Grid Integration of EV and Renewable Energy: Challenges & Opportunities

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Topics

- Introduction
- Part I:
  - Smart Grid
  - Renewable Energy
  - Microgrid and Energy Storage Applications
  - Policy Factors
- Summary
- Part II:
  - Electric Vehicle Integration
  - Energy Management Aspects
  - EV & Future Distribution Systems
  - User Behaviour Modelling
  - Electrification of Heavy Vehicles
- Summary

Introduction

- **Senior Lecturer, (2017 –)**
  Dept of ECSE, University of Auckland, New Zealand

- **Assistant Professor, (2013 – 2017)**
  School of EEE, Nanyang Technological University (NTU), Singapore
  www.ntu.edu.sg

- **Principal Scientist & Scientist, (2006 – 2013)**
  Asea Brown Boveri (ABB) Corporate Research, Baden-Daettwil, Switzerland
  www.abb.com

- **Software Engineer (full-time), (2000 – 2002)**
  InterraIT, Kolkata, India www.interrait.com

Research Interests:

- Renewable Energy & Integration, Microgrid, Energy Storage, Energy Management
- Electric Vehicle, Grid Integration, User behavior Modelling, Energy Efficiency

Research Group at UoA

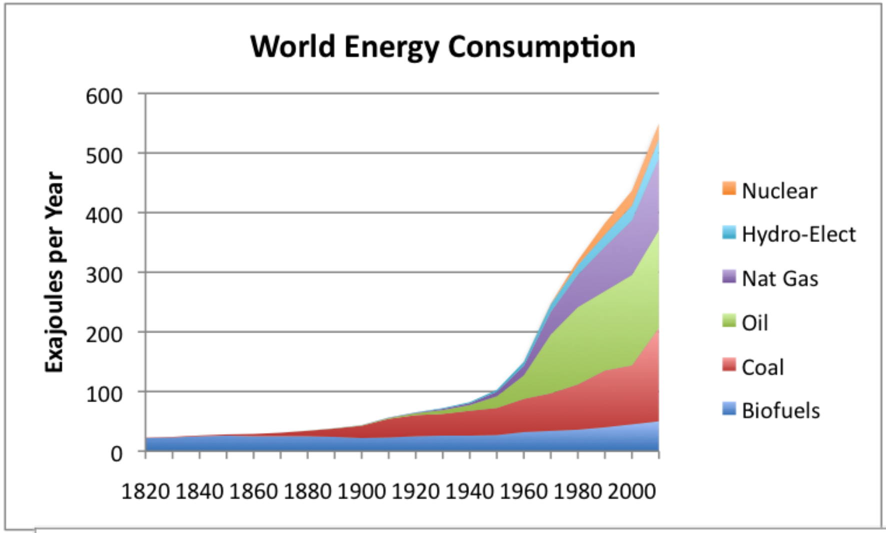
Postgraduate supervision

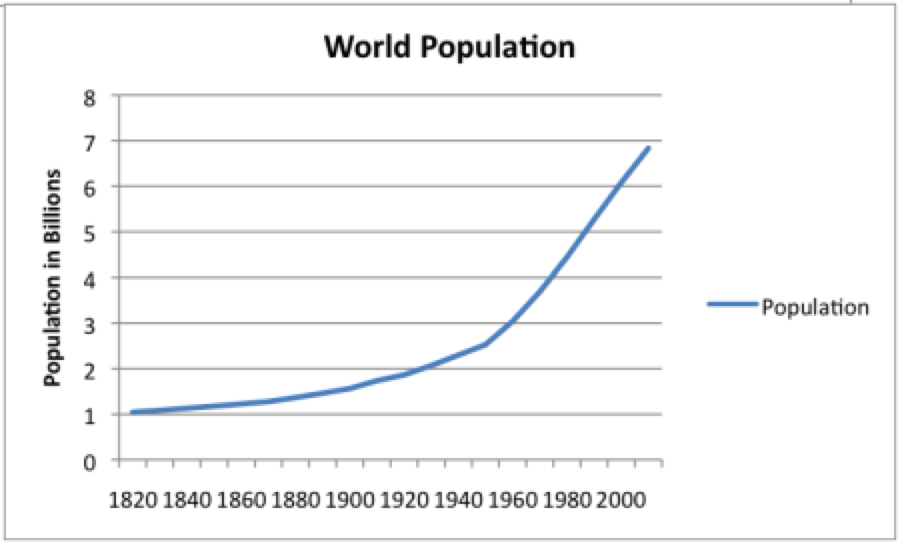
UoA, New Zealand (2017 –):

1. Xibeng Zhang, "Control & Coordination of AC-DC Microgrid," (PhD, 2018–).
2. Muhammad Aqib, "Voltage and Frequency Regulation in Distribution Grid with EV Integration," (PhD, 2018–).
3. Aratrika Ghosh, "Renewable Energy Integration in Distribution Grid," (PhD, 2018–).
4. Dongyu Li, "DC Fault Detection and Management in Multi-terminal HVDC Grid," (PhD, 2019–).
5. Mubashir Wani, "Building Energy Management," (Co-Sup) (PhD, 2018–).
6. Ravi Patel, "Control of Mix-Generation System," (Co-Sup) (PhD, 2019–).
7. Don Gamage, "Energy Management of Smart Grid Connected Hybrid Energy Storage System," (MS, 2018–2019).
8. Ardila Erdiansyah, "Grid Integration and Demand Response Management of Geothermal Power Plant in Indonesia," (MS, 2018–2019).
9. Ugyen Chophel, "Voltage Stability Study of Bhutan Power System During Fault on the Neighbouring System," (MS, 2018–2019).
10. Hizkia Reiner Bontong, "Wind Resource Assessment in East Nusa Tenggara, Indonesia," (MS, 2019).
11. Krunal Tailor, "Fault Detection and Locating Using Electromagnetic Time Reversal (EMTR) Technique for HVDC Transmission Network," (MS, 2019).
12. Kundan Singh, "Fault Detection in HVDC Transmission Line Based on S-Transform Technique," (MS, 2019).
13. Srikanth Gopal, "Validation and Modeling of Electrical Load Profile in Residential Buildings in New Zealand," (MS, 2018).
14. Felipe Resende de Oliveira, "Comparative Analysis of Energy Efficiency in HVAC System," (MS, 2017–2018) [Currently Product Manager at ABB, Brazil].
15. Xibeng Zhang, "Control & Coordination of AC-DC Microgrid," (MS, 2017). [Currently PhD student at UoA].

World Energy Consumption

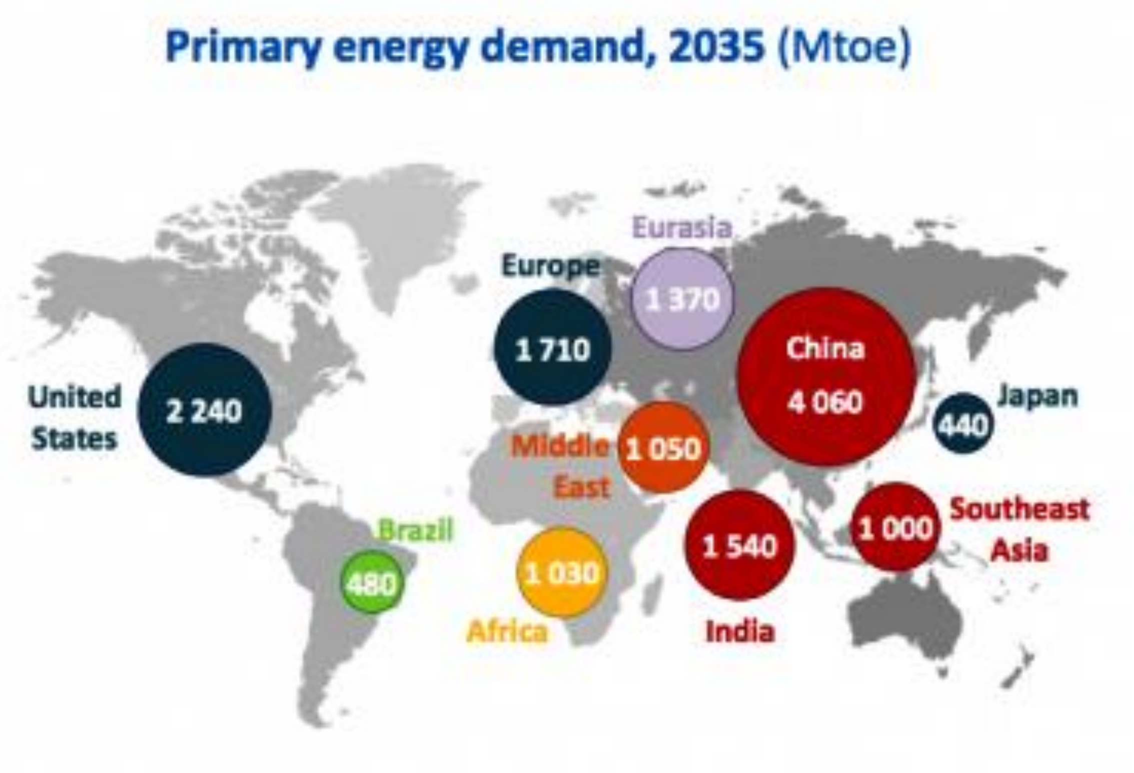
1 Exajoule = 10^{18} Joule = 1,000,000,000,000,000,000 Joule





