CEDRO
CEDRO, with energy efficiency on our mind

Country Energy Efficiency and Renewable Energy Demonstration Project for the Recovery of Lebanon

Prospects and Economics of integrating Wind Energy into the Lebanese Electricity System

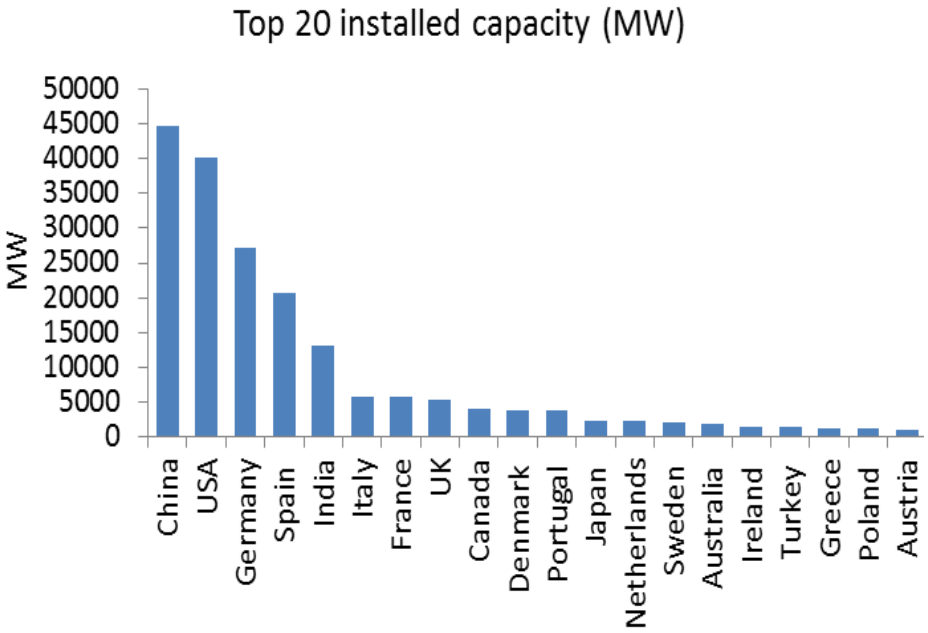
Workshop on Scaling up the Use of Renewable Energy in Rural Areas in ESCWA Member Countries
1-2 February 2012, Beirut.

