The Potential of Renewable Electricity in Israel in 2050

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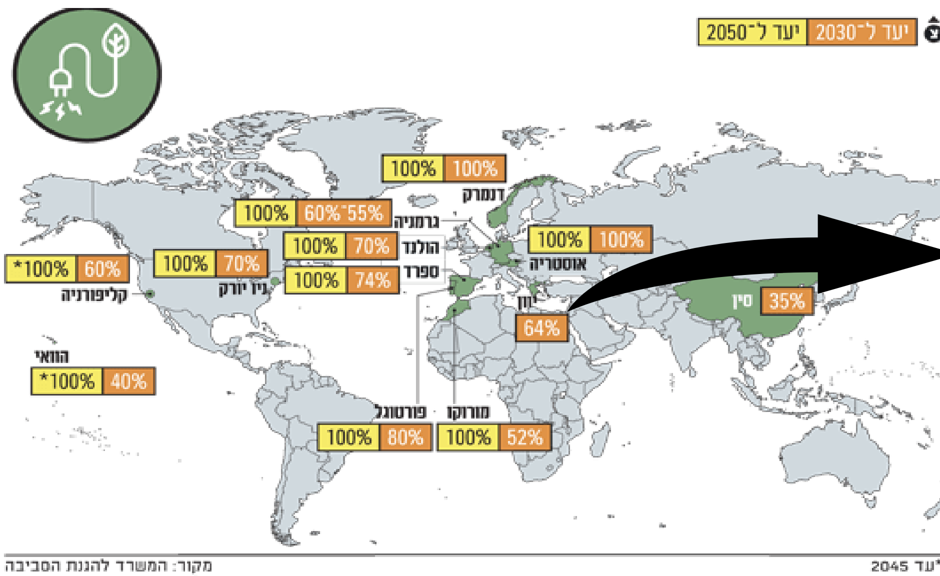
November 29, 2022

Background

- Paris Agreement 2015 (goal 1.5°÷2°C)
- COP 26 (Glasgow, 2021) ISR - reducing GHG emissions: 27% by 2030 and 85% by 2050.



Israeli Government Goals:
2021 - 8% actual
2025 - 17%
2030 - 30%
2050 - ?

In this study: emission reduction is assumed to be promoted only through the generation of renewable electricity

Research Goals

- Develop a holistic approach: input data, models?
  Applicable in a wide range of input data (region, RE, demand, etc.)

- Detailed evaluation of RE resources in ISR

- Obtain the energy mix in 2050 that would allow maximum penetration of renewables to the grid.
  Identify scenarios with:
  - Low energy dumping
  - Reasonable fossil capacity factor/availability

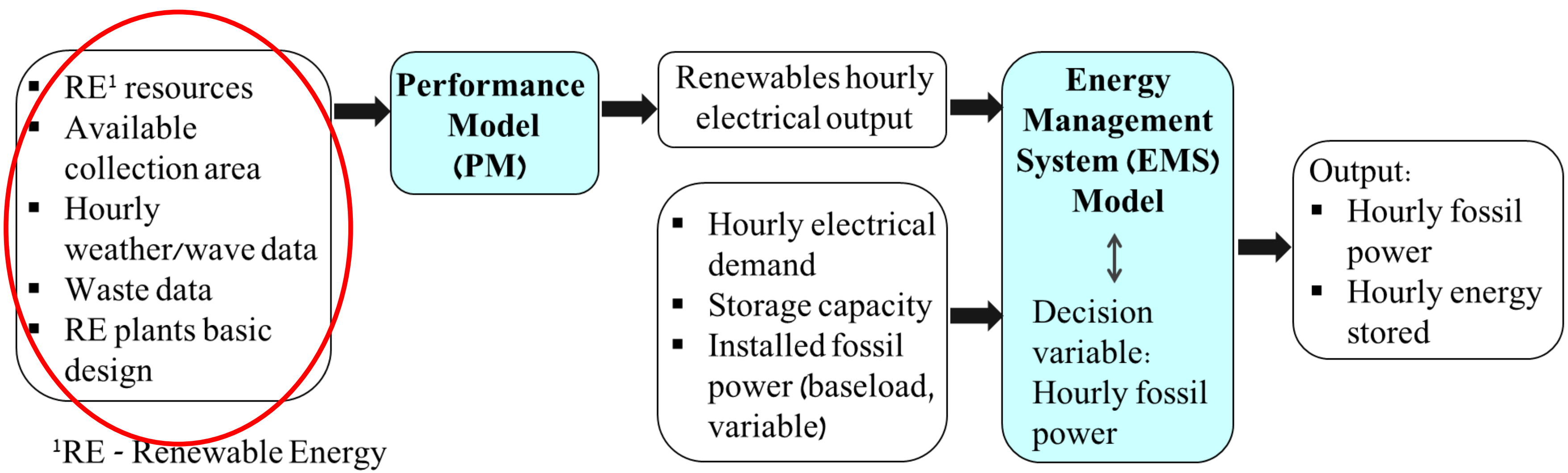
Previous Studies: Recap

- About 20 references (!)
- Input data
  - Weather: specific year, single location
  - Resources: solar and wind. No detailed area planning (agriculture?)
  - Storage: not based on actual market limitations
- Performance Model (PM)
  - Hourly
  - Not detailed (basic design), not dynamic, no complete plant
- Energy management model
  - "Energy system analysis models"
  - Free parameters: grid flexibility, storage capacity
  - No battery charging & discharging power limitations
- No full system integration

Methodology

Features:
- Time step = 1 hr
- No limitations on grid development (TBD)
- ISR grid is isolated, no outage is allowed
- RE: Green Line only, Demand: Green Line and West Bank

Model Structure

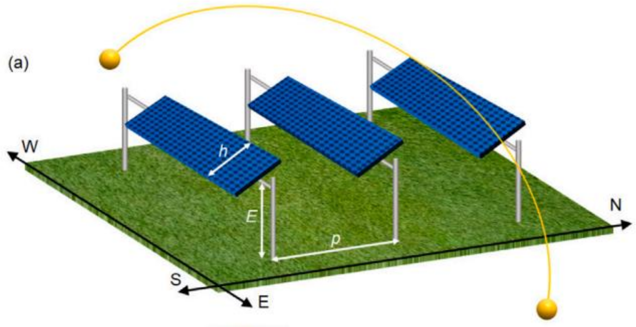


Available Area: PV

Total area [km²]	Open area [km²]	Agricultural area		--	-	0	+	++
		Total Area [km²]	Pre-approved for urbanization [km²]	High Loss [km²]	Loss [km²]	Neutral [km²]	Gain [km²]	High Gain [km²]
21,616	1,129	4,112	2,826	287	632	359	5	3

Incl. unknown impact

Parameter	APV (GCR=0.2564)	PV (GCR=0.5)
Tilt angle	40˚	24˚
Response to shade	*in*tolerant	tolerant
Panel	Bifacial 545M	Bifacial 545M
Land multiplier	1.29	1.29

