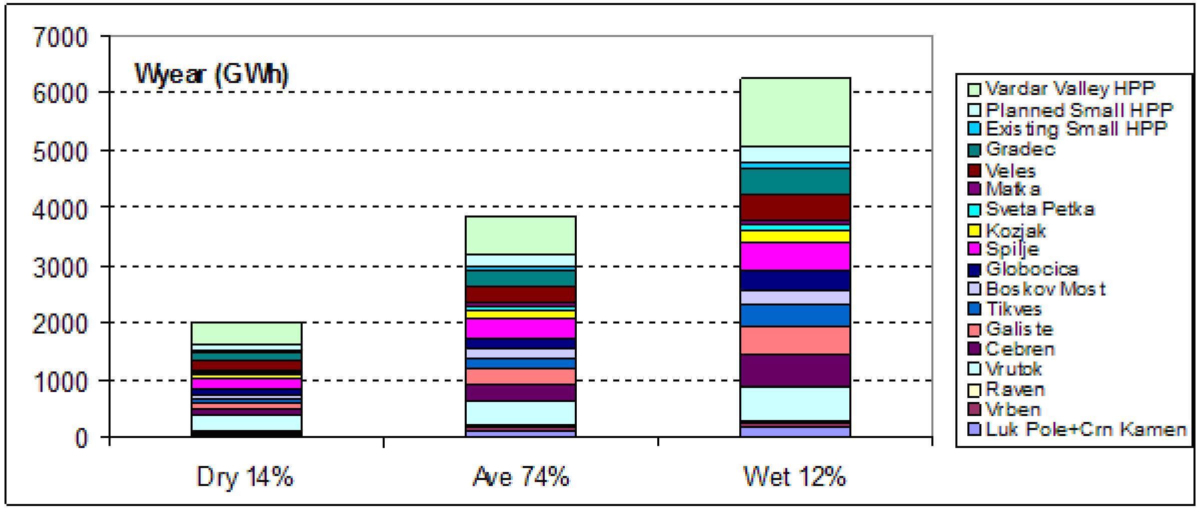


Fig. 2.5. Contribution of HPP generation in the covering electricity demand in Macedonia

Fig.2.6.Annual generation from each HPP (existing and planned) for each hydrology



3. HYBRID SYSTEM

3.1. SYSTEM DESCRIPTION

- off-grid hybrid energy system
- project lifetime - 25 years
- annual interest rate - 6%.
- dispatch strategy - a cycle charging of a battery bank. Also, system with multiple generators, multiple generators to operate simultaneously, system with generator capacity less than peak load are allowed.