Source: BP statistics

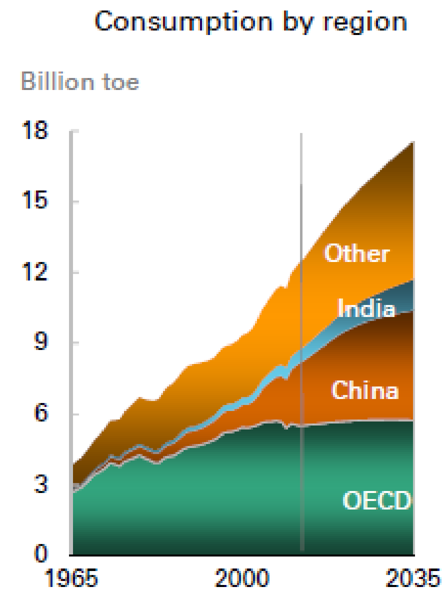
Energy Demand

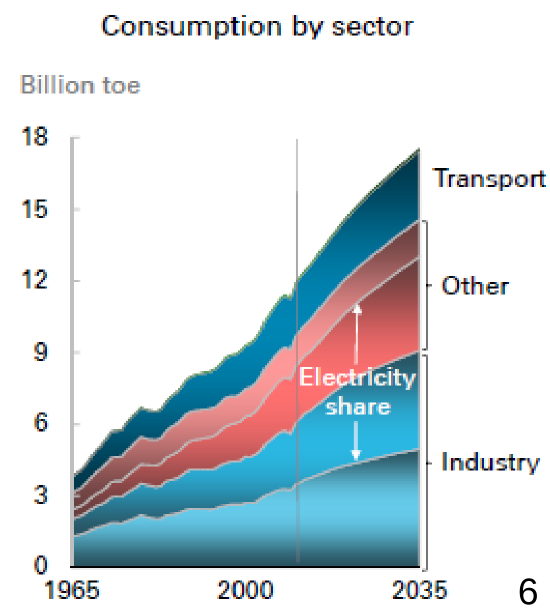


1 Million tons of oil equivalent (Mtoe) =

1163,000,000,0 kWh = 11.63 TWh

Source: IEA, BP





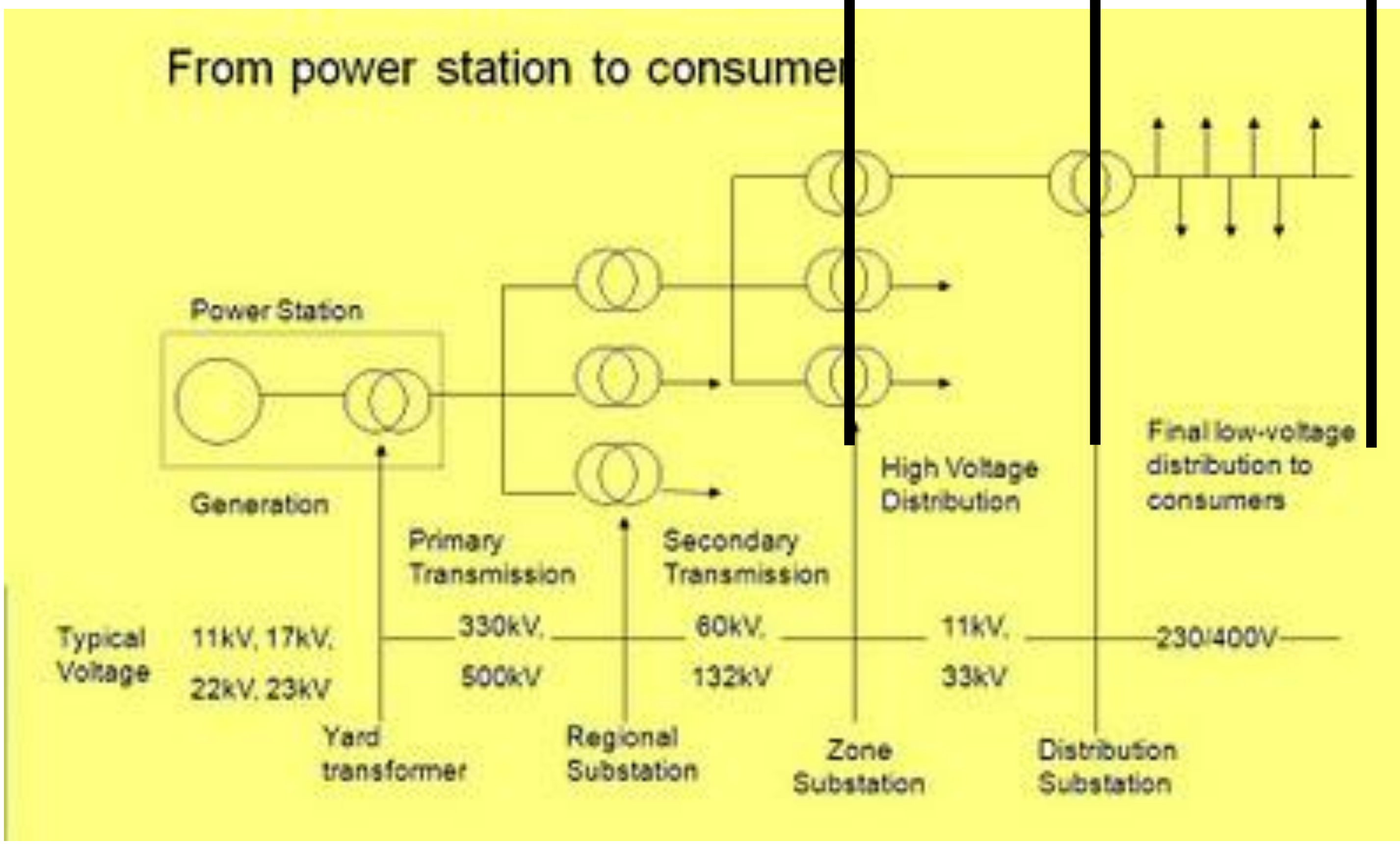
Power System – Generation, T&D

THE UNIVERSITY OF AUCKLAND
Te Whare Wananga o Tamaki Makaurau
NEW ZEALAND

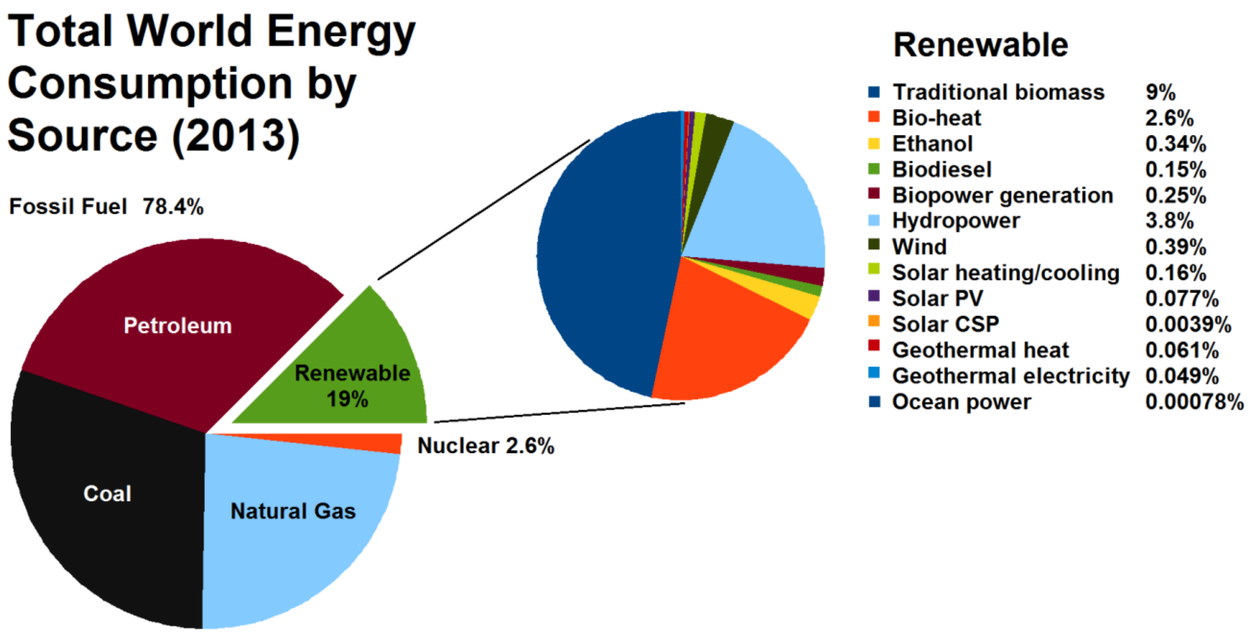
EHV, HV
(CB Cost:
1,000,000 US$)
[V, I, f, communication]

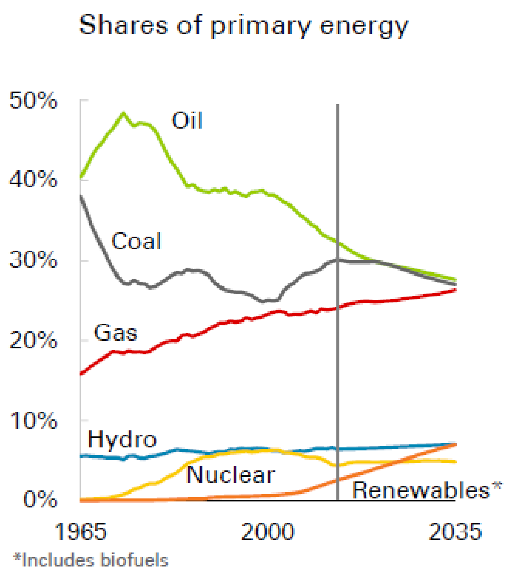
MV
(CB Cost:
10,000 US$
[I, f]

LV
(CB Cost:
100 US$
[I]



Renewable Energy Generation





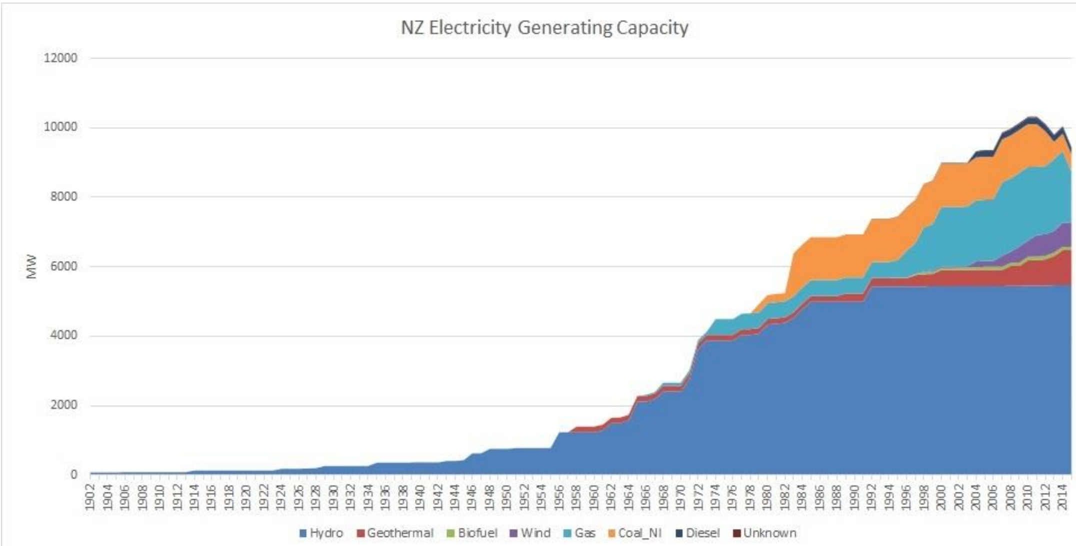
Source: IEA, BP

Four Major Categories of Renewable Energy Sources:

- Hydro, Wave, Tidal
- Solar
- Wind
- Bio-fuels

New Zealand: Energy Landscape

A. Ukil/ECSE



NZ Energy (2017)	
Installed Capacity	9237 MW
Production	42,911 GWh
Renewable Energy	82%
Fossil Energy	18%

Huntly (Coal/Gas) [1435 MW]

Aviemore Dam (Hydro) [220 MW]

Wairakei (Geothermal) [176 MW]

Te Apiti (Wind) [90 MW]

Marlborough (PV) [0.4 MW]

[1] ‘Energy in New Zealand 2018,’ MBIE, 31 October 2018.

Renewable Energy: Hydro Electricity

A. Ukil/ECSE

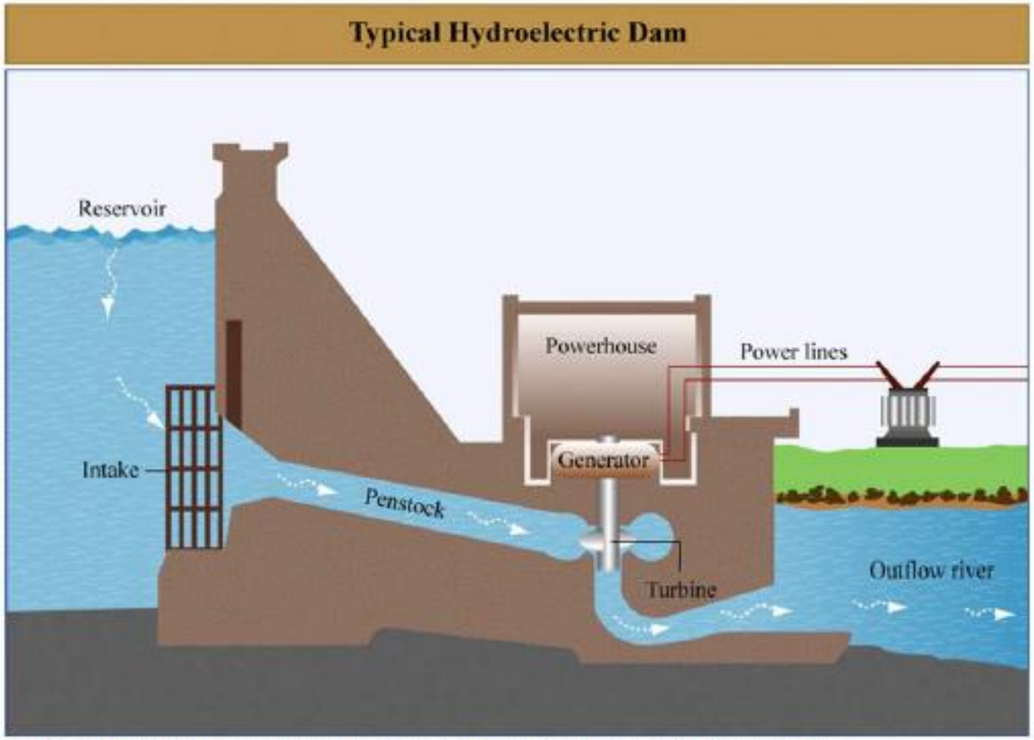


Image by MIT OpenCourseWare. Adapted from Tennessee Valley Authority.