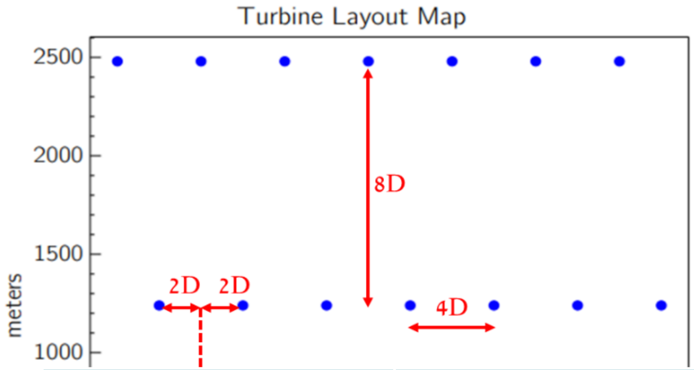


Riaz, IEEE Journal of Photovoltaics, 2021

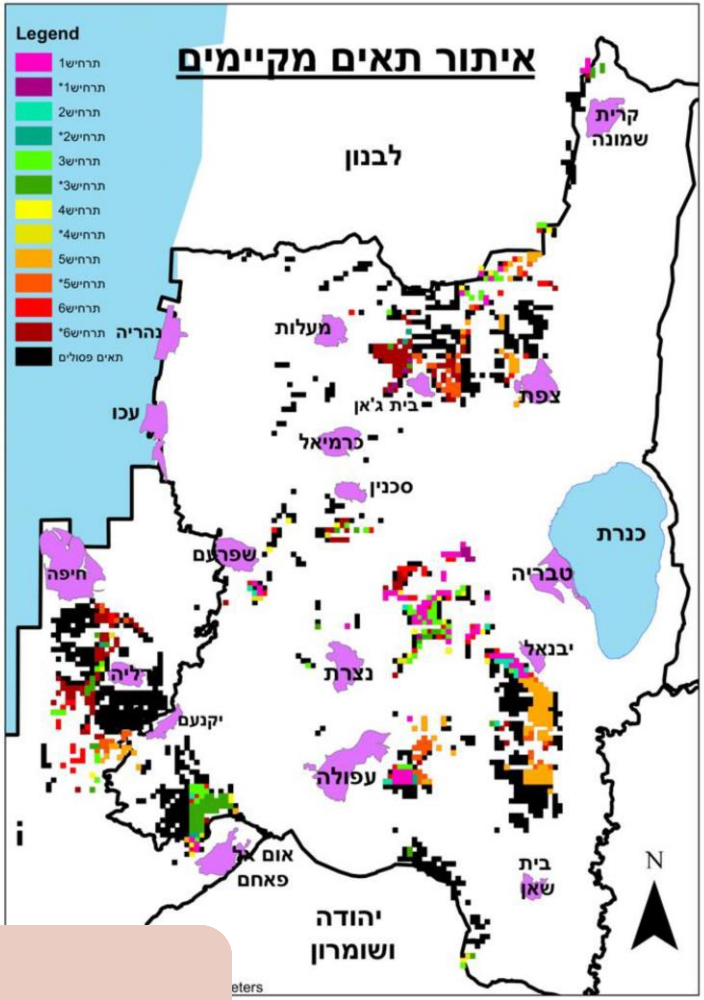
Findings:
Open area: **PV -** 1,129 km² (open) + 367 km² (tolerant), 132 GW
Agriculture: **APV -** 919 km² (intolerant), 40 GW

Cont'd…

Wind farm configuration



Parameter	All farms
Turbine	Vestas 155-3.6
Rows spacing	8D
Turbine spacing	4D
Offset	2D

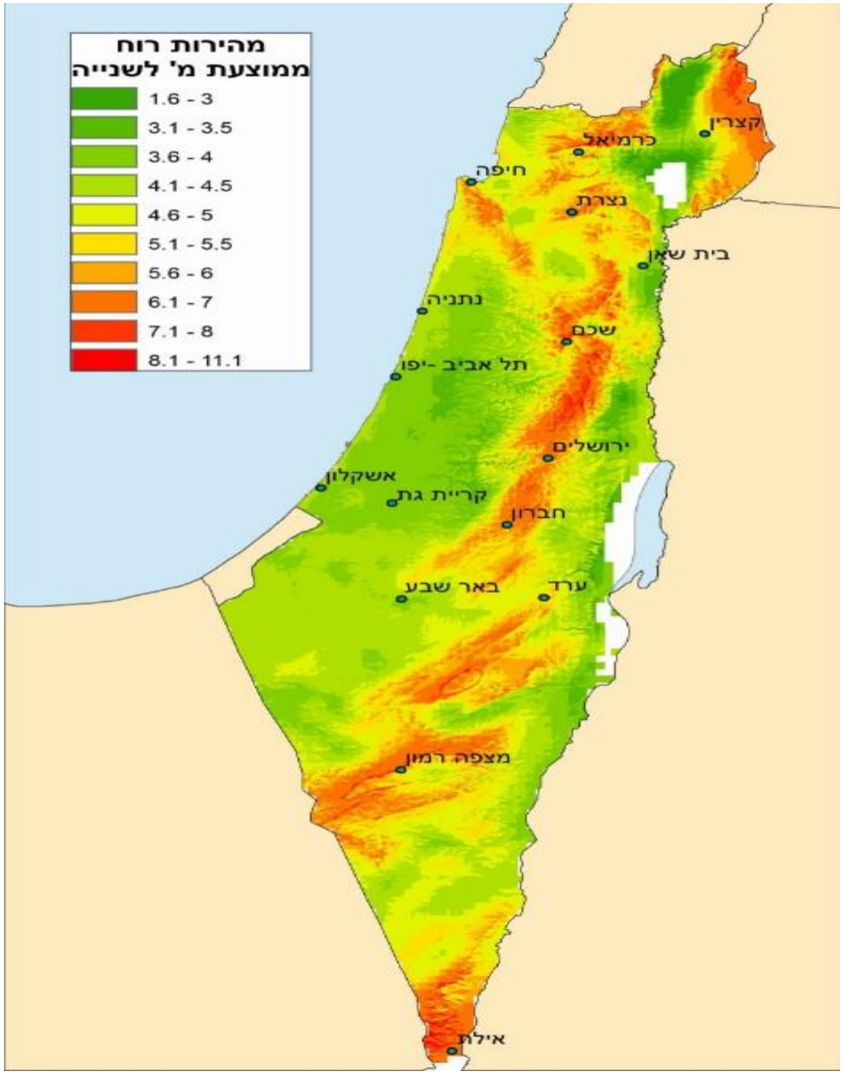


ארז פרי, 2020

Findings:
Onshore (North): 370 km^2, 1.93 GW (535×3.6 MW)
Offshore (Haifa): 400 km^2, 2.88 GW (800×3.6 MW)

Available Area: Wind

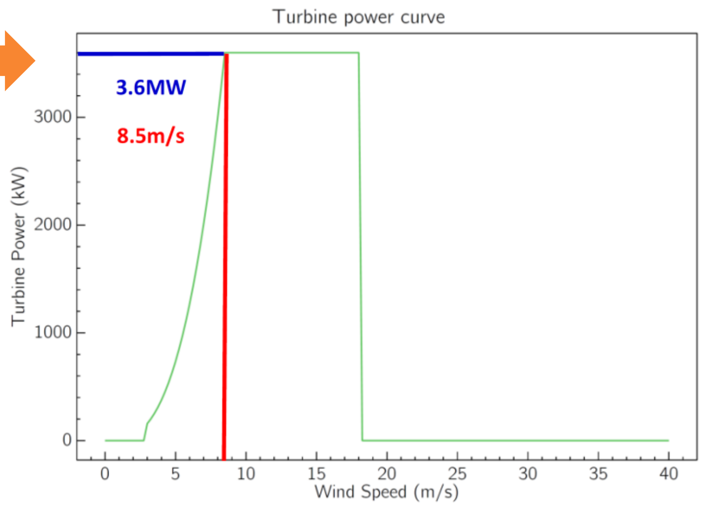
- South: military areas and natural reserves
- East: areas near the West Bank
- North: dictated by public policy (Peri, 2020)



השירות המטאורולוגי הישראלי,2015
בגובה 100 מ'