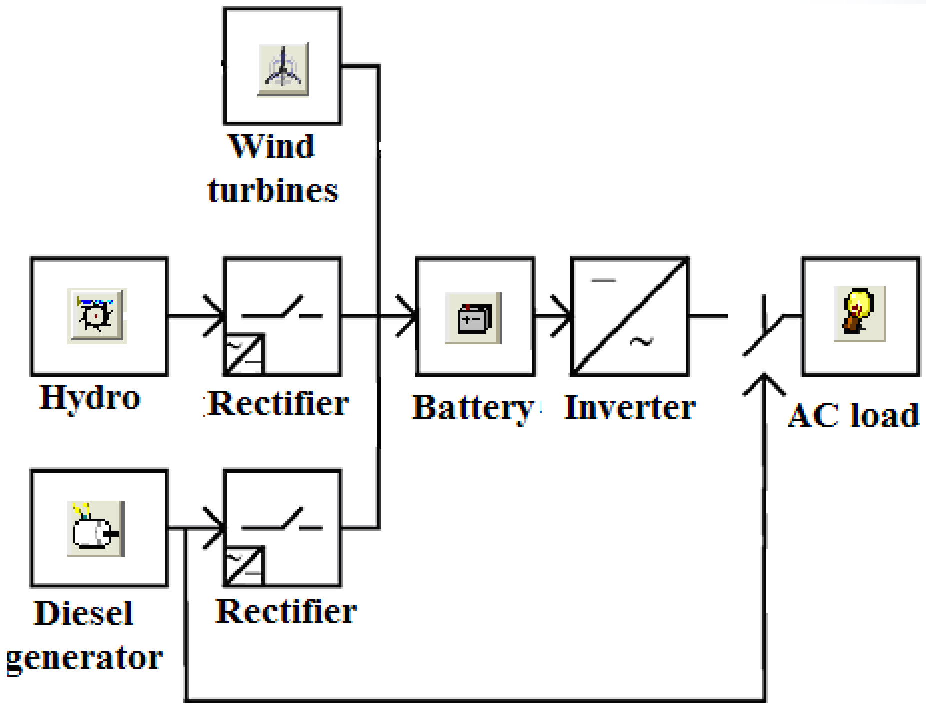


Fig. 3.1. Renewable energy hybrid system

3. HYBRID SYSTEM

3.1. SYSTEM DESCRIPTION

- The basic stand-alone hybrid system: 3 WT of 10 kW, 1 SHPP with nominal power of 39,7 kW, 1 DG of 70 kW, 10 batteries and 10 kW converter.

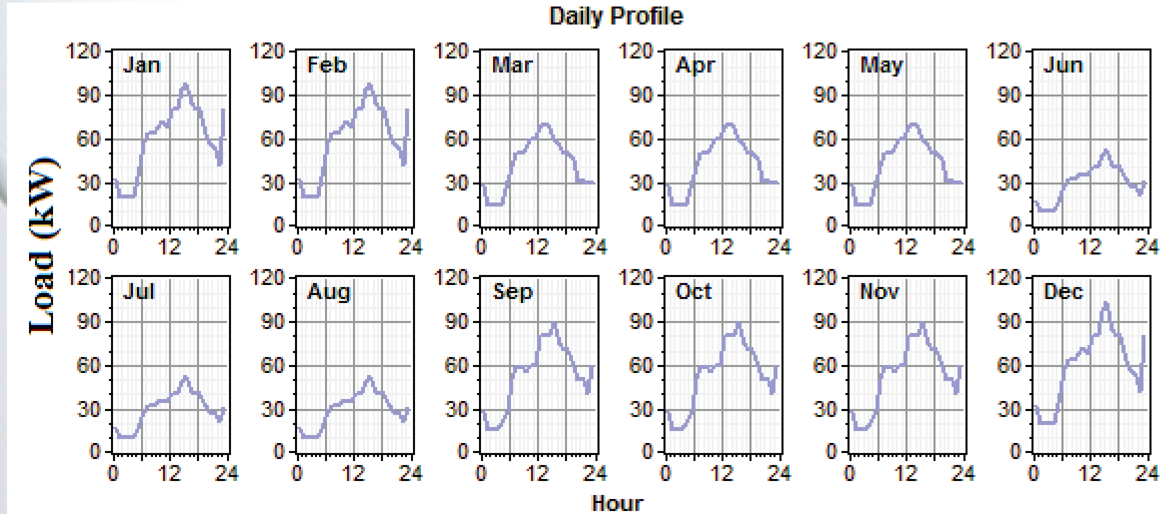


Fig. 3.2. Average daily load profile in each month of the remote rural area

3.1.1. Component characteristics

Wind turbines

- Type of wind turbine - Generic 10kW.
- Connected to DC bus
- Lifetime of the WT - 20 years.