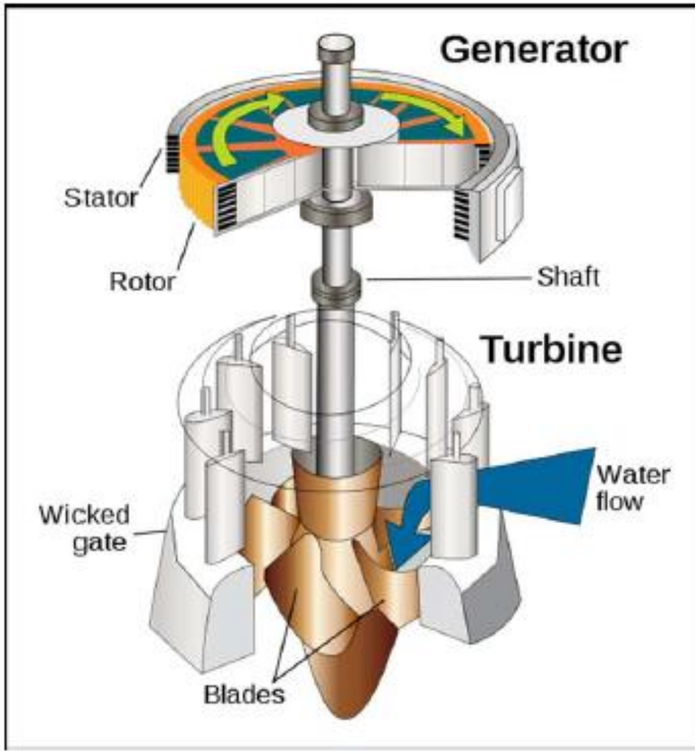
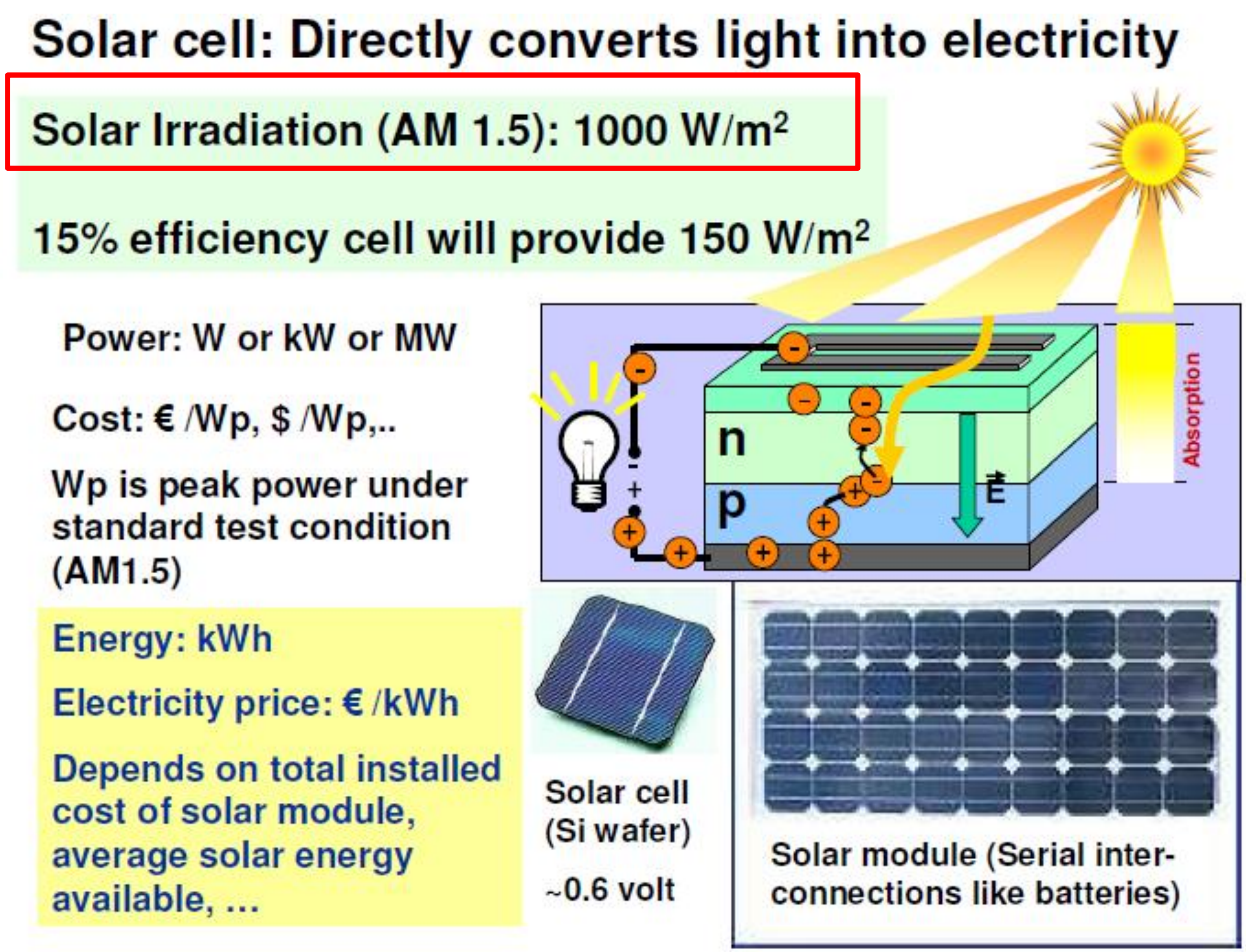
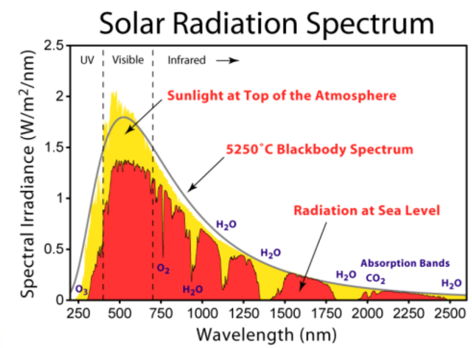


Image by Mikhail Ryazanov on Wikimedia Commons.

Renewable Energy: Solar PV

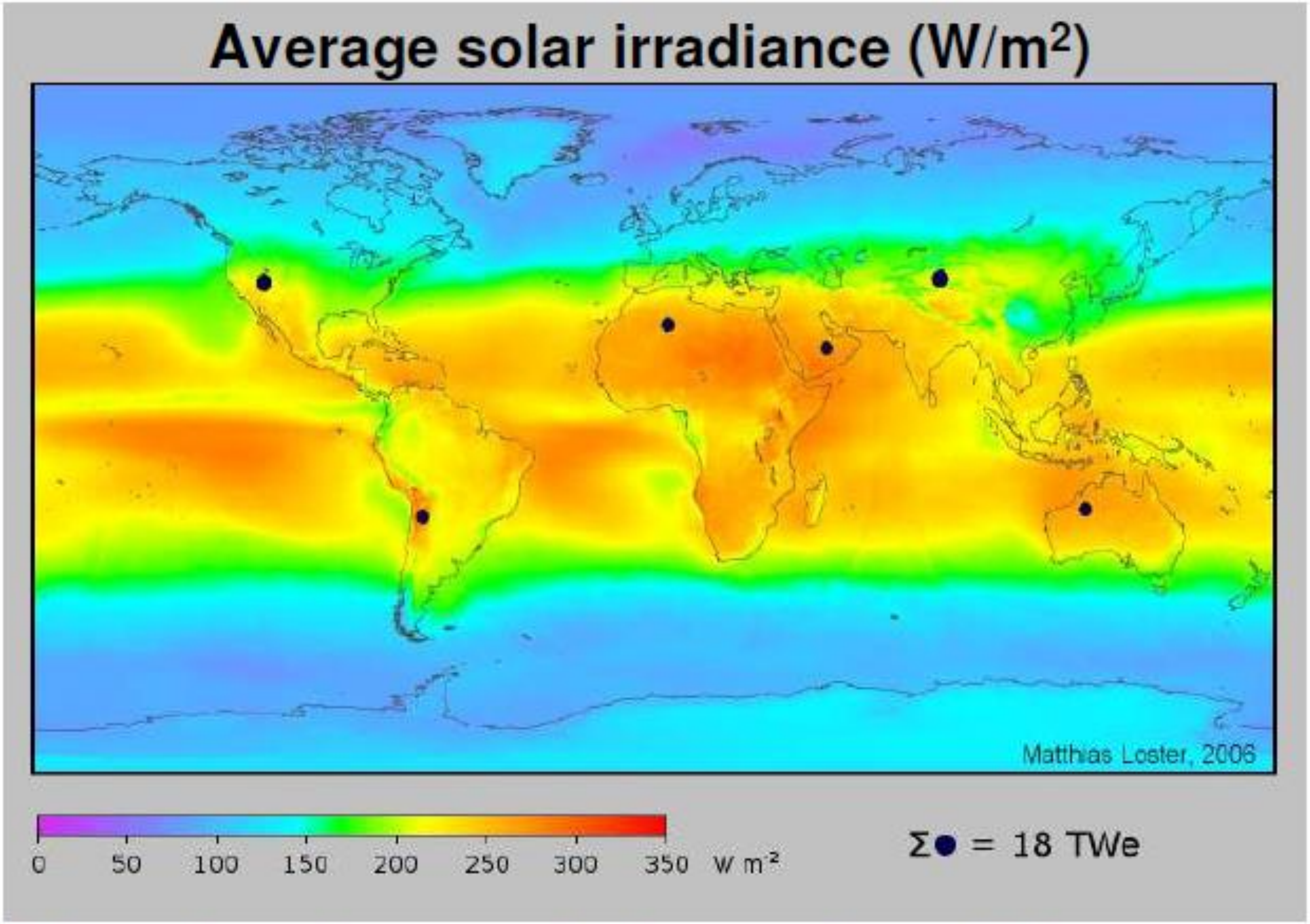




AM: Air Mass Spectrum Coefficient
(i.e., quality of solar spectrum as it travels through the atmosphere)

[1] A. Ukil, "Lecture Notes: ELECTENG 703," Univ. of Auckland, 2018.

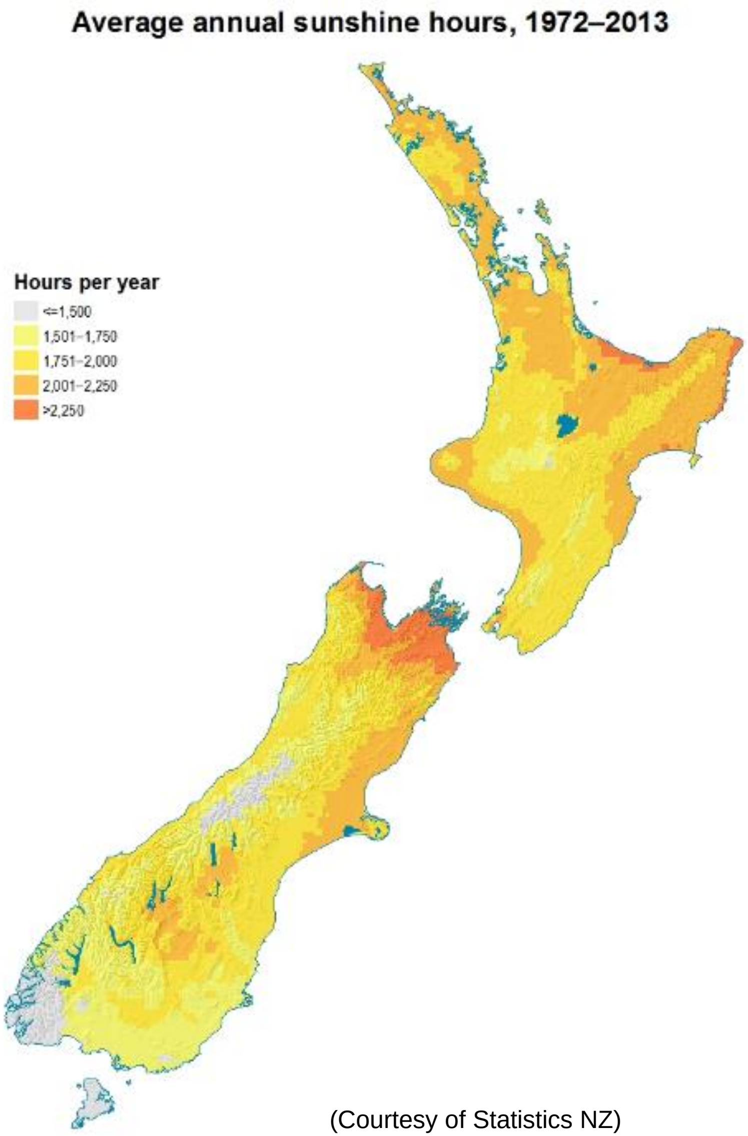
Renewable Energy: Solar PV



Black dots show the area of solar panels needed to generate all the energy needs of the world using 8% eff. PV modules