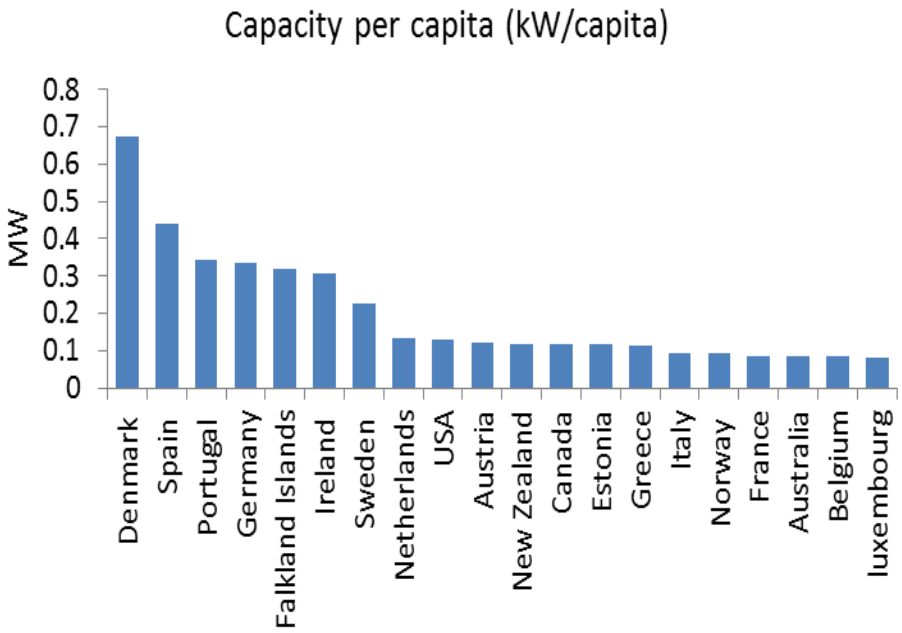
Hassan Harajli
UNDP CEDRO Project

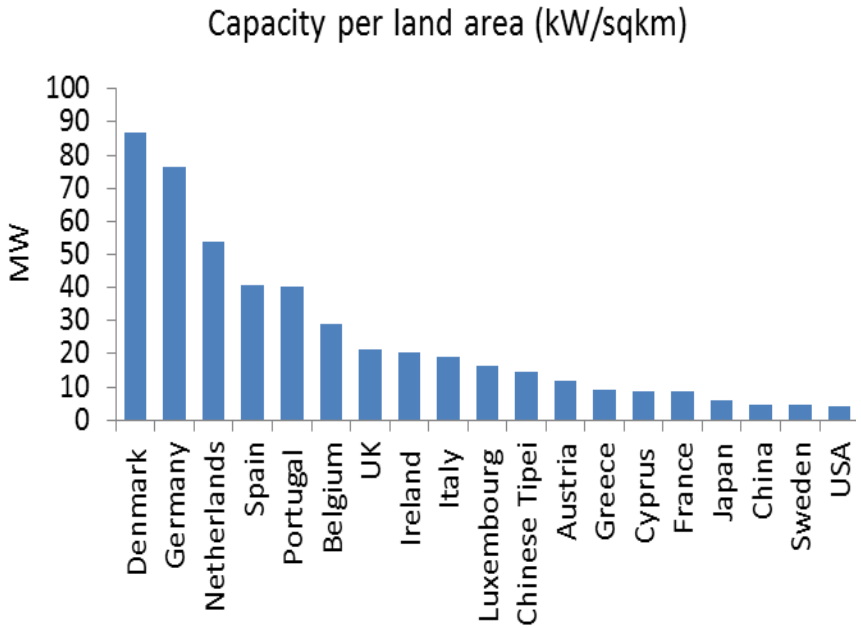
GLOBAL AND REGIONAL OUTLOOK

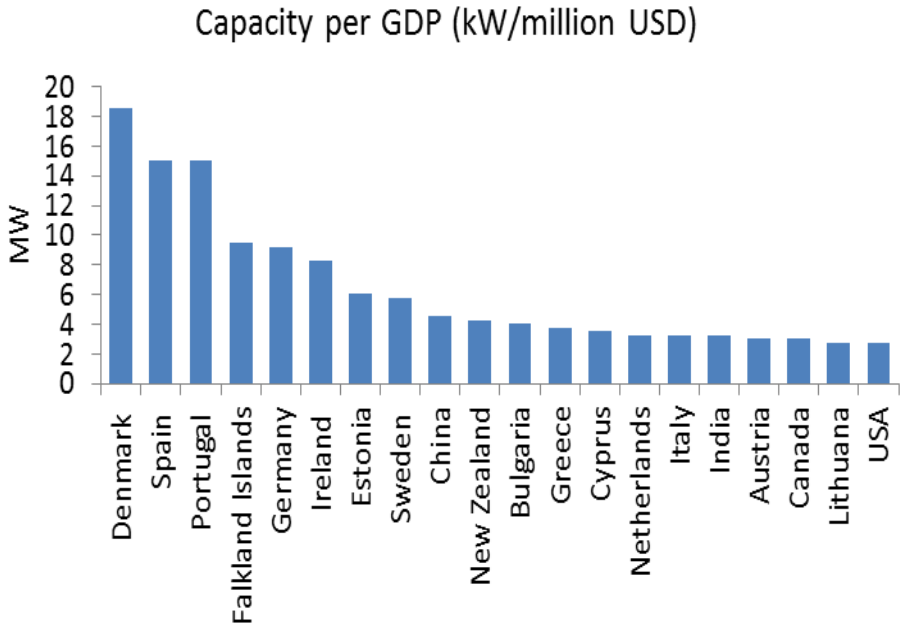
- Worldwide capacity is 240,000 MW (est.) by end of 2011
- Annual growth in capacity ranged bt. 21 – 35% between 2000 -2011
- In 2010, the wind sector had a turnover 40 billion Euros & 670000 were employed
- Wind power integration into electricity systems is increasing world-wide, with the highest 4 countries;
    - Denmark; 21%
    - Portugal; 18%
    - Spain; 16%
    - Germany; 9%
- No Arab Nation is in the top 20 for wind power development, no matter how you look at it. Wind power is max 1 GW (end of 2010) in all Arab Countries.