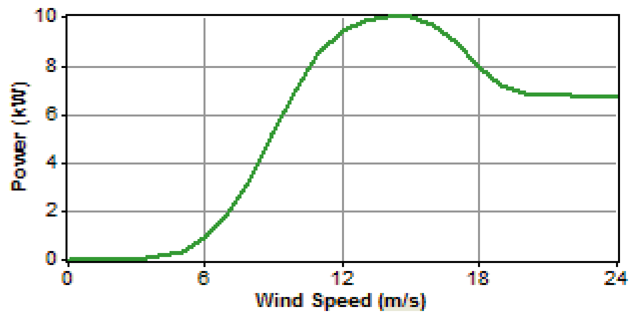


Fig. 3.3. Power curve of WT type Generic 10kW

Table 3.1. Cost data for wind turbines

Quantity	C_C (\$)	C_R (\$)	$C_{O\&M}$ (\$/yr)
1	14000	11750	280

3.1.1. Component characteristics

Small hydro power plant

- run-of-river HPP
- nominal power - 39,7 kW.
- design flow rate - 50 L/s
- available head of the plant - 100 m.
- lifetime - 30 years.
- efficiency of the hydro system - 81%.

Table 3.2. Cost data for small hydro power plant

Size (kW)	C_C ($)	C_R ($)	$C_{O\&M}$ ($/yr)
39,7	99250	54600	1985

3.1.1. Component characteristics

Diesel generator

- lifetime of DG - 12000 operating hours.
- price of the fuel is chosen to be 1,3$/L.

Table 3.3. Cost data for diesel generator

Size (kW)	C_C (\$)	C_R (\$)	$C_{O\&M}$ (\$/h)
1	500	430	0,01

3.1.2. Data for availability of energy resources

Wind resource

- The annual average wind speed is 9,693 m/s.

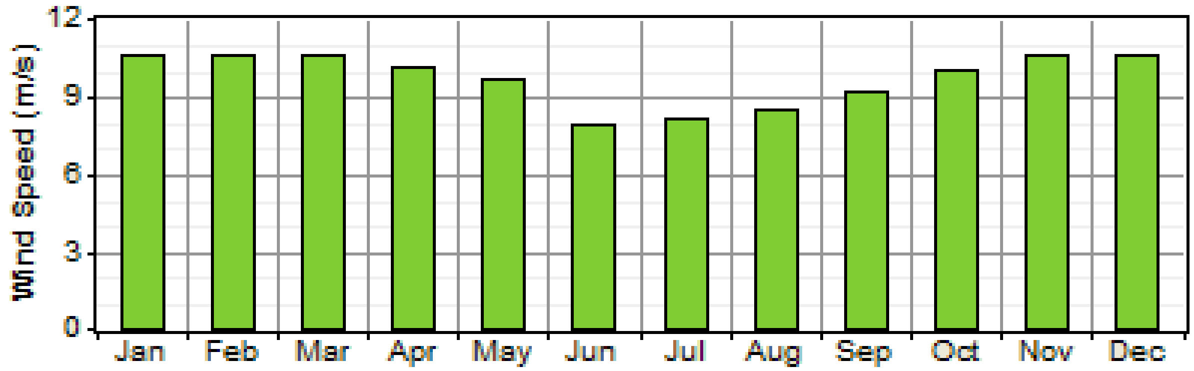
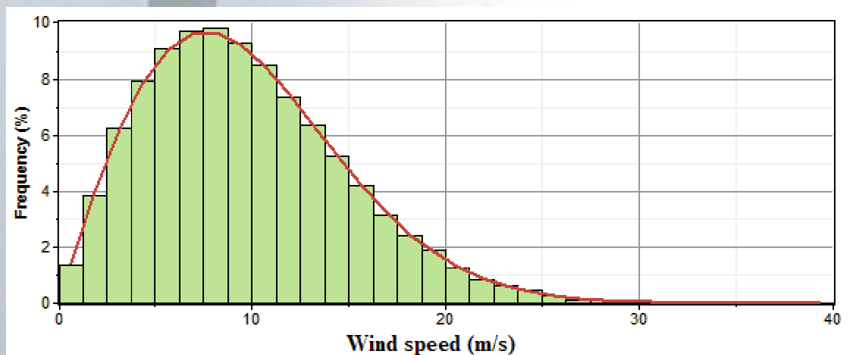


Fig. 3.4. Monthly average wind speeds throughout one year



Weibull distribution for location with $k = 1{,}96$ $c = 10{,}94\,\text{m/s}$

3.1.2. Data for availability of energy resources

Hydro resource

- The annual average stream flow is 55,8 L/s.