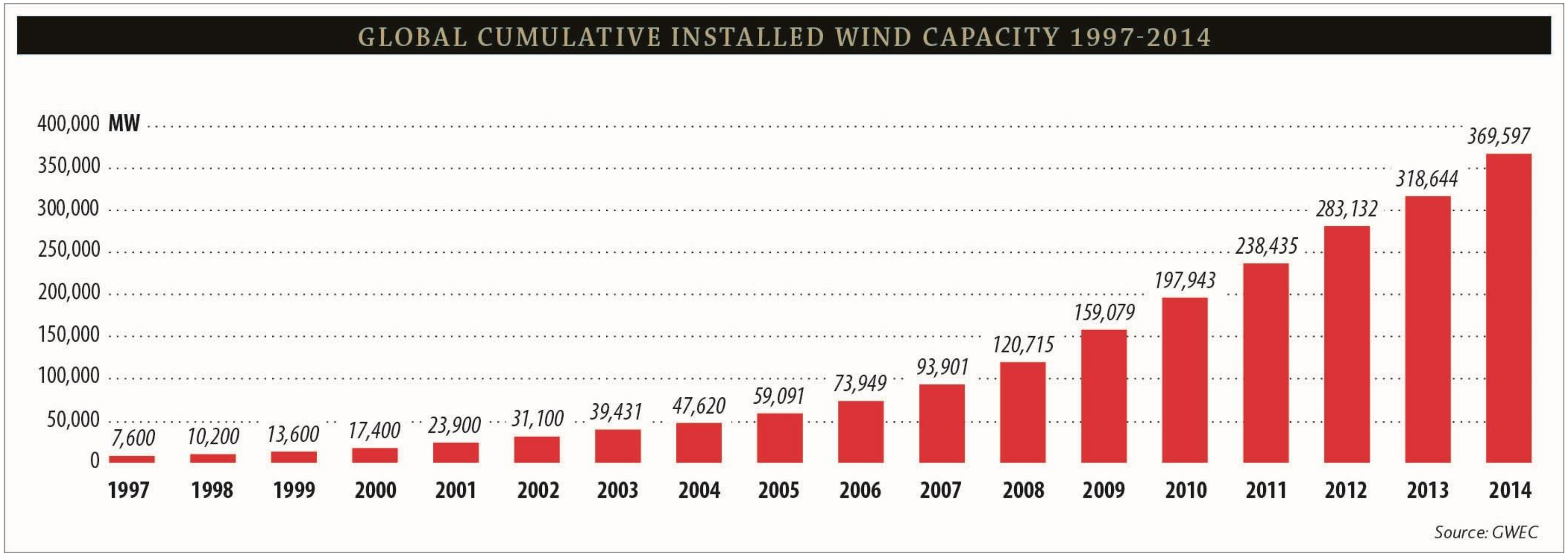
Source: IEA

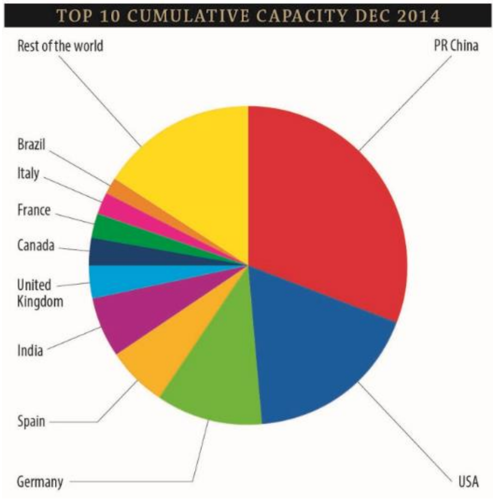
Renewable Energy: Solar PV



(Courtesy of Statistics NZ)

Renewable Energy: Wind



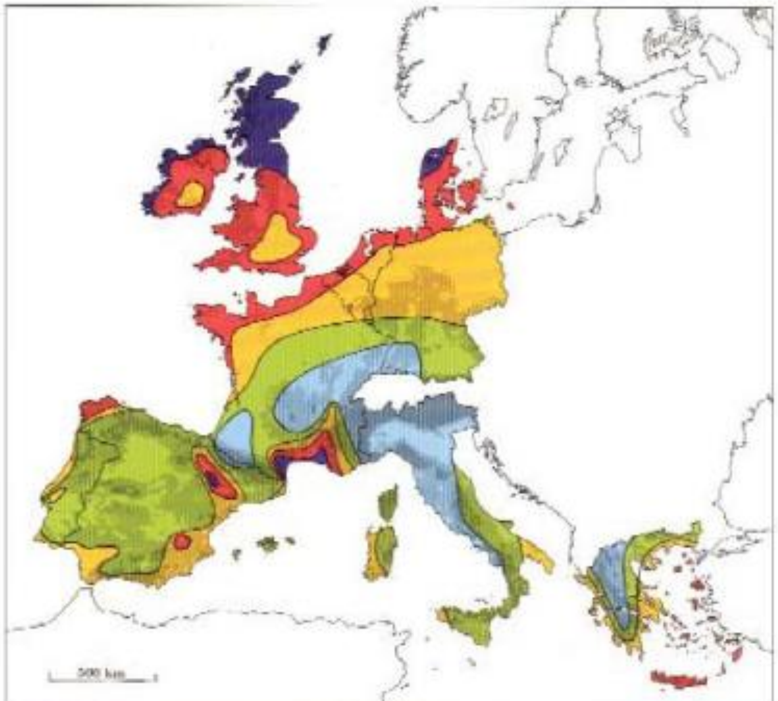


Country	MW	% SHARE
PR China	114,609	31.0
USA	65,879	17.8
Germany	39,165	10.6
Spain	22,987	6.2
India	22,465	6.1
United Kingdom	12,440	3.4
Canada	9,694	2.6
France	9,285	2.5
Italy	8,663	2.3
Brazil*	5,939	1.6
Rest of the world	58,473	15.8
Total TOP 10	**311,124**	**84.2**
World Total	**369,597**	**100**

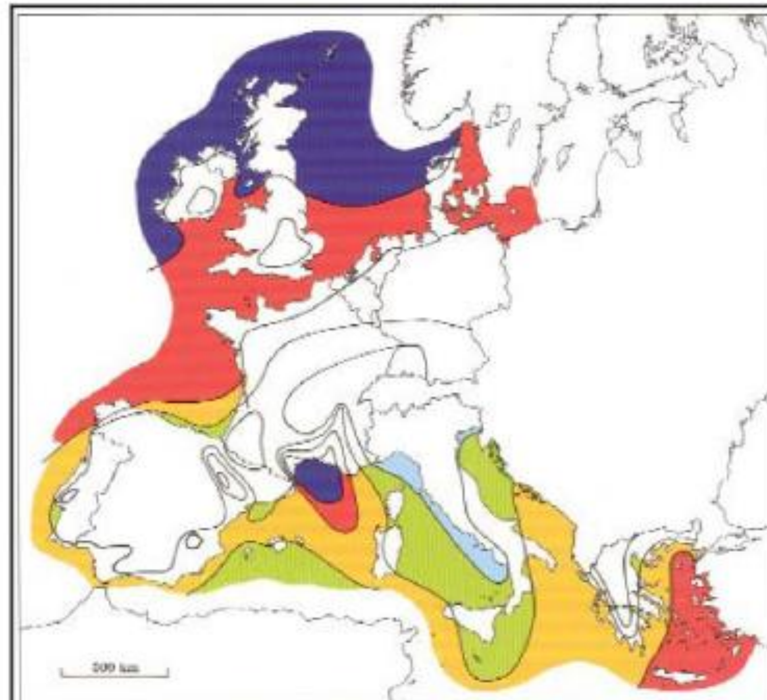
** Projects fully commissioned, grid connection pending in some cases* *Source: GWEC*

[1] GWEC, “World Wind Energy Report,” 2014, www.gwec.net

Wind Energy: Onshore vs Offshore



Wind resources[1] at 50 metres above ground level for five different topographic conditions	Sheltered terrain[2]		Open plain[3]		At a sea coast[4]		Open sea[5]		Hills and ridges[6]	
	$m s^{-1}$	$W m^{-2}$	$m s^{-1}$	$W m^{-2}$	$m s^{-1}$	$W m^{-2}$	$m s^{-1}$	$W m^{-2}$	$m s^{-1}$	$W m^{-2}$
(dark blue)	> 6.0	> 250	> 7.5	> 500	> 8.5	> 700	> 9.0	> 800	> 11.5	> 1800
(red)	5.0-6.0	150-250	6.5-7.5	300-500	7.0-8.5	400-700	8.0-9.0	600-800	10.0-11.5	1200-1800
(orange)	4.5-5.0	100-150	5.5-6.5	200-300	6.0-7.0	250-400	7.0-8.0	400-600	8.5-10.0	700-1200
(green)	3.5-4.5	50-100	4.5-5.5	100-200	5.0-6.0	150-250	5.5-7.0	200-400	7.0-8.5	400-700
(light blue)	< 3.5	< 50	< 4.5	< 100	< 5.0	< 150	< 5.5	< 200	< 7.0	< 400



Wind resources over open sea (more than 10 km offshore) for five standard heights	10 m		25 m		50 m		100 m		200 m	
	$m s^{-1}$	$W m^{-2}$	$m s^{-1}$	$W m^{-2}$	$m s^{-1}$	$W m^{-2}$	$m s^{-1}$	$W m^{-2}$	$m s^{-1}$	$W m^{-2}$
(dark blue)	> 8.0	> 600	> 8.5	> 700	> 9.0	> 800	> 10.0	> 1100	> 11.0	> 1500
(red)	7.0-8.0	350-600	7.5-8.5	450-700	8.0-9.0	600-800	8.5-10.0	650-1100	9.5-11.0	900-1500
(orange)	6.0-7.0	200-350	6.5-7.5	300-450	7.0-8.0	400-600	7.5-8.5	450-650	8.0-9.5	600-900
(green)	4.5-6.0	100-200	5.0-6.5	150-300	5.5-7.0	200-400	6.0-7.5	250-450	6.5-8.0	300-600
(light blue)	< 4.5	< 100	< 5.0	< 150	< 5.5	< 200	< 6.0	< 250	< 6.5	< 300

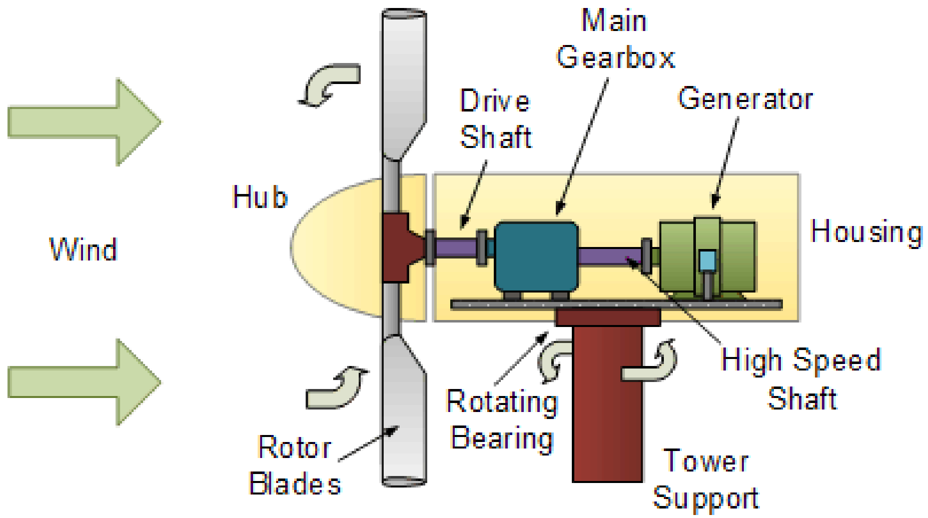
Onshore

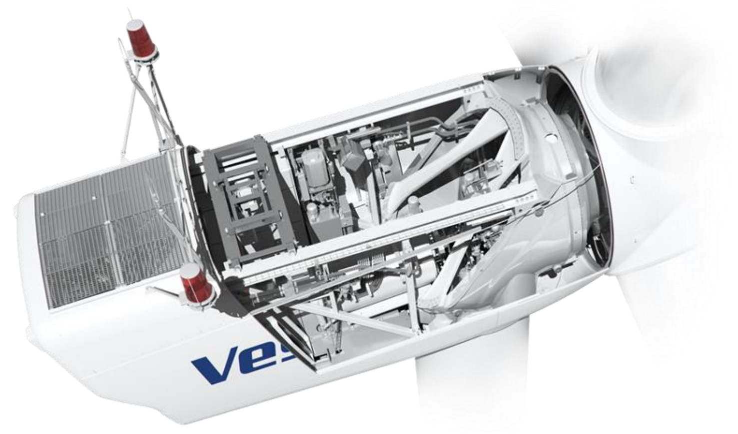
Offshore

Sustainable development commission, Wind Power in the UK, 2005

[1] GWEC, "World Wind Energy Report," 2014, www.gwec.net

Renewable Energy: Wind

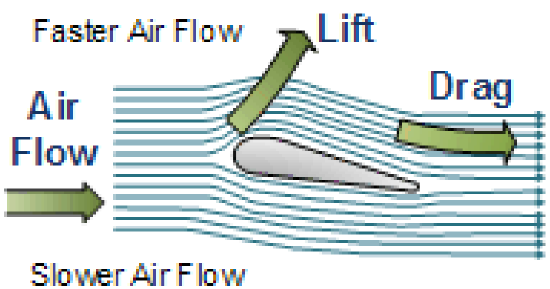


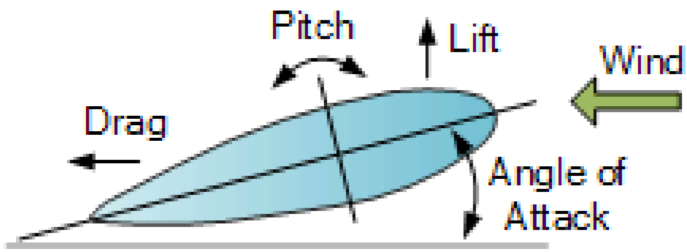


$$P \approx \frac{1}{2}\rho \cdot S \cdot C_p \cdot v^3$$

S = blade surface

v = wind speed





[1] A. Ukil, “Lecture Notes: ELECTENG 703,” Univ. of Auckland, 2018.