WWEA 2010. World Energy Report 2010









WWEA 2010. World Energy Report 2010

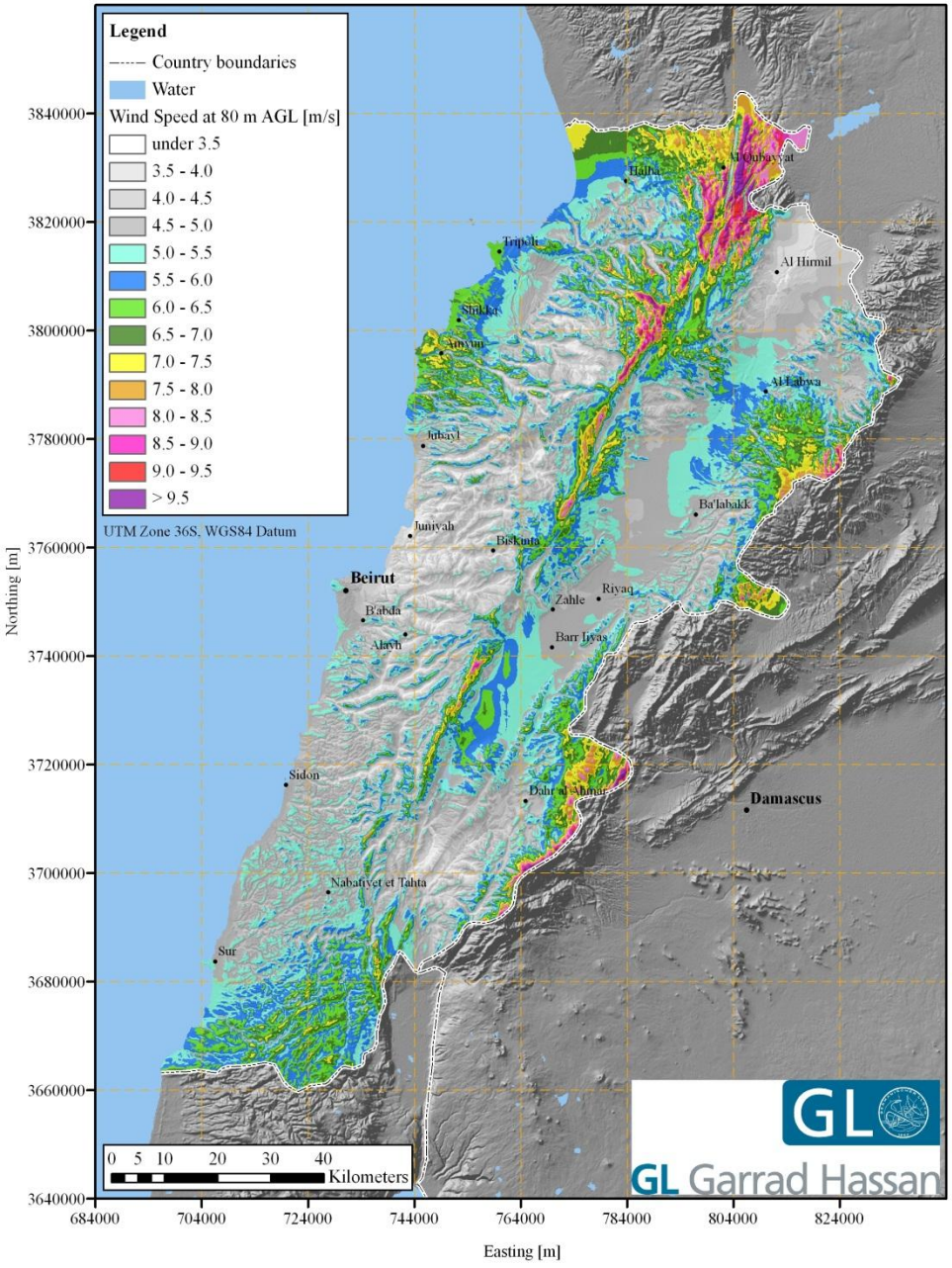
THE LEBANESE WIND ENERGY OUTLOOK

WIND ATLAS

Meso-scale and micro-scale modelling for the entire Republic of Lebanon to produce a wind map with a resolution of 100

Results: Lebanon has **at least 1500 MW** potential with a mean of 6,100 MW!

Therefore the potential is there!


Legend
Country boundaries
Water
Wind Speed at 80 m AGL [m/s]
under 3.5
3.5 - 4.0
4.0 - 4.5
4.5 - 5.0
5.0 - 5.5
5.5 - 6.0
6.0 - 6.5
6.5 - 7.0
7.0 - 7.5
7.5 - 8.0
8.0 - 8.5
8.5 - 9.0
9.0 - 9.5
> 9.5
UTM Zone 36S, WGS84 Datum
Beirut
Damascus
Tripoli
Halba
Al Hirmil
Shikka
Amyun
Al Labwa
Jubayl
Ba'labakk
Junivah