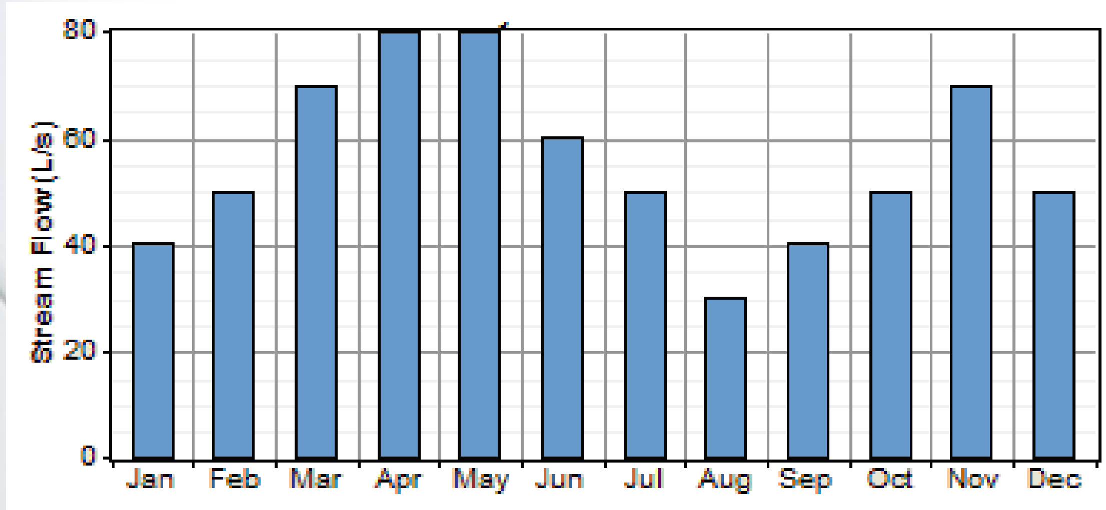


Fig. 3.6. Monthly average stream flow throughout one year

3.2. Results and Discussions

Wind speed change

How wind speed change affects on the wind power generation?

Wind generation system - 3 WTs, each of 10 kW.

Basic scenario

- Weibull distribution - shown on Fig. 5,
- annual average wind speed - 9,693 m/s,
  - WT power generation - 133 867 kWh/yr
  - WTs participate with 23% in the total energy production.
  - Mean output of WTs - 15,3 kW,
  - Capacity factor - 50,9 %.
  - Wind penetration - 33,2 %.
  - Estimated levelized cost of wind energy - 0,0336 $/kWh.