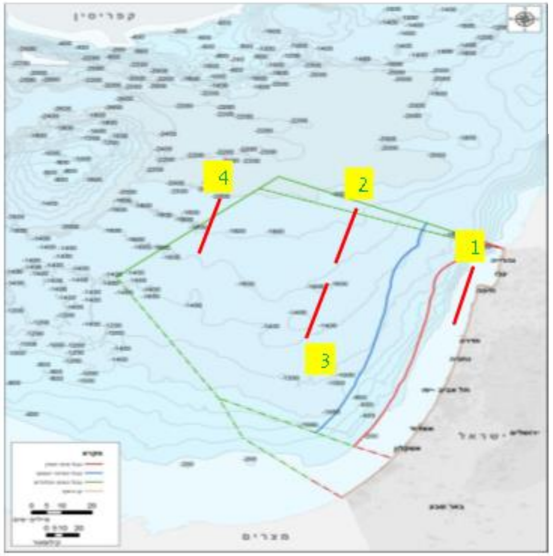
Input Data: Performance Model

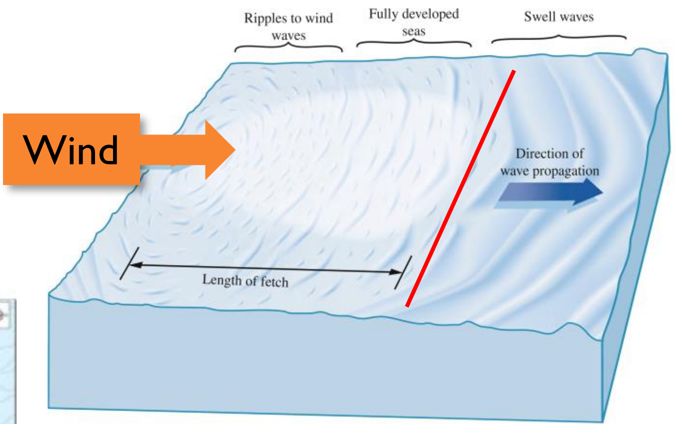
- Weather: TMY from PVGIS
  - Onshore wind (north) speed: 51% of IMS
  - Offshore wind: (Haifa)
- Wave: in-house TMY (next slide)
- Organic waste
- Basic design
  - Main components (panels, inverters, wind turbines, batteries): Tier 1
  - Configuration



Wave

- $P' \sim \mathbf{H}^2 \cdot \mathbf{T}$ [W/m]
- Significant wave height, ***H*** and energy period, ***T*** (2005-2019): Israel Oceanographic and Limnological Research (IOLR), Hadera
- TMY: in-house
- WEC efficiency=50%
- 4×40 km
- Capacity Factor=8.8%





Pecher, Handbook of Ocean Wave Energy, 2017

Eco Wave Power, Gibraltar

Findings:
Israel Exclusive Economic Zone (EEZ): 3.2 km^2, 3 GW

Biomass

Resources

- × Forestry
- × Energy crops
- ✓ Agricultural waste
- ✓ Municipal waste

❖ Data

- MoEP, 2014
- Annual population growth rate - 1.8% [CBS medium, 2017]
- Gasification (0.65 MWhe/ton organic)
- Anaerobic digestion (0.15 MWhe/ton organic)

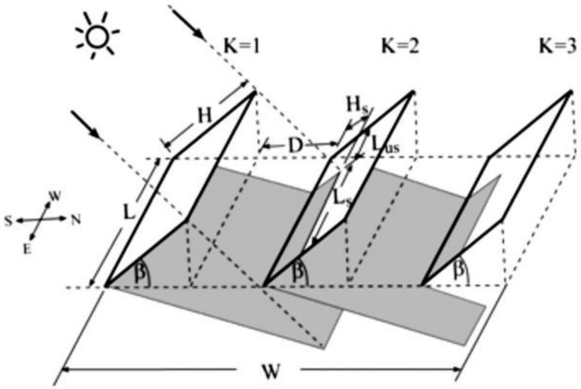
Findings:
Organic waste ≈ 9,000,000 ton/yr (2050)
Annual electric energy 3 TWhe, 0.35 GW (24/7)

Performance Model (PM): SAM

- Powerful simulation tool
- Validation (±5%)

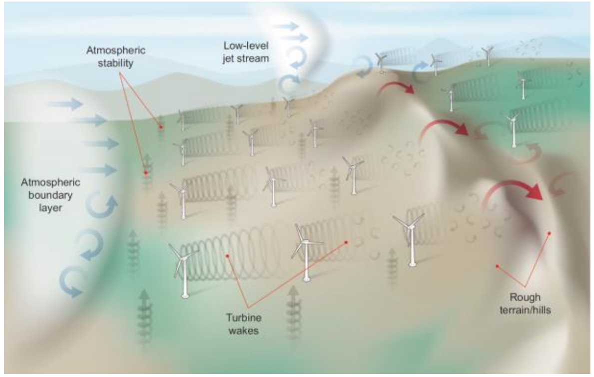
Examples for SAM ***advanced*** models:

- Shading in PV



Weinstock, Journal of Solar Energy Engineering, 2009

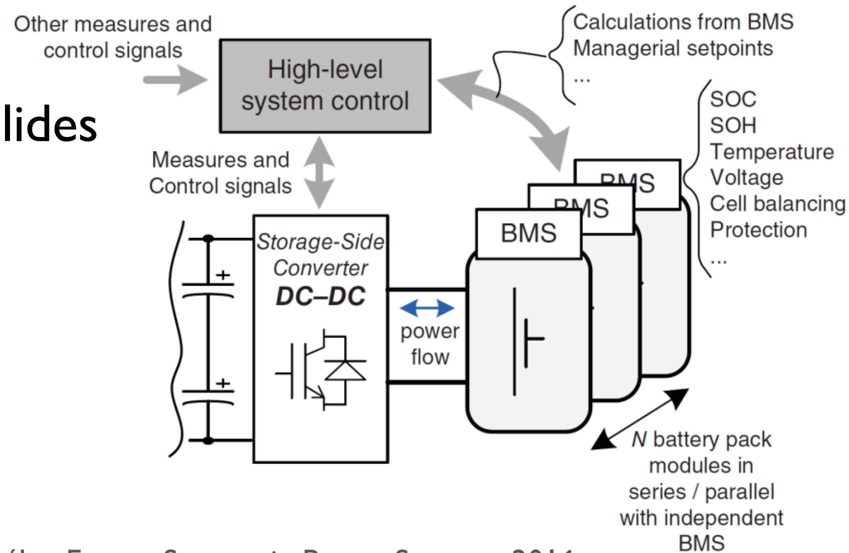
- Wake effect



Ginley, Fundamentals of Materials for Energy and Environmental Sustainability, 2012

Cont'd…

- ❖ Battery system (BMS) – next slides
  - Shepherd model
  - Peukert's law
  - And more…
- ❖ Other features in the SAM
  - Balance of System (BOS)
  - …



Díaz-Gonzáles, Energy Storage in Power Systems, 2016

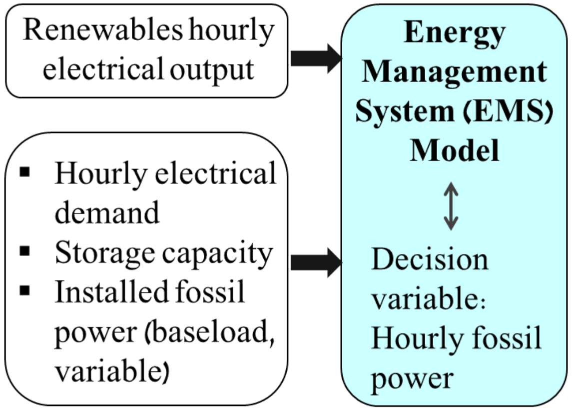
Resource	No. Simulations	Plant area/capacity	No. Units	Total area/capacity
PV	5	1 km^2	1,554	1,554 km^2
APV	5	1 km^2	918	918 km^2
Wind onshore	21	1÷86 km^2	26	372 km^2
Wind offshore	1	10 km^2	40	400 km^2
Storage	1	1 GWh	216	216 GWh

EMS Input

- ❖ Renewables electric output - PM
- ❖ Electric consumption (demand) - total 183.3 TWh
  - IEC 2016
  - Annual growth rate - 2.8% [Electricity Auth., 2020]
  - Annual decrease in energy intensity - 1.3% [MoE, 2020]
  - Transportation - 22.7 TWh [Gal, 2021]