Biskinta
Riyaq
Zahle
B'abda
Alayh
Barr Iyas
Sidon
Dahr al Ahmar
Nabatiyet et Tahta
Sur
0 5 10 20 30 40
Kilometers
GL Garrad Hassan
Northing [m]
Easting [m]
3840000
3820000
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3780000
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3740000
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684000
704000
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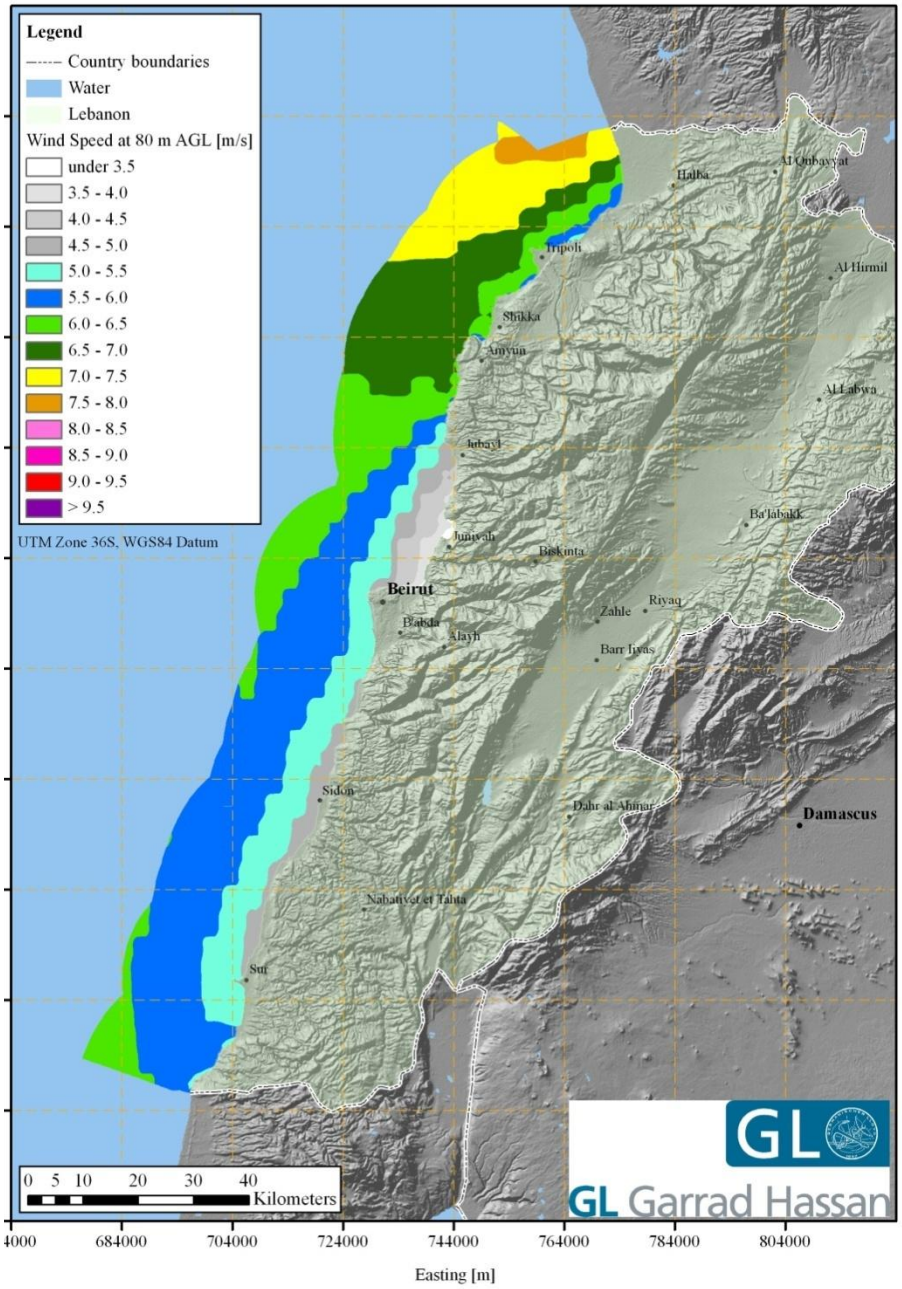
744000
764000
784000
804000
824000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Alayh
Barr Iyas
Sidon
Dahr al Ahmar
Nabatiyet et Tahta
Sur
0 5 10 20 30 40
Kilometers
GL Garrad Hassan
Easting [m]
4000
684000
704000
724000
744000
764000
784000
804000