3.2. Results and Discussions

Wind speed change

Basic scenario

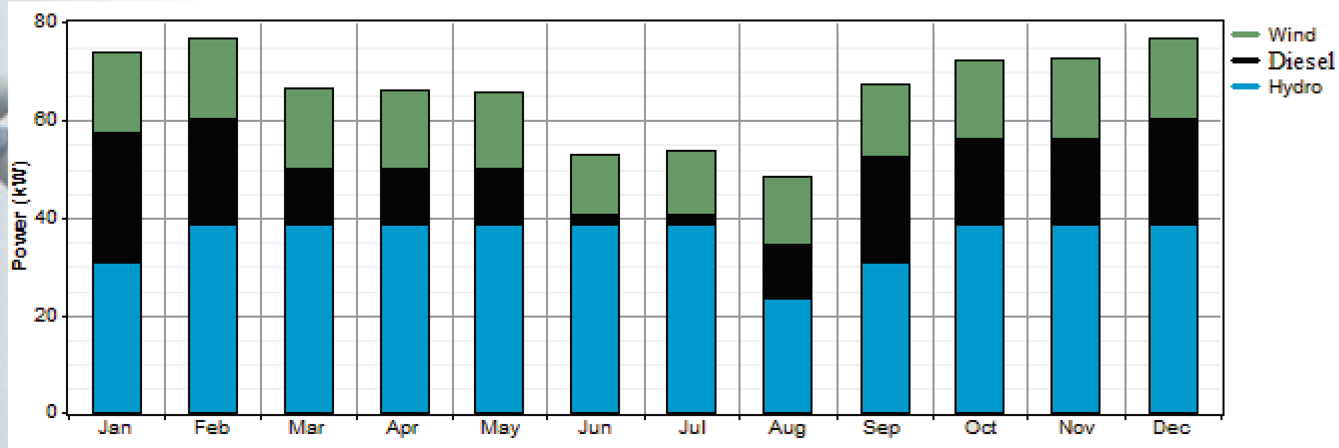


Fig. 3.7. Monthly average electric production

3.2. Results and Discussions

Wind speed change

Simulation of the system with higher and lower wind speeds for 20% of the basic scenario.

Table 3.6. Simulation results for wind power system

Annual average wind speed	11,636 m/s	7,758 m/s
Total production	145 812 kWh/yr	105 632 kWh/yr
Mean output	16,6 kW	12,1 kW
Capacity factor	55,5 %	40,2 %
Wind penetration	36,1 %	26,2 %
Levelized cost	0,0309 $/kWh	0,0426 $/kWh

+8,92%

-21,09%

-8,04%

+26,8%

3.2. Results and Discussions

Stream flow change

How stream flow change affects on the hydro power generation?

Hydro generation system - one run-of-river HPP
with nominal capacity of 39,7 kW.

Basic scenario

- Monthly average stream flow throughout one year - shown on Fig. 6
- annual average stream flow - 55,83 L/s ,
  - HPP generation - 316 054 kWh/yr
  - Mean output of HPP - 36,1 kW,
  - Capacity factor - 90,8 %.
  - Hydro penetration - 78,4 %.
  - Estimated levelized cost of hydro energy - 0,0303 $/kWh.

3.2. Results and Discussions

Stream flow change

Simulation of the system with higher and lower stream flows for 50% of the basic scenario

Table 3.7. Simulation results for hydro power system

Annual average stream flow	83,75 L/s	27,915 L/s
Total production	336 048 kWh/yr	189 231 kWh/yr
Mean output	38,4 kW	21,6 kW
Capacity factor	96,6 %	54,4 %
Hydro penetration	83,3 %	46,9 %
Levelized cost	0,0285 $/kWh	0,0506 $/kWh