Renewable Energy: Geothermal

- Dig a hole in the ground
- Keep digging until you reach steam or hot water - steam mixture under pressure
- This hot fluid is forced to the surface
- Use it to make steam
- Use the steam to make electricity
- Pump the water back into the earth

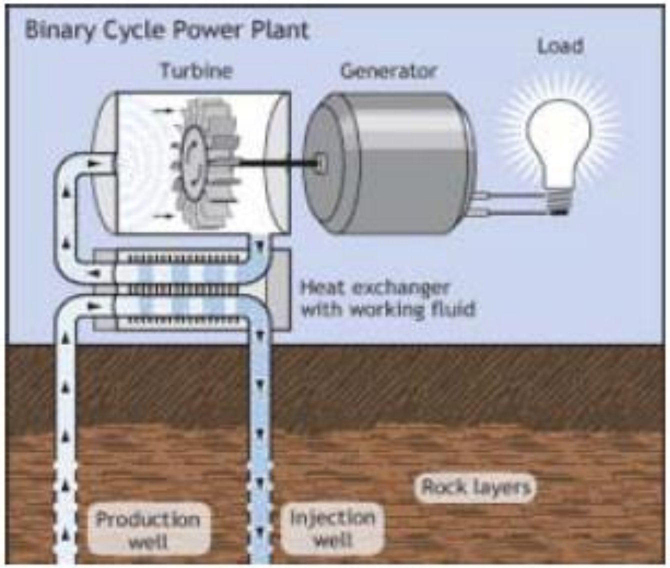


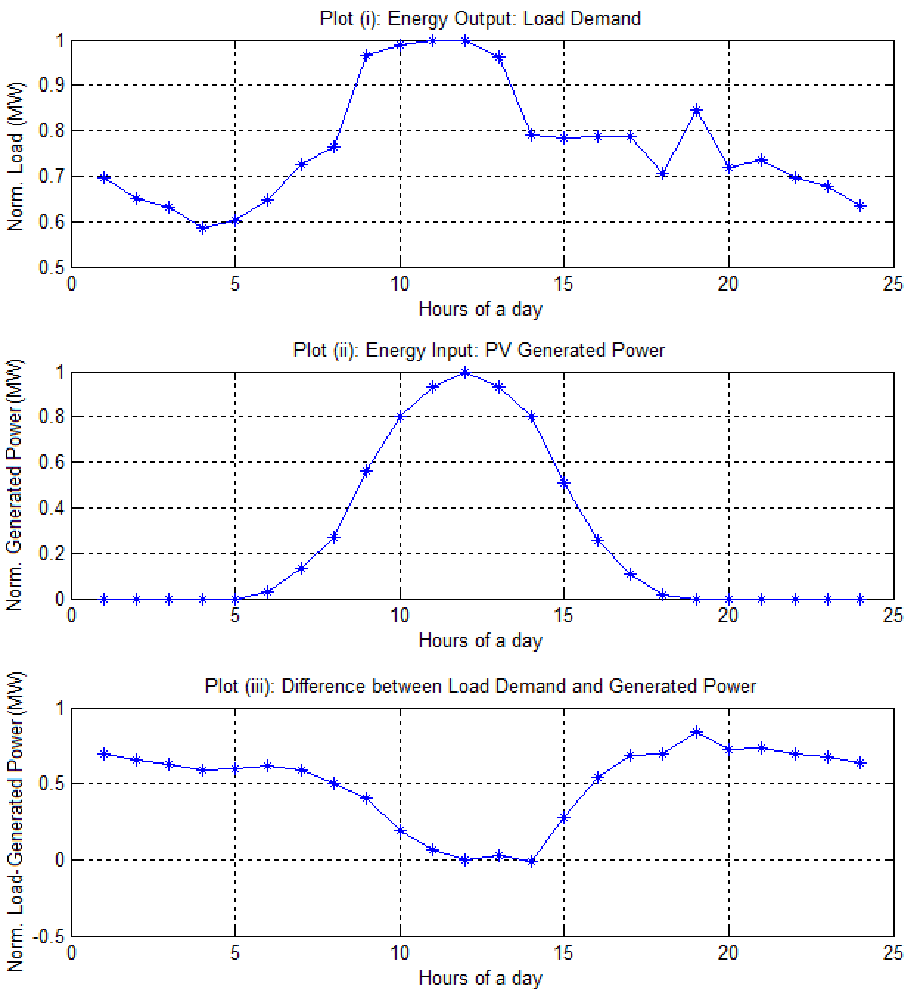
Image from EERE.

Grid Integration of Renewable Energy

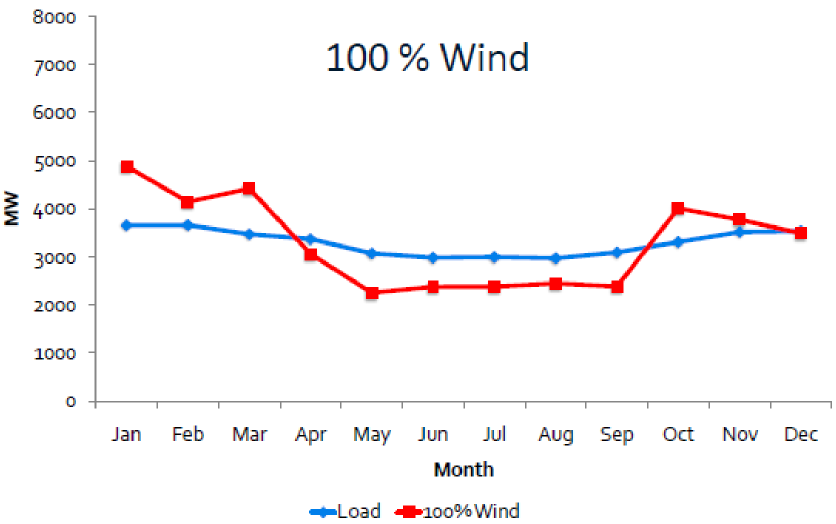
A. Ukil/ECSE

Grid integration issue: Total Power & Demand

Typical Daily Solar Irradiation



Yearly Wind Profile (Data from Europe)



[1] A. Ukil, "Lecture Notes: ELECTENG 703," Univ. of Auckland, 2018.

Grid Integration of Renewable Energy

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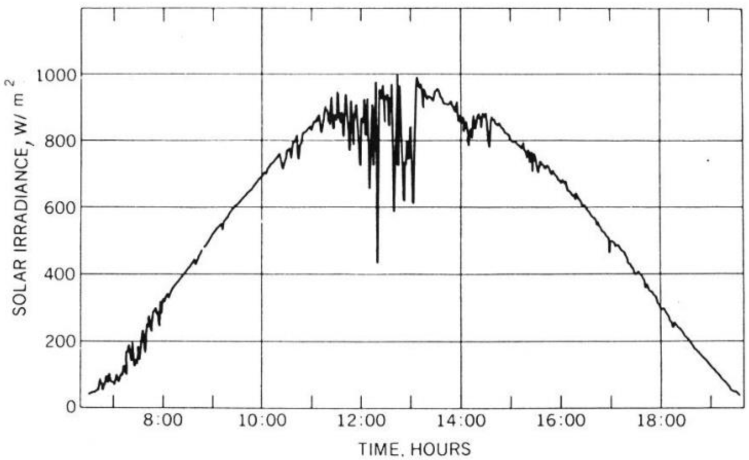
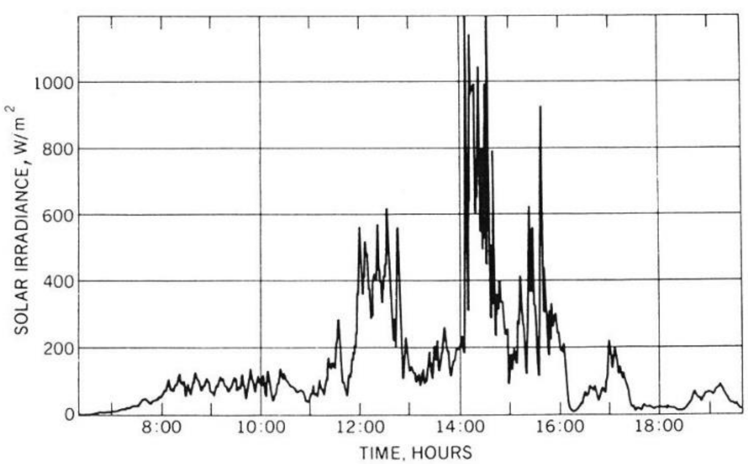
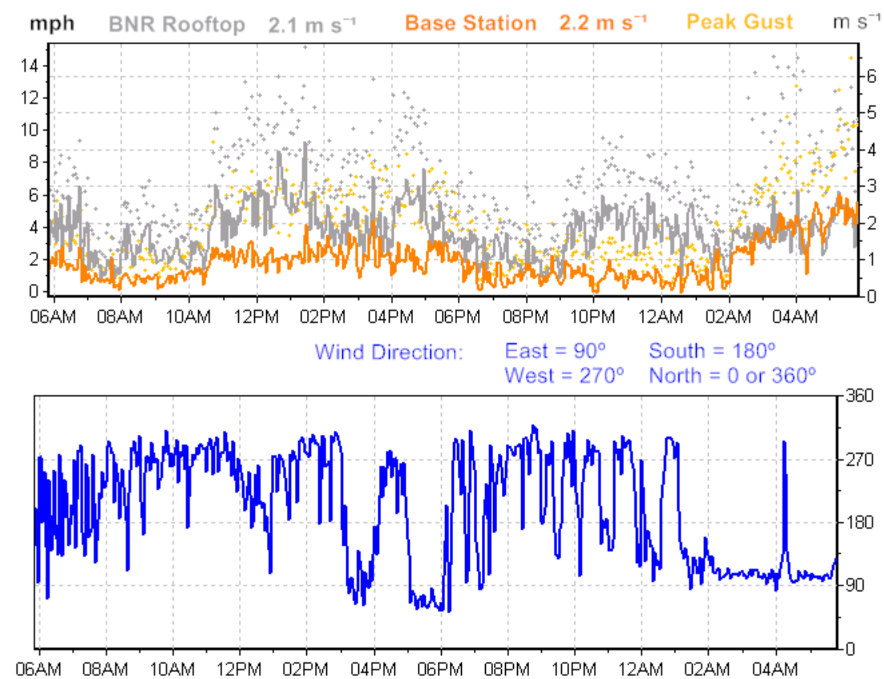
Grid integration issue: Intermittency



(a)



(b)



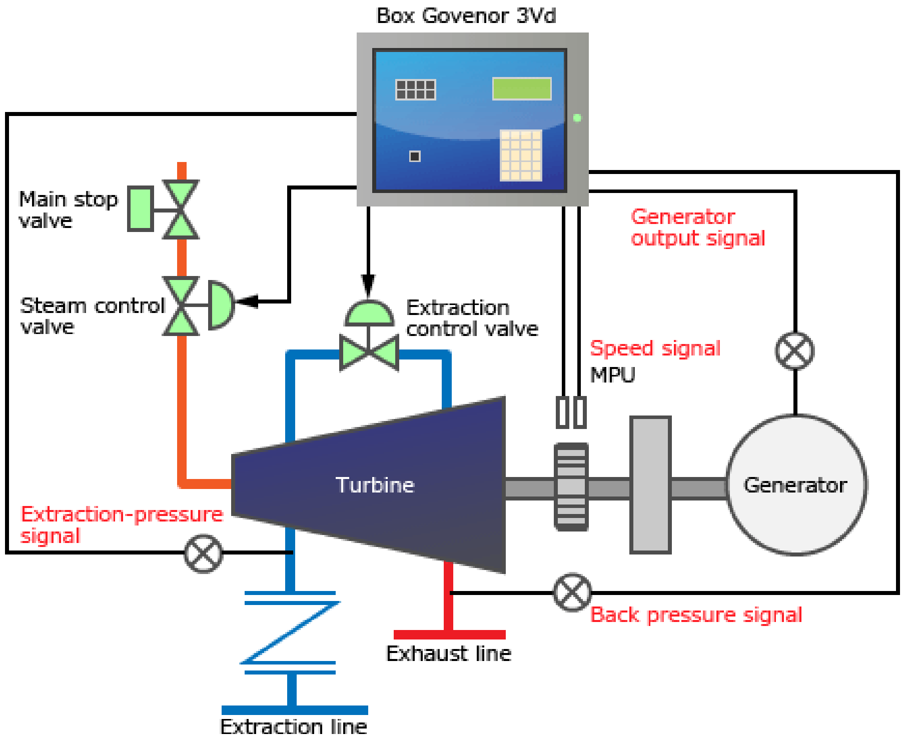
With such input power fluctuation, grid (frequency) will be unstable