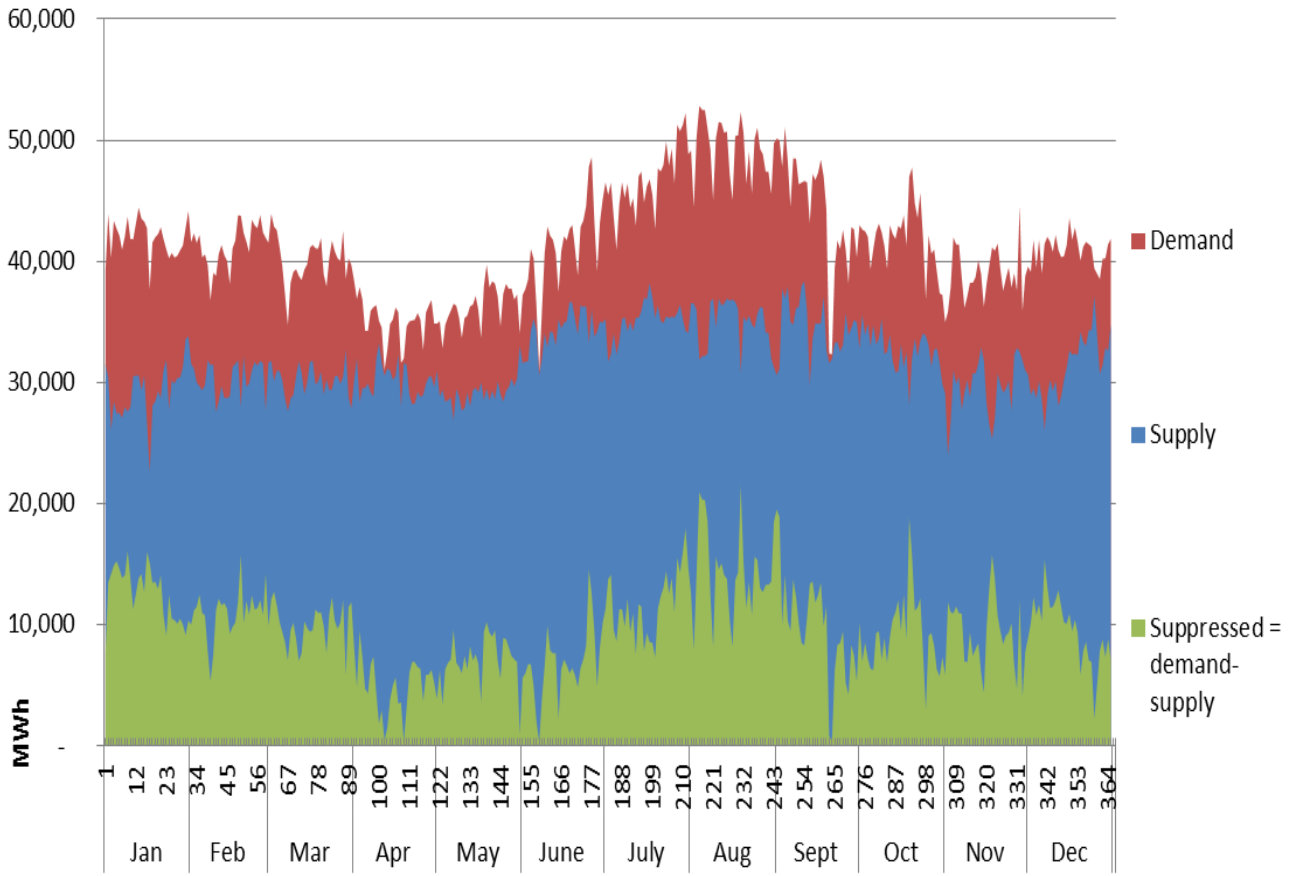
The Lebanese Electricity Sector

Current Situation

- Deficient Supply
- Transmission losses
- Highly Polluting
- Low Diversity
- Yearly Demand Increase of 7%
- Monopoly – EDL
- Private Generators

Planned Situation

- Increase capacity of generation (4-5,000 MW)
- Reduce Network Losses
- Allow participation of Private entities
- 12% target – with focus on Wind Power: 60-100 MW



Daily Demand, Supply, and Suppressed Electricity in Lebanon, year 2009.

Integrating Wind Power in LES

Integrating wind energy into the Lebanese electricity system;
Preliminary analysis on capacity credit and economic performance

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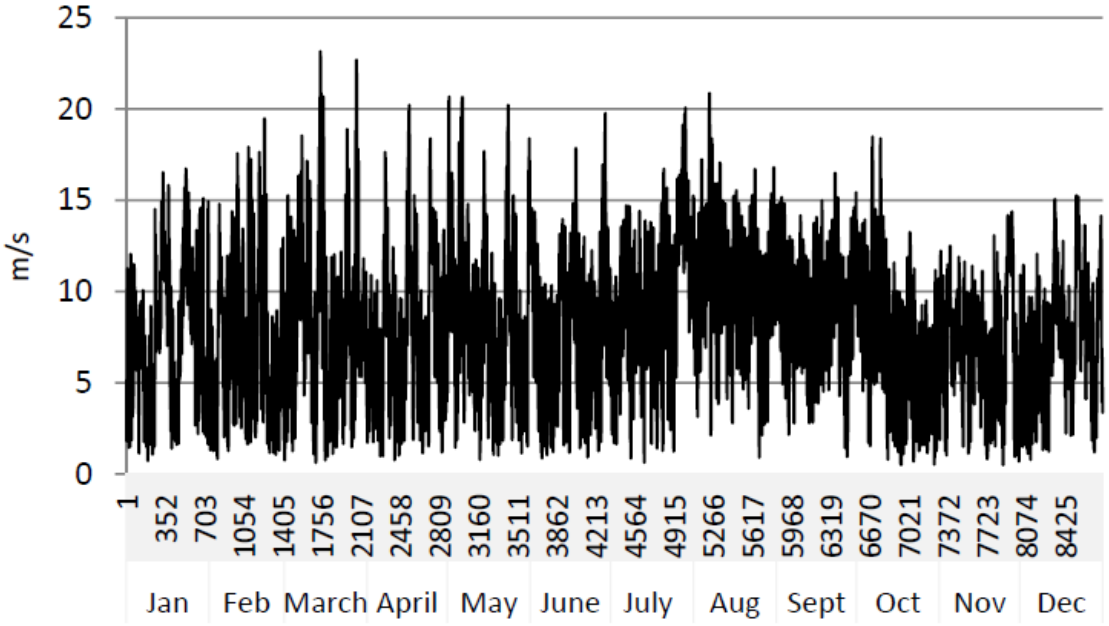
Scenarios of wind integration will be considered

Scenario	Wind Power (MW)	Electricity Supply System
A	99	Current
B	99	Future
C	241	Future
D	498	Future

Calculating Wind Power

STEP 1: Obtaining 10 minute wind speed measurements at 80 meters

Equation (MacKay, 2009): V(80m) = V(40m) x (80m/40m)^0.11
- Where 0.11 is the calculated shear factor at Sindyanah Site (GL GH, 2010)