} 160.5 TWh

Type of vehicle	No. of vehicles [million]	Annual trip [km]	Energy consumption [kWh/100 km]	Energy consumption in transport [TWh]
BEV	6.6	16,200	18	19.25
PHEV	0.4	16,200	20	1.30
Bus	0.022	71,000	120	1.87
Minibus	0.015	62,500	35	0.32

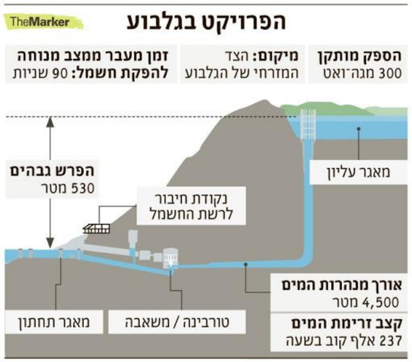


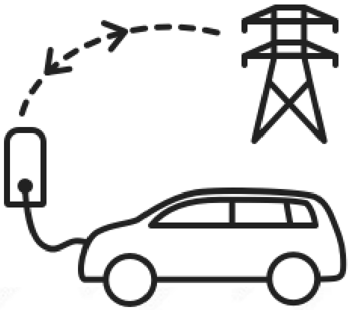
- ❖ Installed fossil power: 25÷31 GW

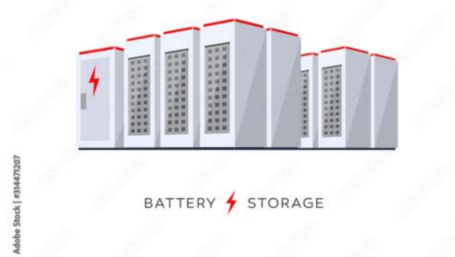
Storage

Total capacity: 216 GWh

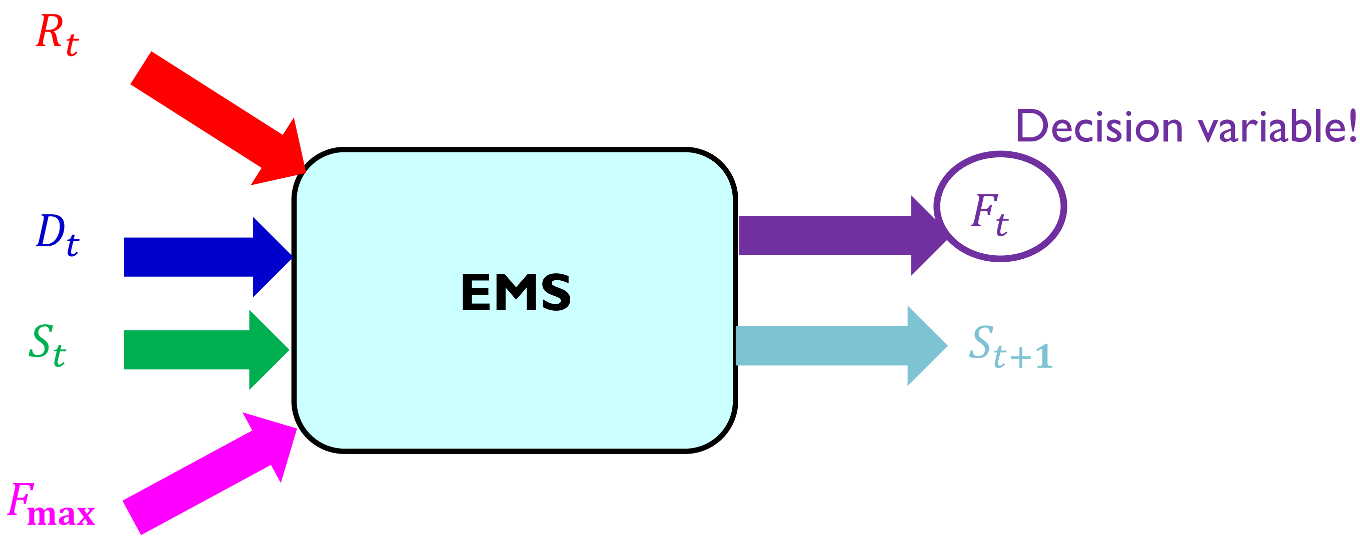
- ❖ Pumped Hydro ≈ 8.0 GWh
  - Ma'ale Gilboa - 3.0 GWh
  - Kokhav Ha'Yarden - 3.4 GWh
  - Manara Cliff - 1.56 GWh
- ❖ Vehicle to Grid (V2G) - 169.4 GWh
  - 7.0 million vehicles, 50 kWhe each
  - Lower SoC limit for daily use - 30% (15% use)
  - Vehicles simultaneously plugged in - 2/3
- ❖ Stationary battery - 39.2 GWh
  - Identical to ISR vehicle global share - 0.87%
- ❖ Battery: LG JH4 Li-ion, 72.5 Ah







EMS - Mathematical Model



- R_t - Renewable electric energy during interval t
- D_t - Electrical energy demand during interval t
- S_t - Amount of stored energy at the beginning of interval t
- $F_{\max}$ - Installed fossil power (baseload and variable)
- F_t - Amount of fossil electrical energy produced during interval t

Cont'd…

Other variables	Description
Q_t	Amount of energy dumped during interval t
B_t	Amount of energy charged into the battery bank at interval t
U_t	Amount of energy discharged from the battery bank at interval t

The objective function

Minimize $\sum_{t=1}^{T} F_t$

The contribution of renewables

RE[%]=1- $\frac{\sum_{t=1}^{T} F_t}{\sum_{t=1}^{T} D_t}$

Subjected to:

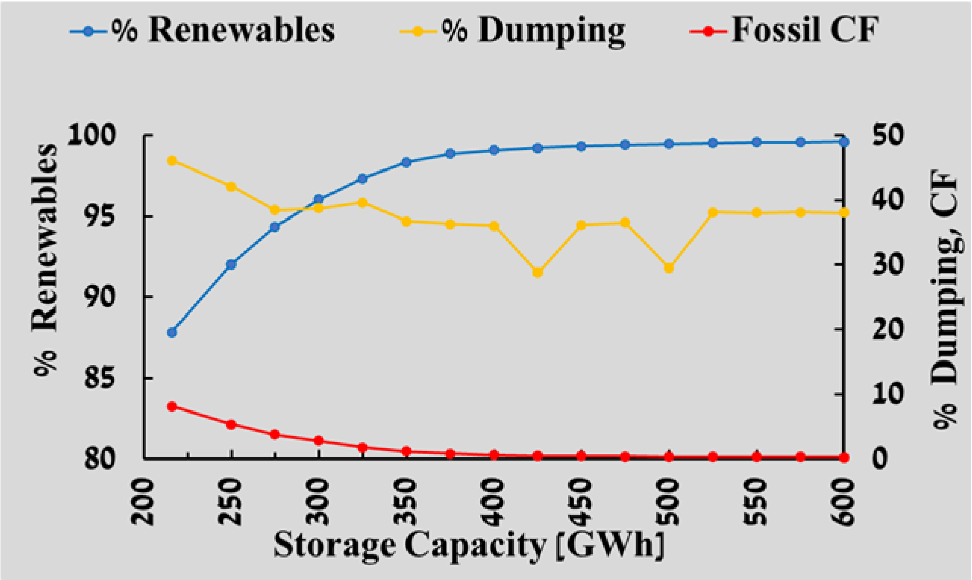
$F_t + R_t - D_t = B_t - U_t + Q_t$	$\forall t = 1, \dots, T+1$
$S_t \leq S_{t-1} + \eta_{ch} B_{t-1} - \frac{1}{\eta_{dc}} U_{t-1}$	$\forall t = 2, \dots, T+1$
$\eta_{ch} B_t \leq \Delta S_{\max}^{\text{ch}}$	$\forall t = 2, \dots, T+1$
$\frac{1}{\eta_{dc}} U_t \leq \Delta S_{\max}^{\text{dc}}$	$\forall t = 2, \dots, T+1$
$S_1 = s_1$	
$S_{\min} \leq S_t \leq S_{\max}$	$\forall t = 2, \dots, T+1$
$F_{\min} \leq F_t \leq F_{\max}$	$\forall t = 1, \dots, T$
$B_t, U_t, Q_t \geq 0$	$\forall t = 1, \dots, T+1$