3.2. Results and Discussions

Stream flow change

When the annual average stream flow is 27,915 L/s

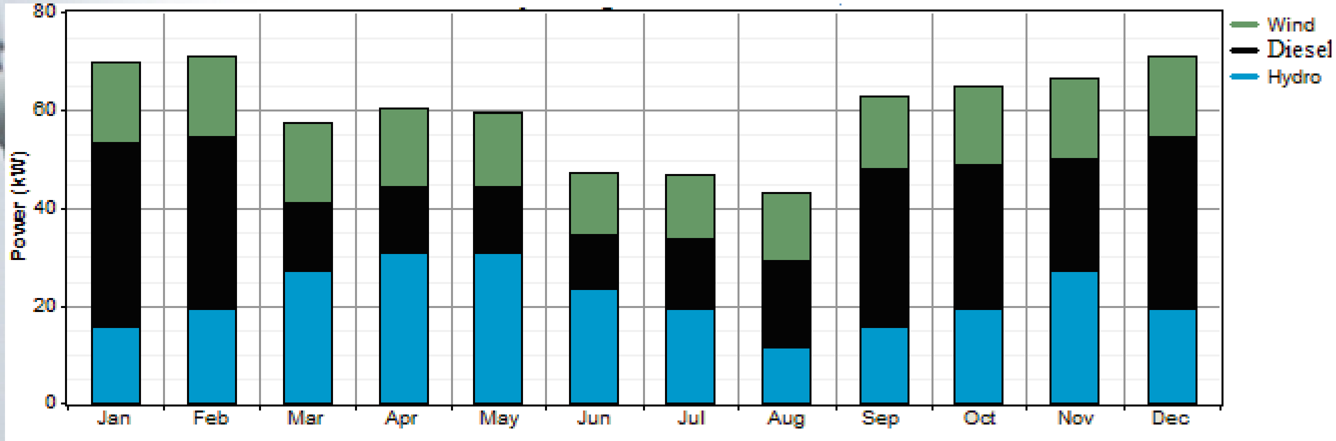


Fig. 3.8. Monthly average electric production

3.2. Results and Discussions

Different system configurations and designs

- different number of WTs of 10kW (0, 2, 3, 6),
- different sizes of DG (0, 50 kW, 70 kW, 90 kW) and
- system with or without hydro system.

❑Emissions inputs

Penalties for

CO_2 - 100$/t

SO_2 - 2000 $/t

NO_x - 4000 $/t

3.2. Results and Discussions

Different system configurations and designs

- Emissions factors
  - Carbon monoxide(CO) – (6.5 g/L of fuel)
  - Unburned hydrocarbons – (0.72 g/L of fuel)
  - Particulate matter – (0.49 g/L of fuel)
  - Nitrogen oxides (NOx) – (58 g/L of fuel)
  - Proportion of fuel sulfur converted to PM (%) - 2.2%

3.2. Results and Discussions

Different system configurations and designs

Results -16 feasible solutions.

- The total net present costs for the system over the project life increases as the number of WTs and DG size increase.

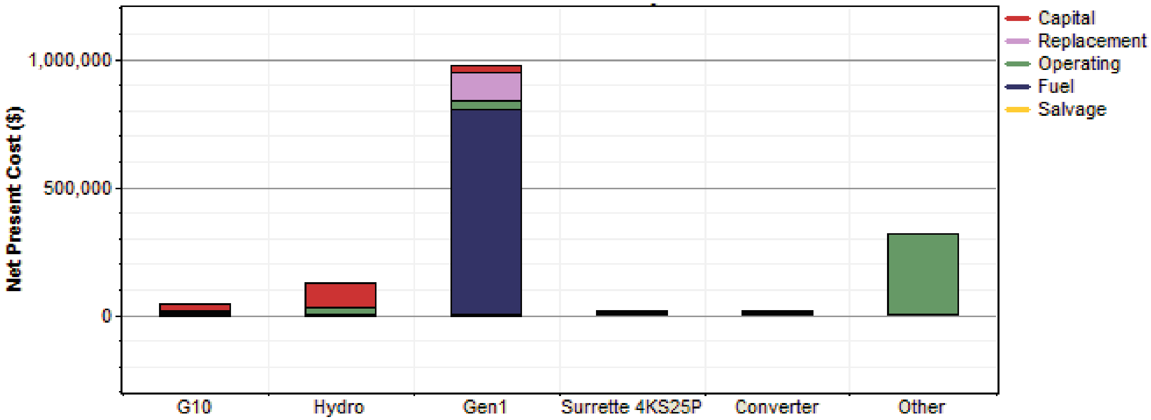
Categorized

G10	Hydro (kW)	Gen1 (kW)	S4KS25P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)
2	39.7	50	10	10	$ 171,750	102,014	$ 1,475,831	0.287	0.78	48,490
	39.7	50	10	10	$ 143,750	115,136	$ 1,615,568	0.314	0.69	56,032
2		90	10	10	$ 92,500	321,022	$ 4,196,236	0.814	0.19	157,306
		90	10	10	$ 64,500	341,107	$ 4,424,995	0.858	0.00	168,900