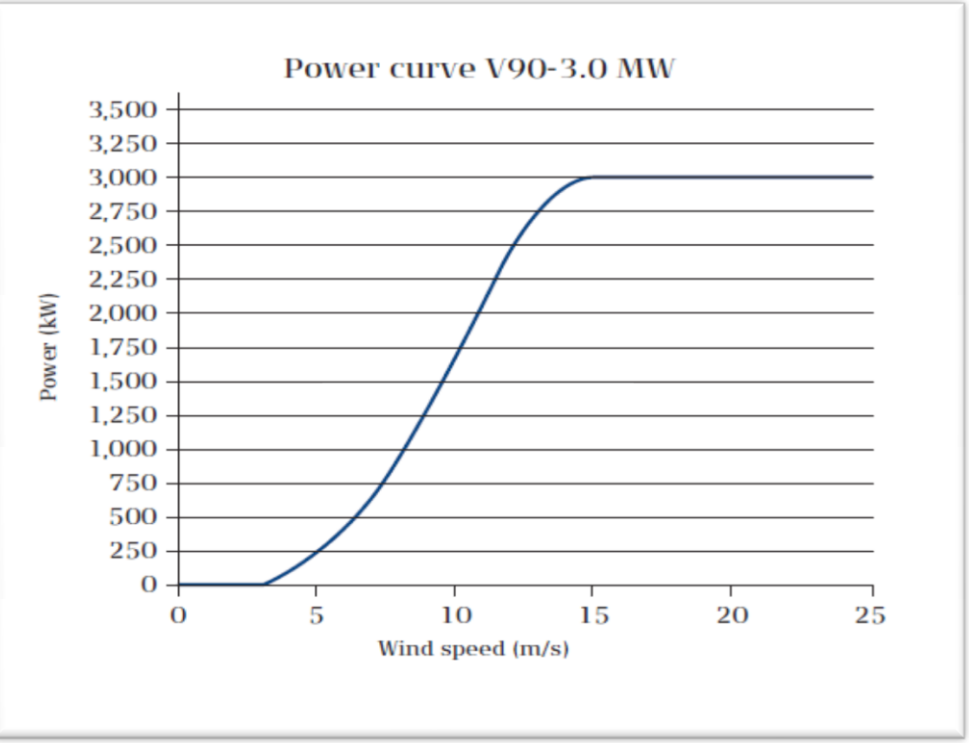
Hourly Wind Speeds (m/s) at Sindianah for 2009

Year	Avg Wind Speed (m/s)
2007	8.18
2008	8.29
2009	8.08

Calculating Wind Power

STEP 2: Select wind turbine manufacturer

Selected **3MW** Vestas Wind Turbine (yet others can be selected)



3MW Vestas Turbine Power Curve

Results: Integrating Wind Power In Current LES

Scenario A

- Assumption; All wind production will be absorbed by the grid.
- Savings in terms of value of lost load (VOLL)
- VOLL value for Lebanon is 0.7 USD/ kWh not produced (MoEW, 2010)

99 MW wind integrated into Current LES (year 2012)	
Suppressed Demand	4.337 Million MWh
Wind Power delivered	0.276 Million MWh
Reduction of Blackouts	6.36% (21 minutes)
Reduction in VOLL	193.2 Million USD/yr
CO2 reduction	234,600 tons/yr

In this case, wind power does not displace any conventional supply due to supply shortage

Integrating Wind Power In the Future LES

- Expected full demand supplied /catered for by Lebanese Electrical System

- Those scenarios should take into consideration the Capacity Credit (replacement) of Wind Generation (i.e., Integrating wind into an electricity system will not add to supply capacity on a 'megawatt to megawatt' basis).

- There are many ways to calculate the CC, however one method is by using an analytical formula:Voorspools and D'haeseleer's (2006);

$$CC = \propto . \left(\frac{CF_{wind}}{R_{System}}\right) . (1 + \beta . e^{-b.(x-1)}), \text{ where}$$

CC	: Capacity Credit in % installed rated wind power
X	: Penetration level of wind in % of peak load (see below)
CF_{wind}	: Capacity factor of wind project in % (easily obtained from above)
R_{System}	: Reliability of conventional plants in % (not so easy to obtain)
$\propto$	:37.6
β	: 1.843
b	: 0.094

Integrating Wind Power In Future LES

The penetration level of wind as percent of peak load (peak load was estimated for the periods from June 15 to September 15 - estimated for 2015 using 7% annual electricity demand increase)

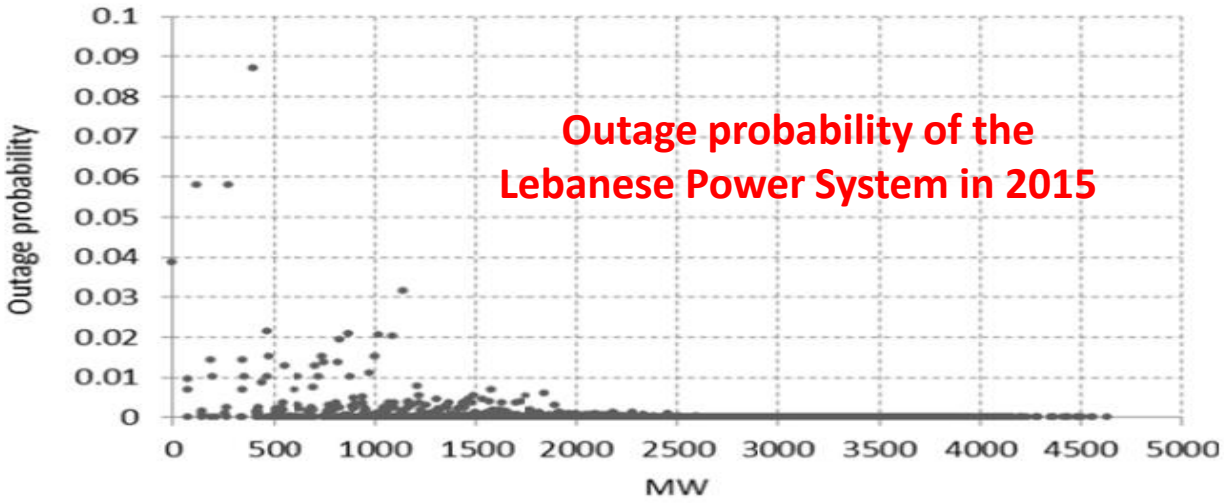
Wind Power (MW)	X (%)
99	1.3
249	3.5
498	7

Integrating Wind Power In Future LES

Reliability of the power system is obtained through the loss of load expectation (LOLE).