Fixed, from PM (η_{ch})

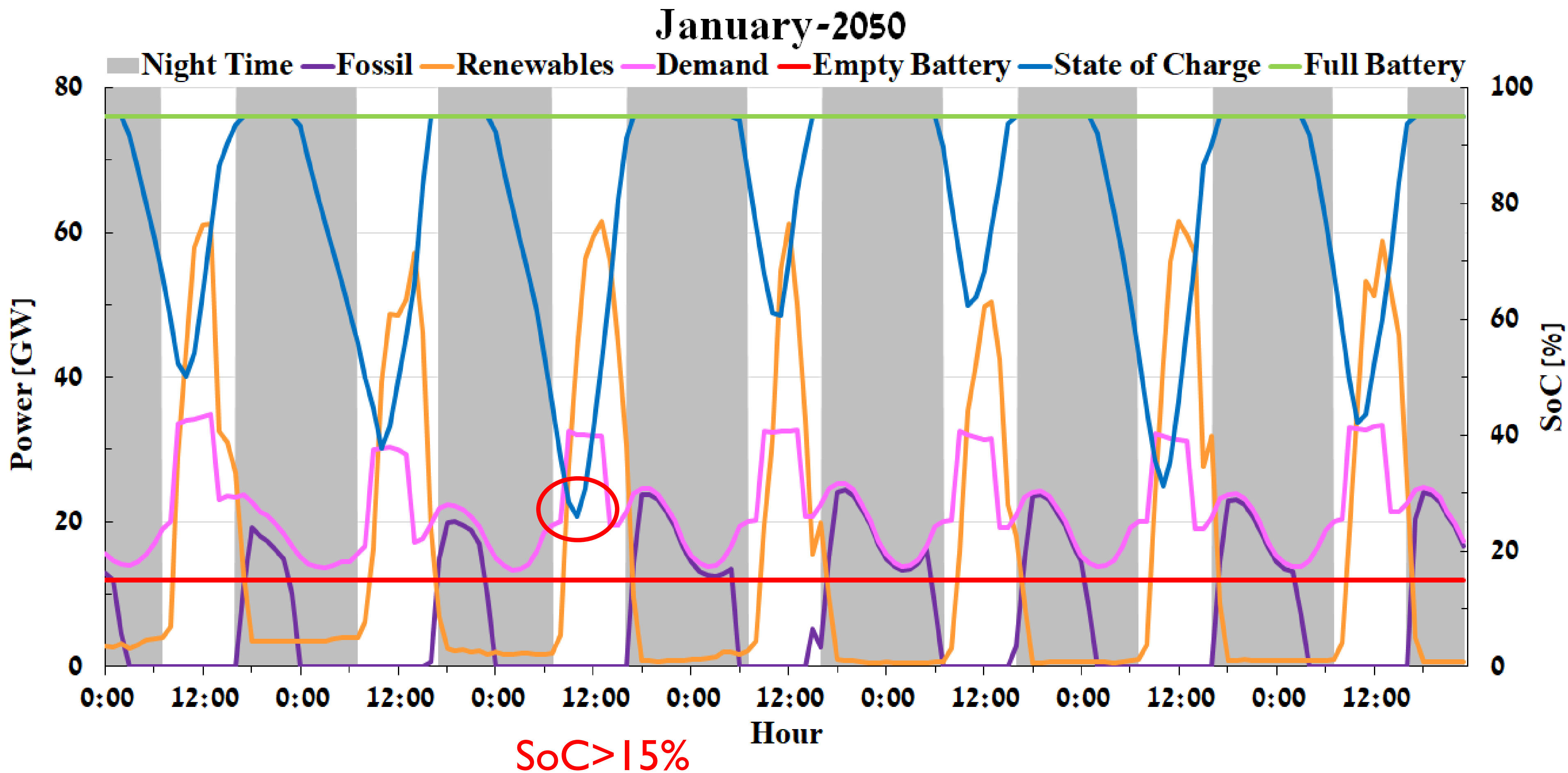
Results

Scenarios/Sensitivity

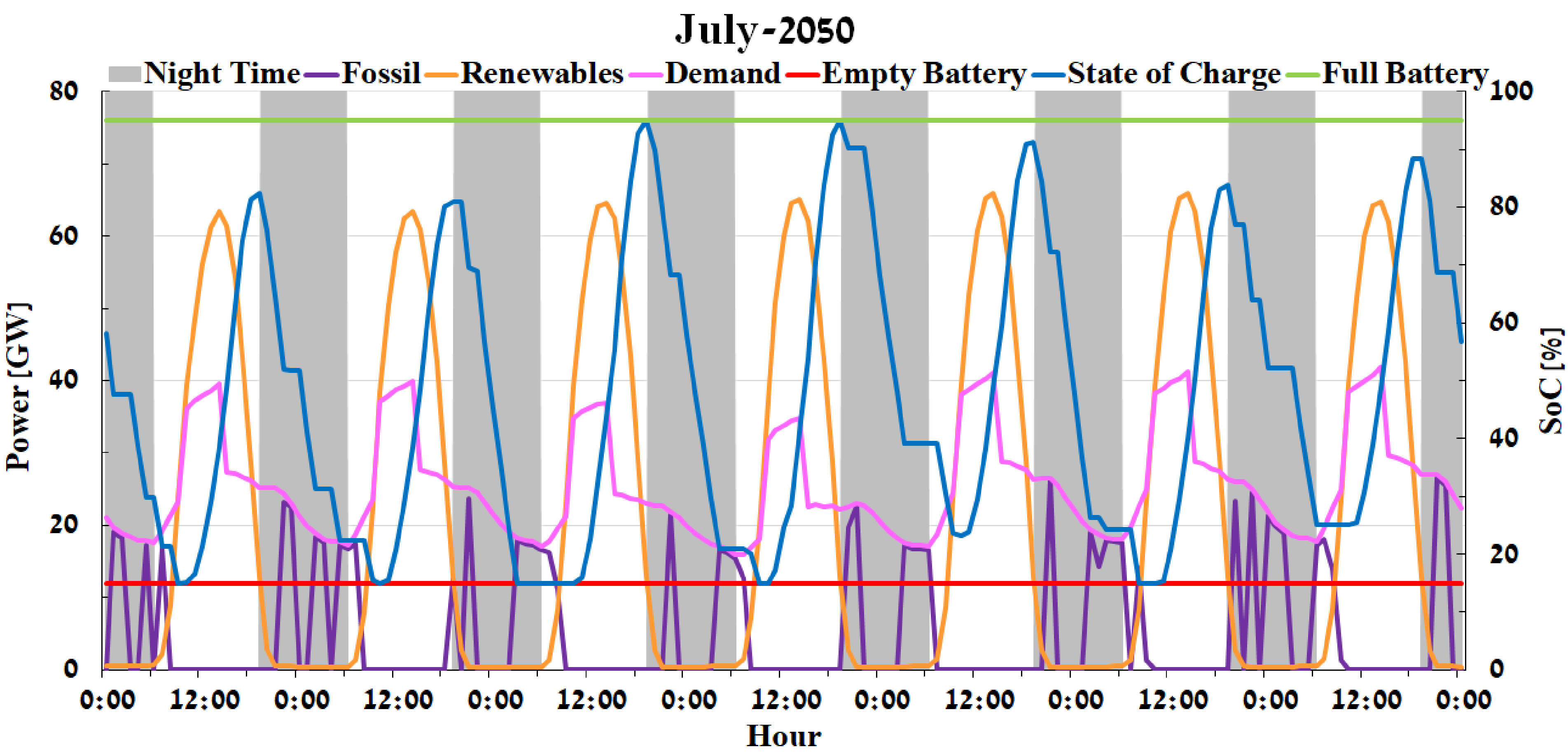
Scenario	Installed Power R/F [GW]	Storage Capacity S [GWh]	Renewables Share [%]	Dumping [%]	Fossil Capacity Factor (CF) [%]
2030	25.6/11	60	47.3	13.0	**54.7**
2050-A	172.5/31.2	216	87.8	46.1	**8.2**
2050-B	86.3/30.6	216	80.1	4.9	**13.6**
2050-S	172.5/30.8	500	99.5	29.5	**0.4**