[1] Source: GWEC, NREL

Grid Integration of Renewable Energy

A. Ukil/ECSE

Traditional Control of Frequency and Voltage

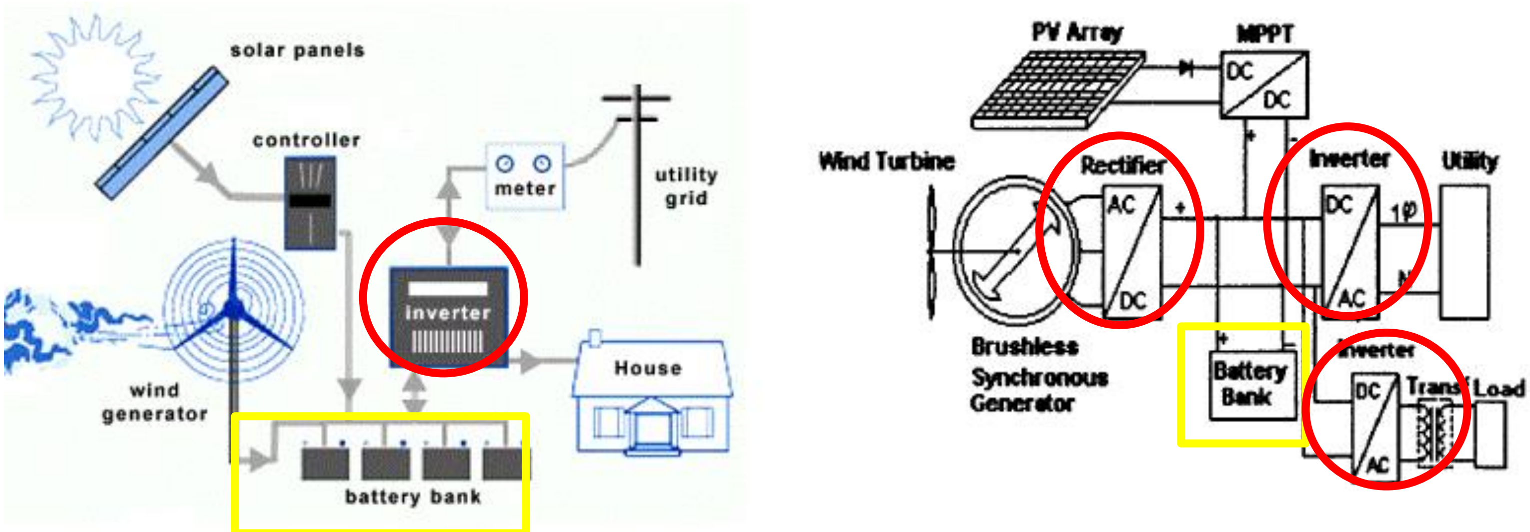


Frequency :: Active Power
Voltage :: Reactive Power

THE CONTROL IS IN OUR HAND – How much steam (speed) we need
Voltage & Frequency remain constant

WE CANNOT CONTROL NATURE – SOLAR or WIND

How to Solve Grid Integration Issue?



(a) (b)

BATTERY/STORAGE: ALLOWS US TO CONTROL SOLAR/WIND FLUCTUATION AT OUR WILL

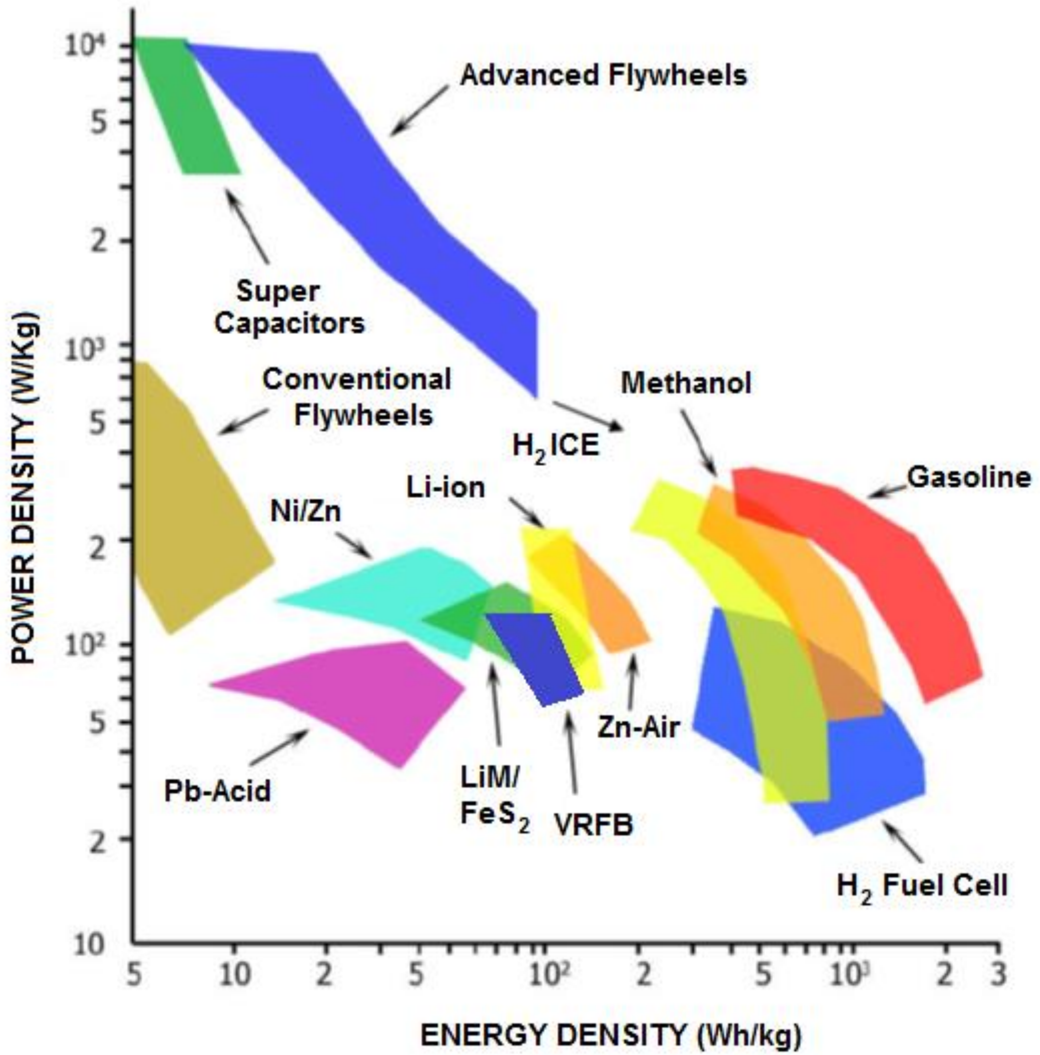
RECTIFIER: CONVERTS AC TO DC

INVERTER: CONVERTS DC TO AC

[1] A. Ukil, "Lecture Notes: ELECTENG 703," Univ. of Auckland, 2018.

Energy Storage: Key Factor

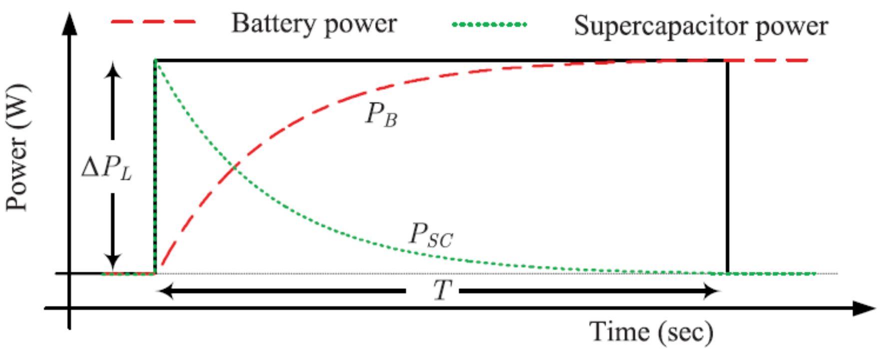
Comparison of Different Energy Storage Technologies: RAGONE Plot

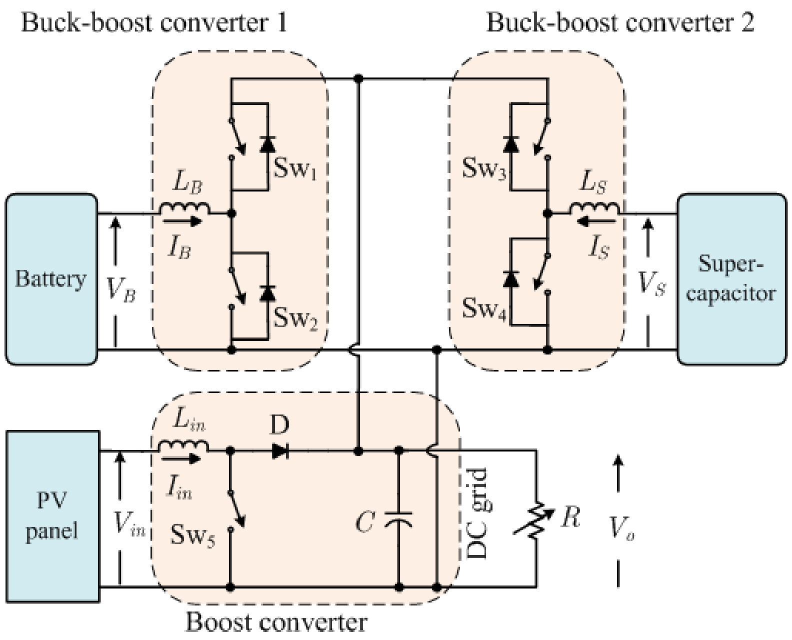


[1] Y. Shi, C. Eze, B. Xiong, W. He, H. Zhang, T.M. Lim, A. Ukil, J. Zhao, *Applied Energy*, vol. 238, pp. 202–224, 2019.

Hybrid Energy Storage System (HESS)

- Objective: to optimize the charge/discharge rates of the battery (expensive)
- Supercapacitor is used with battery to form hybrid energy storage system (HESS)
- Advantages: battery stress levels are optimized, and state of charge (SOC) of the battery is maintained, increasing lifetime of battery

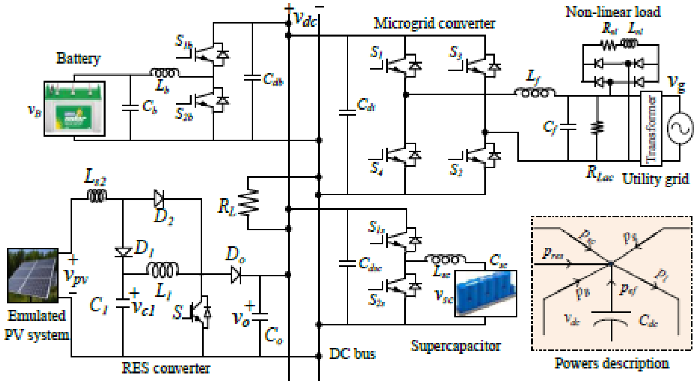




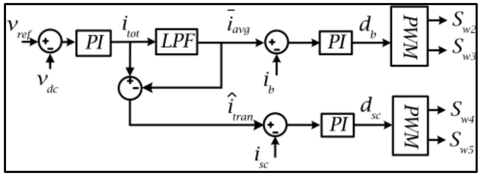
[1] S. K. Kollimalla, A. Ukil, H. B. Gooi, U. Manandhar, N. Reddy. *IEEE Transactions on Sustainable Energy,* vol. 8, no. 2, pp. 516-529, 2017.