$LOLE = \sum_{i=1}^{n} P_i \ (C_i < L_i)$, where;

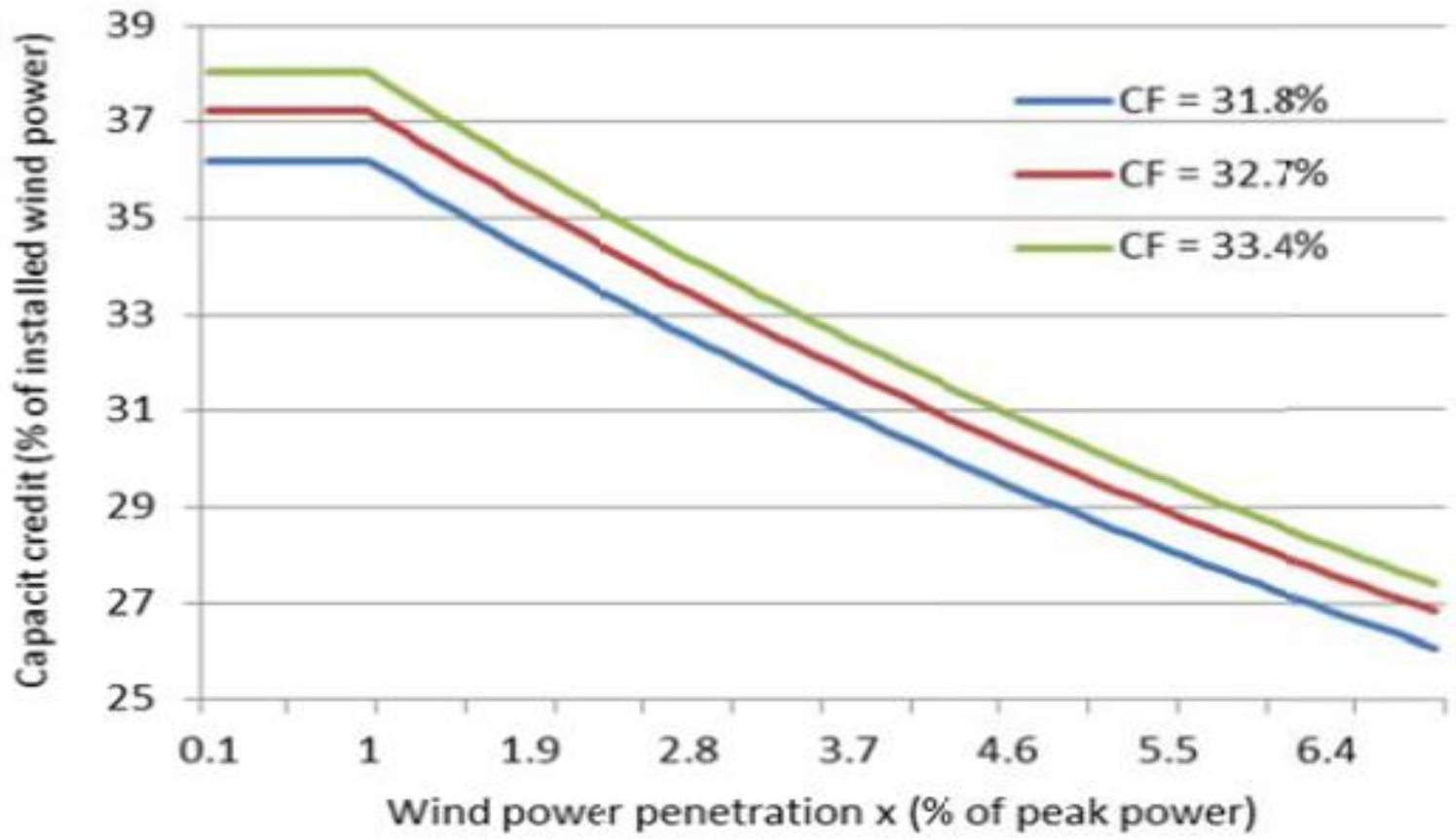
i	index acting as time step (taken as an hour)
n	full time period (taken to be 8760 hours)
C_i	available power-generation capacity in period i
L_i	maximum electric load in period i
$P_i(C_i < L_i)$	probability that maximum load exceeds available capacity in period i.