3.2. Results and Discussions

cost-effective system configuration

Fig.3.9. Net present costs by component



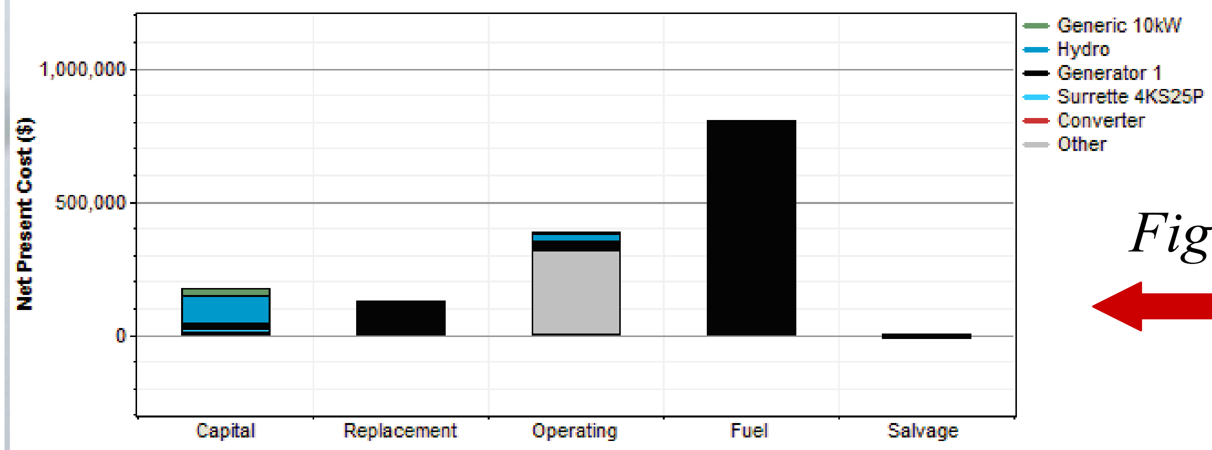


Fig. 3.10. Net present costs by cost type

3.2. Results and Discussions

cost-effective system configuration

Table 3.8. Amount of each pollutant emission

Pollutant	Emissions (kg/yr)
Carbon dioxide	127 690
Carbon monoxide	315
Unburned hydrocarbons	34,9
Particulate matter	23,8
Sulfur dioxide	256
Nitrogen oxides	2 812

3.2. Results and Discussions

Sensitivity analysis

Objective – how resource availability affect on the cost-effectiveness and emissions of the system

- annual average wind speed (9,693 m/s, 7,758 m/s and 11,636 m/s) and annual average stream flow (55,8 L/s, 83,75 L/s and 27,915 L/s)
- previous mentioned emission penalties are included in this analysis

Results -9 optimization results.

3.2. Results and Discussions

Sensitivity analysis

Wind speed (m/s)	Stream flow (L/s)	Emission cost ($)	TNPC ($)	LCOE ($/kWh)	Renewable fraction
9,693	55,8	387 317	1 820 660	0,353	0,78
9,693	83,75	351 869	1 677 668	0,325	0,80
9,693	27,915	557 756	2 488 726	0,483	0,62
11,636	55,8	386 338	1 816 026	0,352	0,78
11,636	83,75	350 986	1 673 598	0,325	0,81
11,636	27,915	558 395	2 491 655	0,483	0,62
7,758	55,8	392 350	1 840 393	0,357	0,76
7,758	83,75	355 283	1 690 853	0,328	0,79
7,758	27,915	566 571	2 522 013	0,489	0,59

4. CONCLUSION

- Renewable energy depends directly on ambient natural resources such as wind patterns and intensity, hydrological resources, and solar radiation.
- RES are more sensitive to climate variability than fossil or nuclear energy systems that rely on geological stores.
- RES are connected with climate change in very complex ways:
    - their use can affect the magnitude of climate change, while the magnitude of climate change can affect their prospects for use.

4. CONCLUSION

- Changes in wind patterns and strength due to climate change could have an effect on wind energy production at existing sites.
- Increased variability in wind patterns creates additional challenges for more accurate wind power prediction.
- Hydro power is vulnerable to climate change.
- Changes in flow regimes and hydrology are of great importance to determine the variations in hydro power generation.
- Climate change - an important issue for wind energy and hydro energy production and planning for future development, depending on the rate and scale of that change, as well as for wind power and hydro power industry.

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