Hybrid Energy Storage at LV-DC/AC

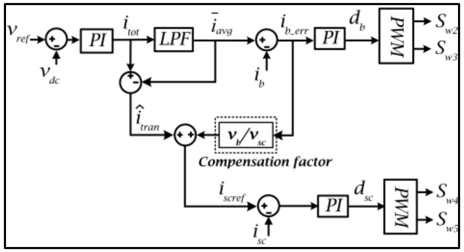
A. Ukil/ECSE

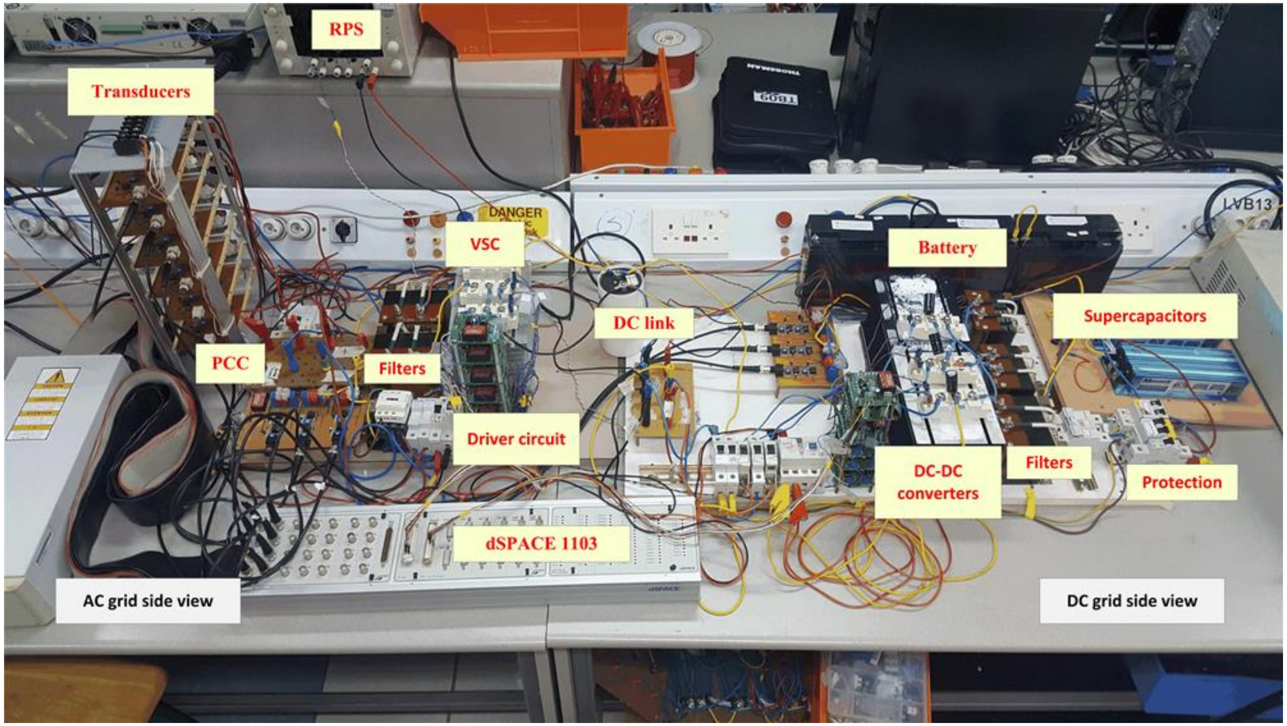


State of art control strategy



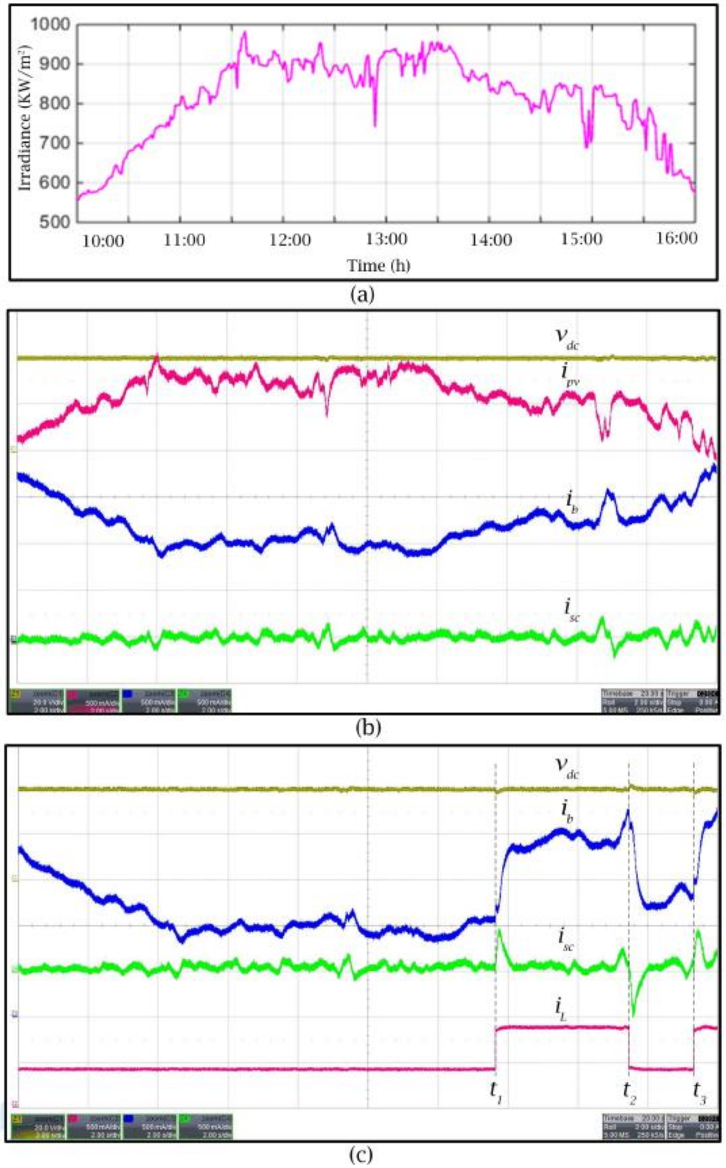
Faster joint control strategy [1]





[1] U. Manandhar, N. R. Tummuru, S. K. Kollimalla, A. Ukil, H. B. Gooi, K. Chaudhari. *IEEE Tr. Industrial Electronics,* vol. 65, no. 4, pp. 3286–3295, 2018

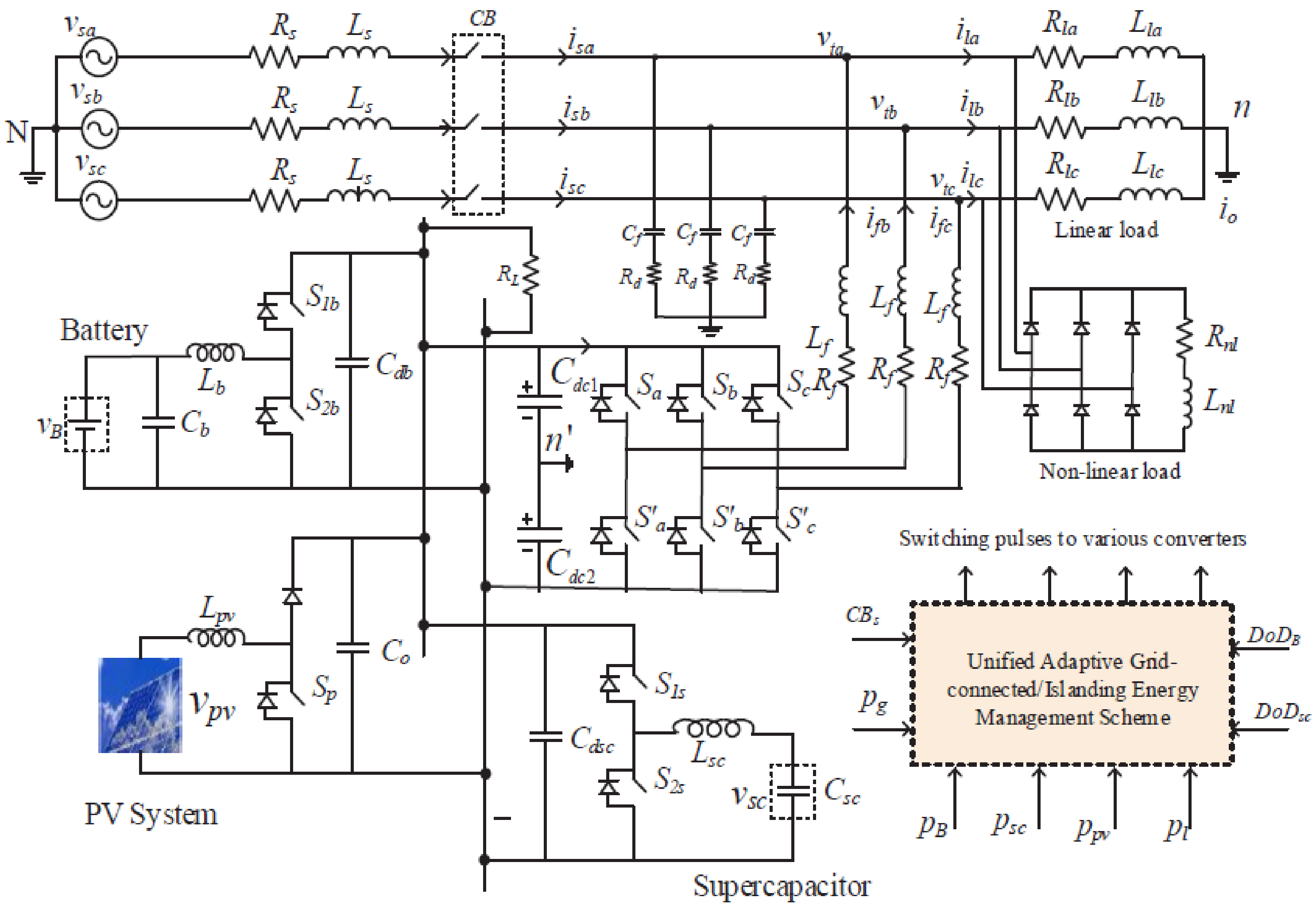
Experimental Results for PV



Experimental results for PV generation: (a) Input irradiation pattern, (b) PV change with constant load, (c) PV change with variable load demand.

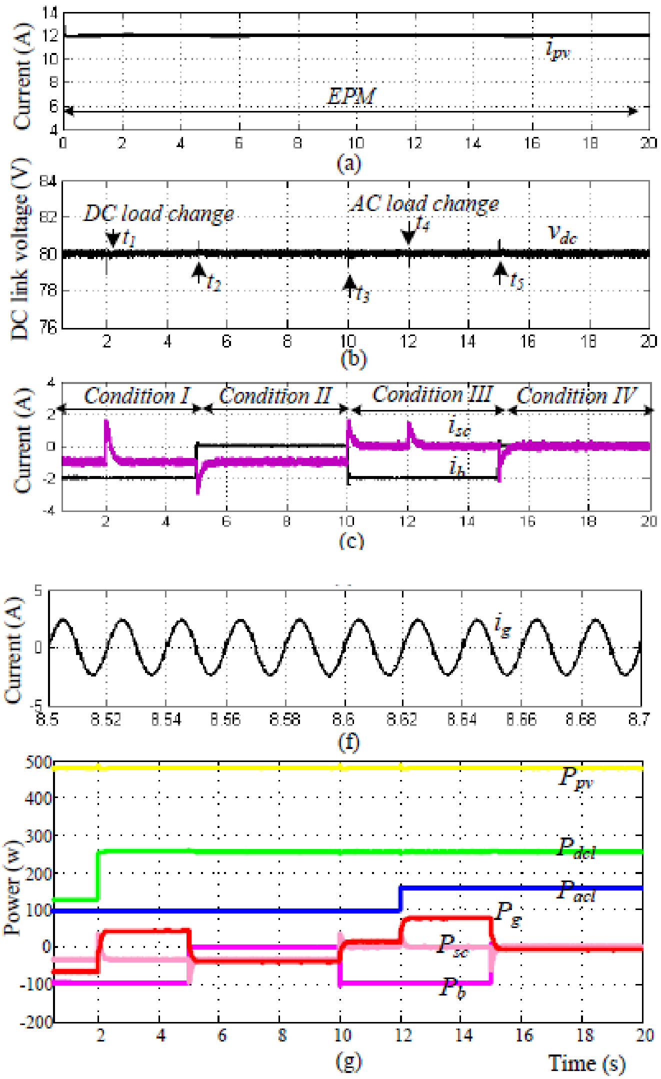
[1] U. Manandhar, N. R. Tummuru, S. K. Kollimalla, A. Ukil, H. B. Gooi, K. Chaudhari. *IEEE Tr. Industrial Electronics,* vol. 65, no. 4, pp. 3286–3295, 2018

Hybrid AC-DC Microgrid



[1] N.R. Tummuru, U. Manandhar, A. Ukil, H.B. Gooi, S.K. Kollimalla, S. Naidu, *Int. J. Electric Power & Energy Systems*, vol. 104, pp. 807–816, 2019.