Outage probability of the Lebanese Power System in 2015

The reliability of the LES in 2015 is calculated to be 93.9%

Integrating Wind Power In Future LES



Capacity (replacement) Credit as a function of wind power penetration levels and capacity factors

Economics of Wind Power in Lebanon

To calculate the present value (PV) of the benefits of integrating wind power in the Lebanese grid, the equation below was used:

$$PV = C_c + \sum_{t=1}^{25} \frac{S_F + S_e}{(1+r)^t}$$

Where,

C_c, is the reduced need for conventional energy

S_F, is the savings on fuel

S_e, is the saving on emissions

r , is the discount rate

Economics of Wind Power in Lebanon

Assumptions:

- Conventional capacity displaced is the capacity credit calculated in the previous sections.
- The cost of 1MW of CCGT is 1 million USD
- The cost of wind power per MW is between 1500-1680 (Syria Wind Farm)
- Price of fuel considered for several scenarios between $400/ton → $800/ton (2008 and 2010 respectively)
- Emissions level of 270 g/kWh
- Social cost of Carbon emissions of $65/ton (El-Fadel et al., 2010)
- Discount rate considered for 2 scenarios (5 and 10 percent)

Economics of Wind Power in Lebanon

Result

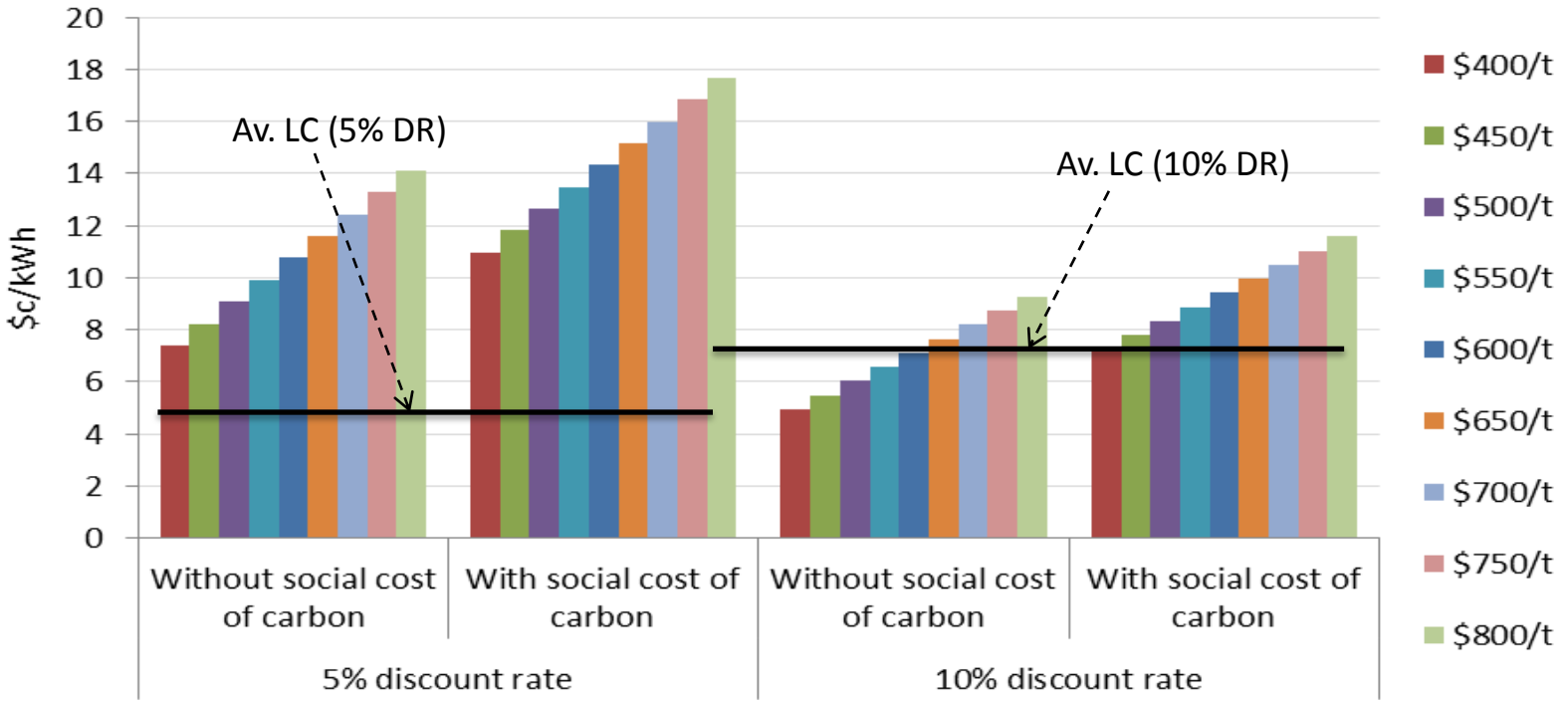


Fig.7 Benefits of wind power integration as factor of discount rate, fuel prices, and the social cost of Carbon

Limitations

Limitations of the Study

1. Using 1 wind measurement site and 3 years of data
2. Geographical dispersal of wind farms increase s capacity credit
3. Using turbines with different power curves
4. Capacity credit should be calculated for several years
5. Scaling of wind speed from 40 meters to 80 meters
6. Scaling the electricity demand from 2011 to 2015 using a constant growth factor of 7%.
7. The economic cost of CO2 emissions, the discount values and other factors related to the grid in Lebanon are subject to debate/uncertainty.

Conclusion

Scenario	Wind Power (MW)	Electricity Supply System	Capacity Credit (%)	Displaced Capacity (MW)
A	99	Current	N/A	Reduction of blackouts by 6.36%
B	99	Future	36.4	36
C	241	Future	32	80
D	498	Future	26	129.5

- Positive results for a discount rate of 5 %
- For discount rate of 10%, highly dependent on price of fuel

THANK YOU