Operating Schedule 2050-B: Winter



Operating Schedule 2050-B: Summer

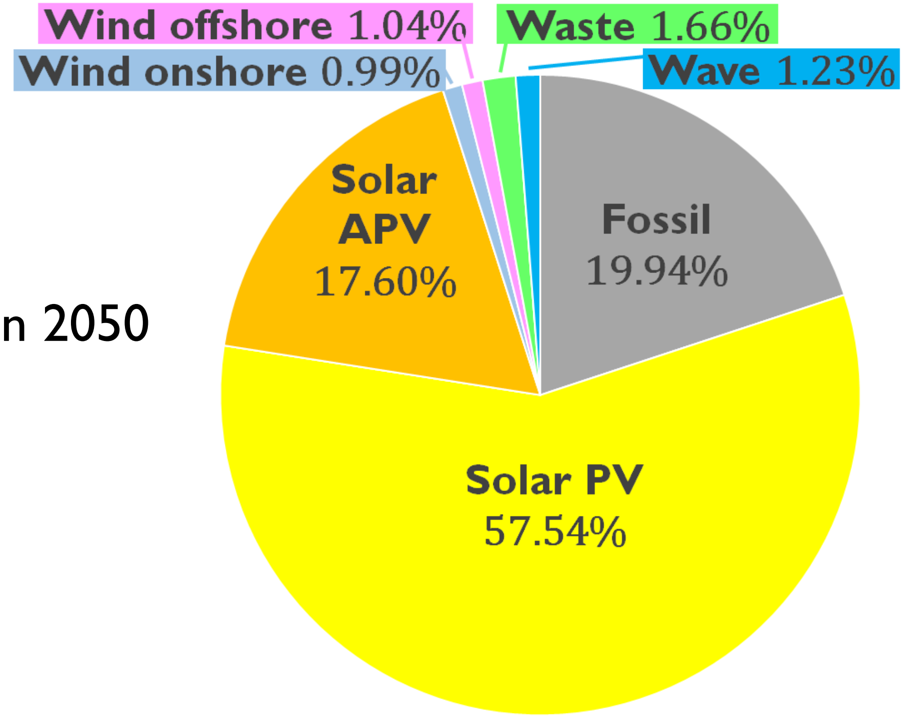


Electrical Energy Mix: 2050-B

	Fossil	Solar PV	Solar APV	Wind onshore	Wind offshore	Biomass (waste)	Wave	Total
Installed Power [GW]	30.60	66.05	20.20	1.93	2.88	0.35	3.00	125.61
Energy [GWh]	36,534	119,292	36,492	1,807	1,914	3,045	2,253	201,338

Total demand 183.26 TWh

Electricity supply mix in 2050

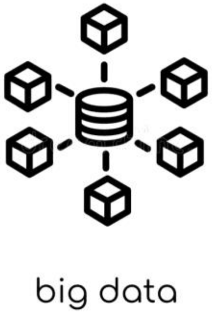


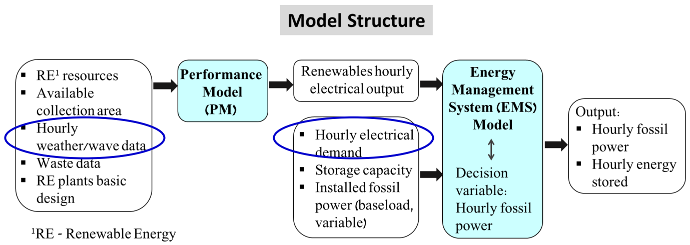
Comparison to Previous Works: 2050

Reference	Electric Demand [TWh]	Storage [GWh]	Installed Power [GW] Fossil - F Renewables - R	% Renewables	% Dumping	Fossil CF [%]
Greenpeace	88	n/a	R = 21.9	47	n/a	n/a
Ministry of Energy	**158**	**265**	**F = 16.0 R = 170.0**	**80**	**n/a**	**n/a**
NZO	162	320	F = 17.5 R = 116.5	95	n/a	n/a
Ministry of Environmental Protection	158	230	F = 17.1 R = 80.9	80	n/a	n/a
Current study 2050-B	**183**	**216**	**F = 30.6 R = 94.4**	**80**	**4.94**	**13.6**

Conclusions

- Input data:
  - ✓ ***Detailed***: weather, wave, area planning, basic design
  - Future refinement:
    - Wind data (onshore and offshore)
    - Wave data at deep sea
    - Crops response to shade
- Modeling/analysis
  - ✓ ***Holistic*** approach
  - ✓ ***Applicability***: any ***input data*** (region, year)
  - Future refinement: No. sites, time steps



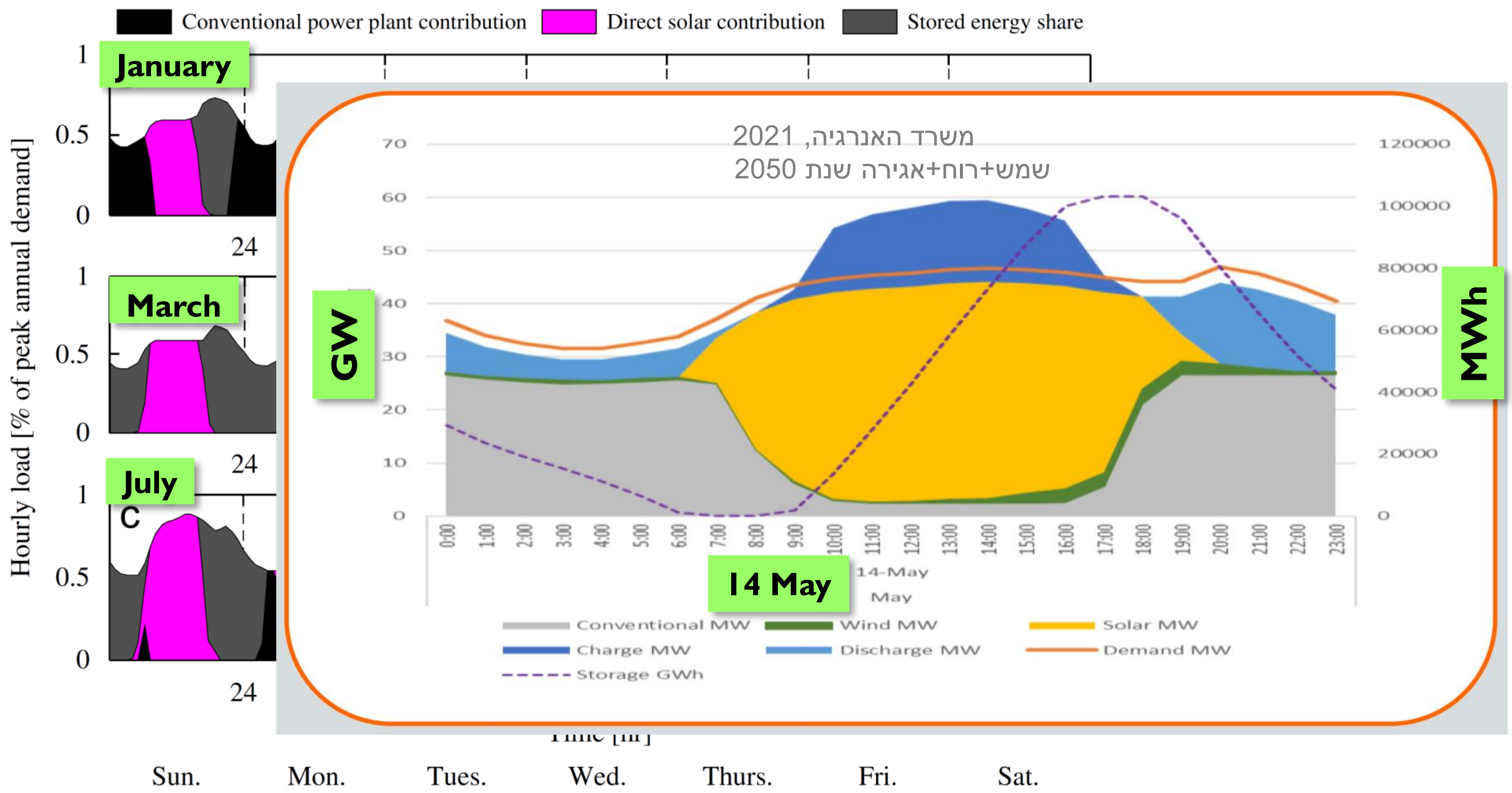


THANK YOU!

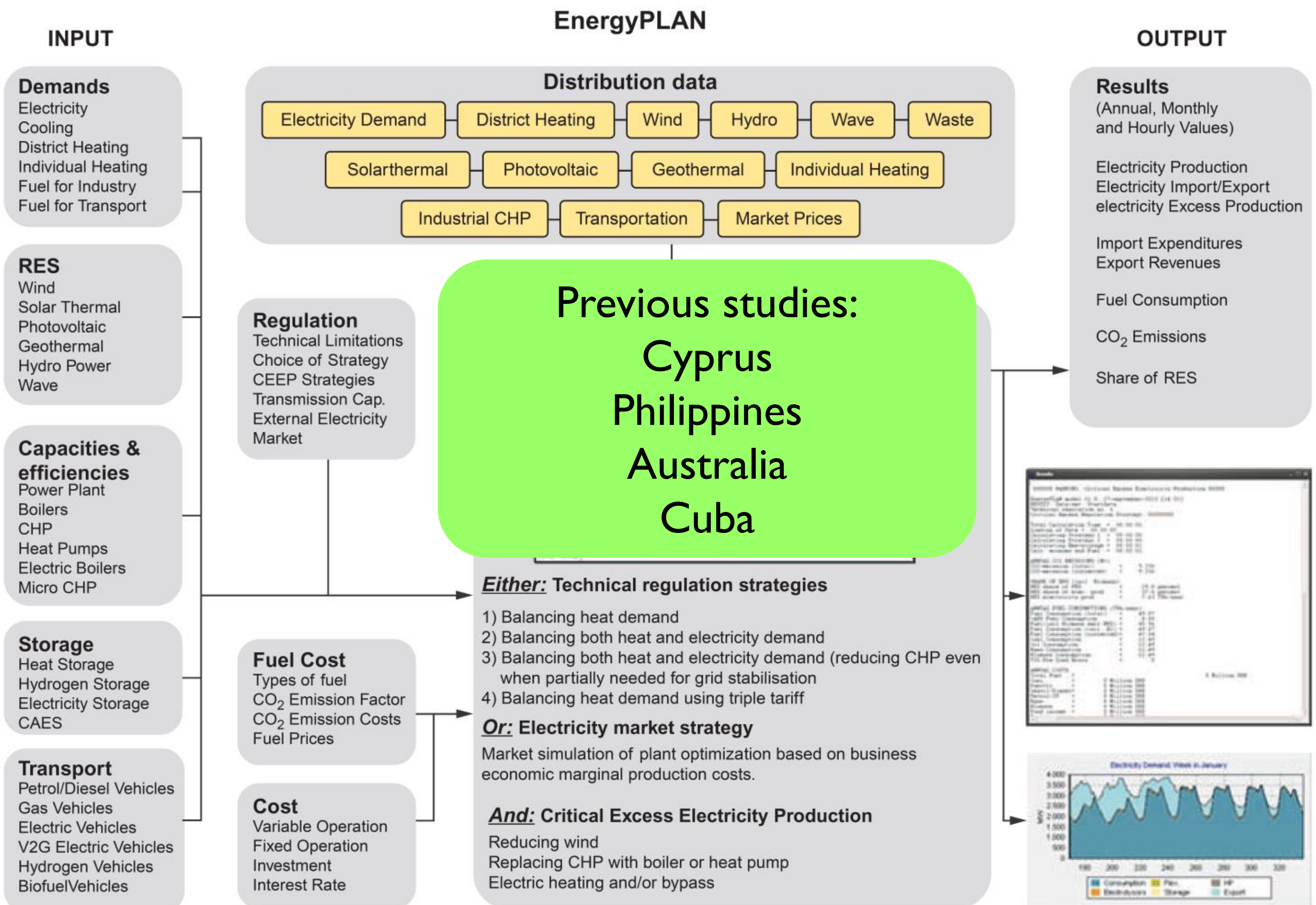
Supporting Material

Previous Studies: Examples

Solomon, Energy Policy, 2010
PV+storage, IEC 2006



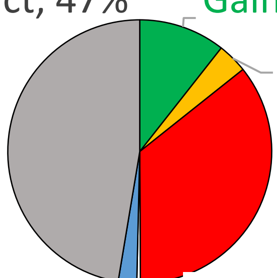
Energy Management System

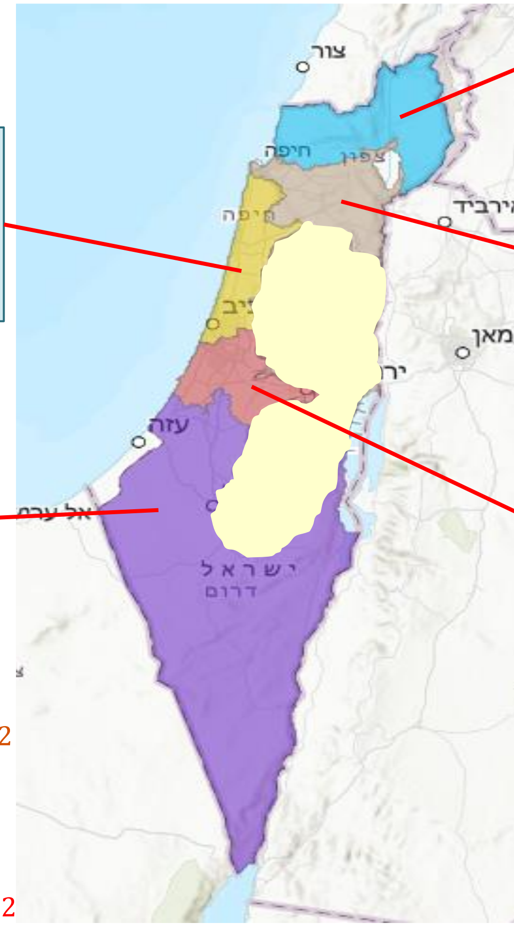


Previous studies:
Cyprus
Philippines
Australia
Cuba

Available Area: Agrivoltaics (APV)

- Crop (yield) response to shade:
  - **Benefit (Gain)**
  - **Neutral**
  - **Loss**



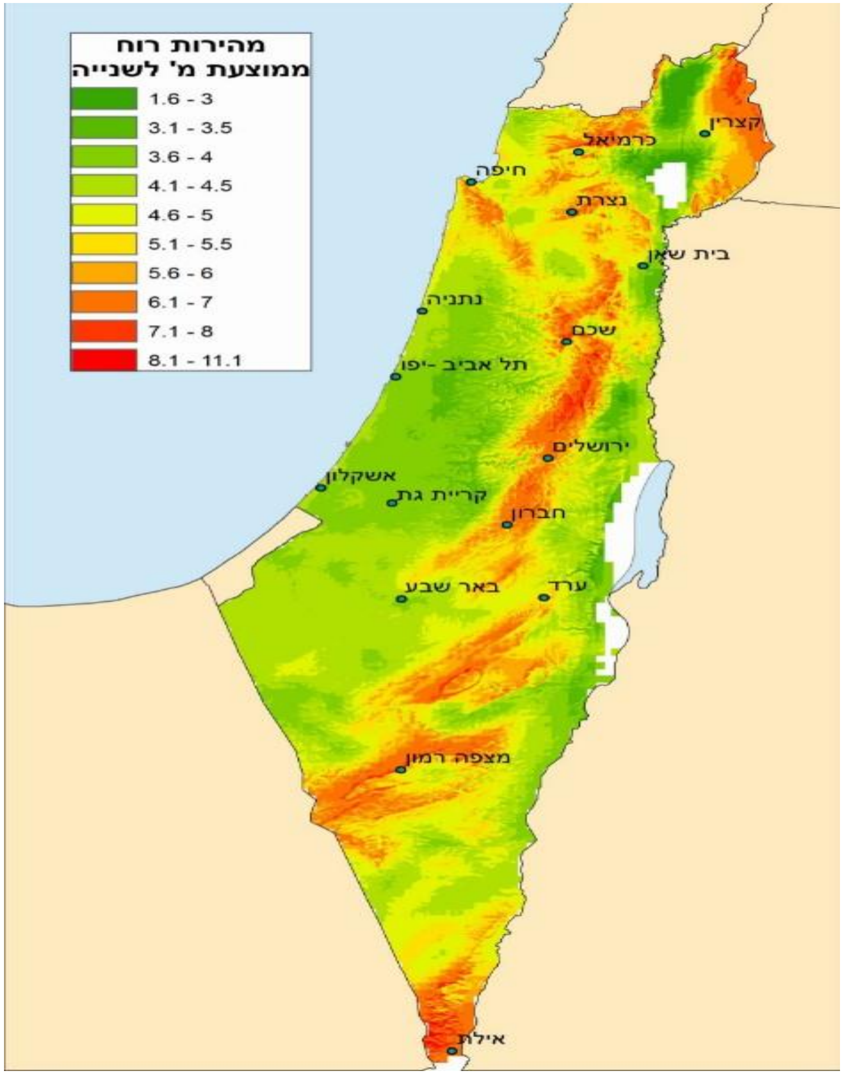


משרד החקלאות, 2022

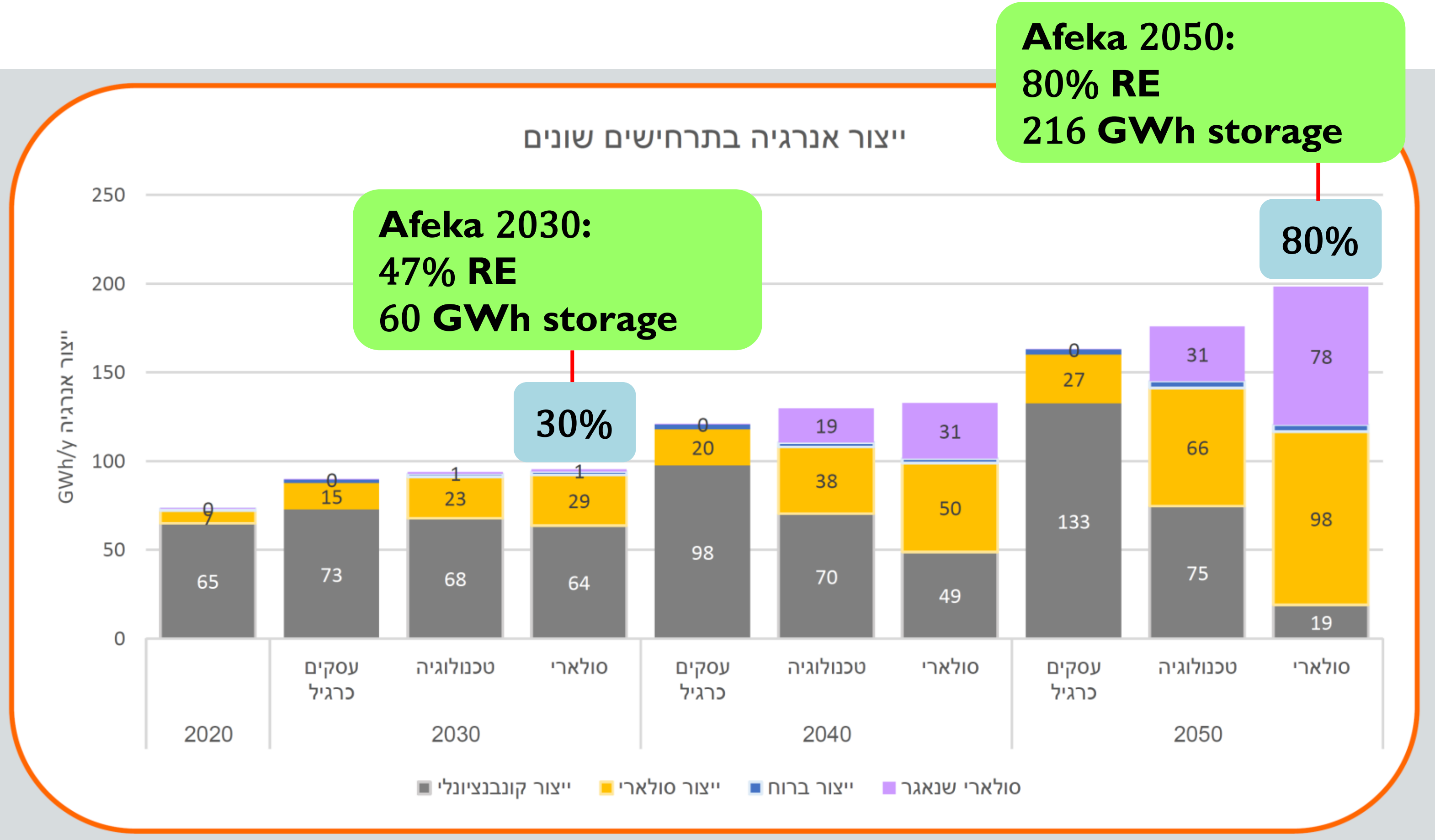
Available Area: Wind

- South: military areas and natural reserves
- East: areas near the West Bank
- North: dictated by public policy (Peri, 2020)

השירות המטאורולוגי הישראלי,2015
בגובה 100 מ'



ISR 2050?

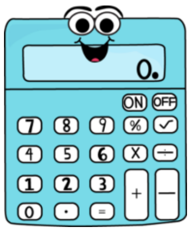


משרד האנרגיה, מפת הדרכים למשק אנרגיה דל פחמן עד שנת 2050 (אוקטובר 2021)

Conclusions

big data

- ❖ Input data:
- ❖ Modeling/analysis



- ❖ Economics are currently excluded
  - Micro level (2050?):
    - Power plants
    - Infrastructure
  - Macro level
    - Environmental impact
    - Climate crisis cost?

Acknowledgments

- Prof. Erel Avineri

- Lev Zhivin (graduate, Energy Eng.)

- Dr. Ohad Eizenhendler
  School of Industrial Engineering and Management

- Dr. Yossef Luzon
  School of Industrial Engineering and Management

Team members: all Afeka (!)

THANK YOU!