Hybrid AC-DC Microgrid - Control



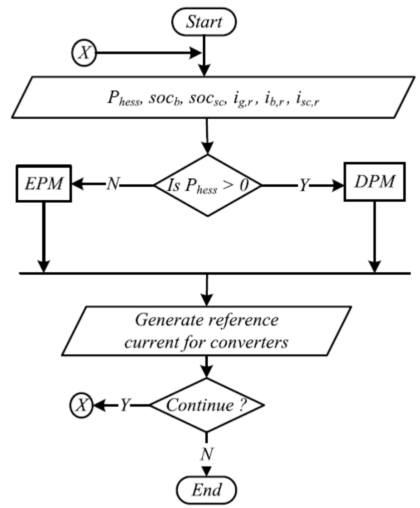
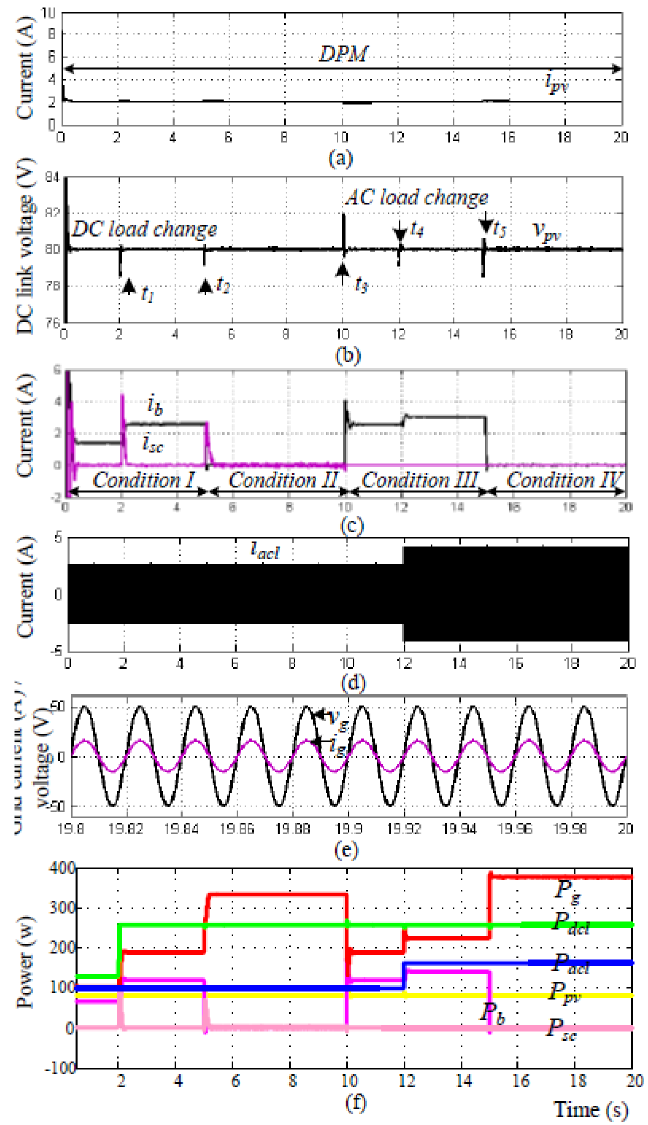


TABLE II
DPM

Conditions	Current setting
$SOC_b > L_b$ & $SOC_{sc} > L_{sc}$	$i_b^* = \gamma.i_{avg}, i_{sc}^* = i_{sc,r}$ $i_g^* = (1-\gamma).i_{avg}$
$SOC_b < L_b$ & $SOC_{sc} > L_{sc}$	$i_b^* = 0, i_{sc}^* = i_{sc,r}$ $i_g^* = i_{avg}$
$SOC_b > L_b$ & $SOC_{sc} < L_{sc}$	$i_b^* = \gamma.i_{avg}, i_{sc}^* = 0$ $i_g^* = (1-\gamma).i_{avg} + i_{sc,r}$
$SOC_b < L_b$ & $SOC_{sc} < L_{sc}$	$i_b^* = 0, i_{sc}^* = 0$ $i_g^* = i_{avg} + i_{sc,r}$

TABLE III
EPM

Conditions	Current setting
$SOC_b < H_b$ & $SOC_{sc} < H_{sc}$	$i_b^* = -i_{b,ra}, i_{sc}^* = -i_{sc,ra} + i_{sc,r}$ $i_g^* = i_{tot}$
$SOC_b > H_b$ & $SOC_{sc} < H_{sc}$	$i_b^* = 0, i_{sc}^* = -i_{sc,ra} + i_{sc,r}$ $i_g^* = i_{tot}$
$SOC_b < H_b$ & $SOC_{sc} > H_{sc}$	$i_b^* = -i_{b,ra}, i_{sc}^* = 0$ $i_g^* = i_{tot}$
$SOC_b > H_b$ & $SOC_{sc} > H_{sc}$	$i_b^* = 0, i_{sc}^* = 0$ $i_g^* = i_{tot} + i_{sc,r}$



[1] U. Manandhar, A. Ukil, H.B. Gooi, N.R. Tummuru, S.K. Kollimalla, B. Wang, K. Chaudhari, IEEE Trans. on Smart Grid, vol. 10, pp. 1626–1636, 2019
[2] N.R. Tummuru, U. Manandhar, A. Ukil, H.B. Gooi, S.K. Kollimalla, S. Naidu, Int. J. Electric Power & Energy Systems, vol. 104, pp. 807–816, 2019.

Policy Factors

- Renewable energy is costly mainly due to energy storage cost
- There is currently no subsidy on solar rooftop PV in New Zealand
- **Policy** can effectively promote renewable energy like solar PV installation at households, schools, agricultural sector, remote parts (without grid connection)
- **Policy** for energy storage devices is strongly needed, without which, cost will always dominate the renewable energy factor
- **Policy** for R&D on Renewable energy will emphasize uptake of cutting-edge technology and training manpower in New Zealand

Policy on Renewables: Global Example

A. Ukil/ECSE

- **Germany: Amendment of the Renewable Energy Sources Act (EEG 2012)**

Jurisdiction:	National
Date Effective:	2012
Policy Type:	Policy Support, Economic Instruments>Fiscal/financial incentives>Feed-in tariffs/premiums, Economic Instruments>Fiscal/financial incentives
Policy Target:	Wind>Onshore, Bioenergy>Biomass for heat, Hydropower, Geothermal>Power, Solar>Solar photovoltaic, Wind
Policy Sector:	Electricity
Size of Plant Targeted:	Small and Large
Agency:	Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB)

On 1 January 2012 the amendment of the Renewable Energy Sources Act (EEG) will come into force (EEG 2012). In agreement with the Energy Concept of the government dating from September 2010, it aims at reaching the following minimum shares of renewable energy in electricity supply:

- 35% by 2020
- 50% by 2030
- 65% by 2040
- 80% by 2050

The basic principles of the EEG, in particular priority purchase, transport and distribution of electricity generated from renewable energy sources as well as statutory feed-in compensation, remain unchanged.

According to the growing share of renewables in the total electricity production, market integration, system integration and grid integration gain considerably in importance. Main mechanisms to improve integration are:

- - A market premium (optional for all renewables, from 2014 compulsory for new biogas facilities).
- - A flexibility premium (for new and existing biogas facilities).
- - A rebate in compensation payments for utility companies selling electricity generated at least 50 % from fluctuating renewable energy sources, inclusion of photovoltaic plants in the feed-in management, as well as supporting instruments outside the EEG.

Policy on Renewables: Global Example

A. Ukil/ECSE

- **Germany: Sixth Energy Research Programme (2011)**

Jurisdiction:	National
Date Effective:	2011
Policy Type:	Research, Development and Deployment (RD&D)
Policy Target:	Multiple RE Sources>All
Policy Sector:	Multi-sectoral Policy

The German governments 6th Energy Research Programme entitled "Research for an environmentally sound, reliable and affordable energy supply" is a joint project of the Federal Ministry of Economics and Technology, the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, the Federal Ministry of Food, Agriculture and Consumer Protection and the Federal Ministry of Education and Research. The programme sets out the guiding principles and priorities of the German governments support policy in the field of innovative energy technologies for the coming years, thus laying the groundwork for an environmentally sound, secure and economical restructuring of Germanys energy supply. With its 6th Energy Research Programme, the German government is adding a new strategic approach to its energy and climate policy. This approach places emphasis on enhanced assistance for research and development of forward looking energy technologies. The German governments budget for energy research clearly reflects its commitment in this regard as it is making around EUR 3.4 billion available for energy research for the period from 2011 to 2014. The remarkable increase in funding of around 75 percent compared to the period from 2006 to 2009 will mainly be used for the newly established "Energy and Climate Fund". The funds will be employed for strategic priority areas that are vital for a speedy transformation of Germanys energy supply: renewable energies, energy efficiency, energy storage, grid technologies and the integration of renewable energies into the energy supply system.

Policy on Renewables: Global Example

A. Ukil/ECSE

- **Germany: Subsidy for Solar PV with Storage Installations, 2016**

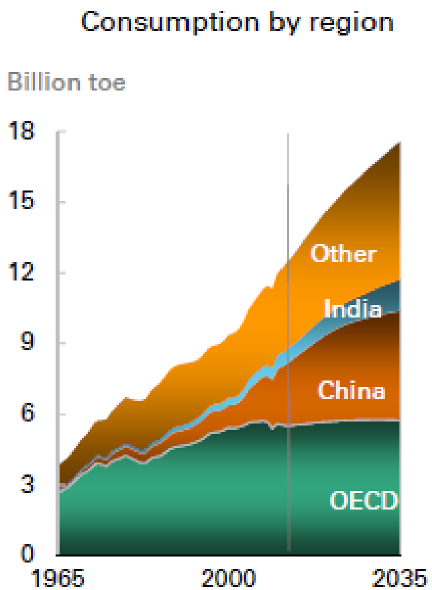
Jurisdiction:	National
Date Effective:	2016 (March 1st)
Policy Type:	Economic Instruments>Fiscal/financial incentives>Loans, Economic Instruments>Fiscal/financial incentives>Grants and subsidies
Policy Target:	Solar>Solar photovoltaic
Policy Sector:	Electricity
Size of Plant Targeted:	Small

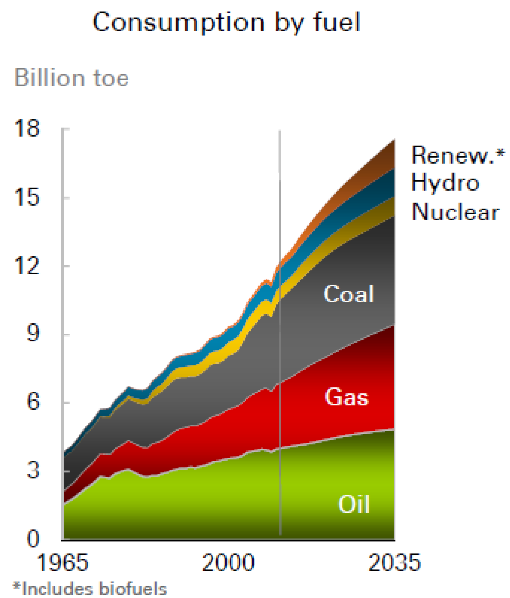
Germany on 1st of March will start a new EUR 30m programme to support investments into the battery storage of electricity generated from PV residential installations in order to strengthen grid services of solar plants and help cost reduction. The programme will last until 2018.

The scheme provides:

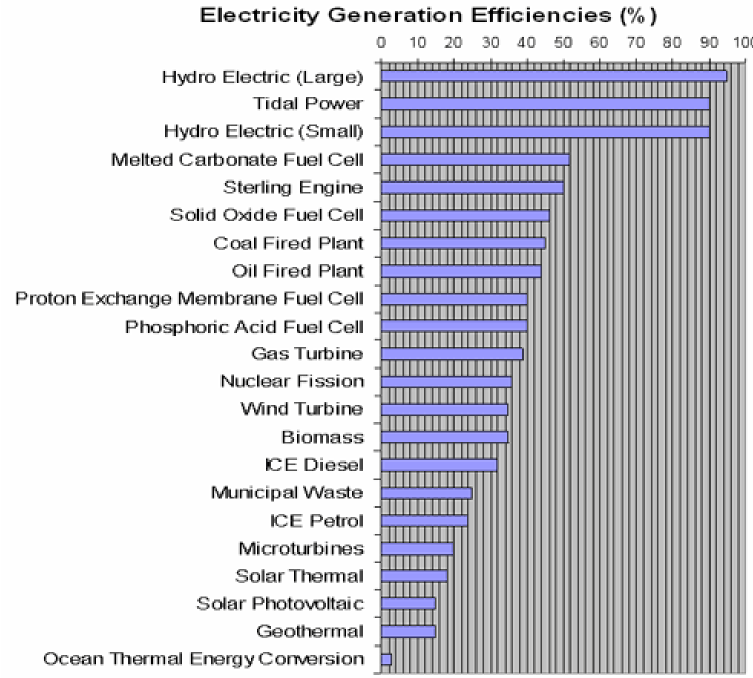
- Soft loans up to EUR 2,000 / kW for the solar PV system and
- Capital grant covering up to 25% of the eligible solar PV panel

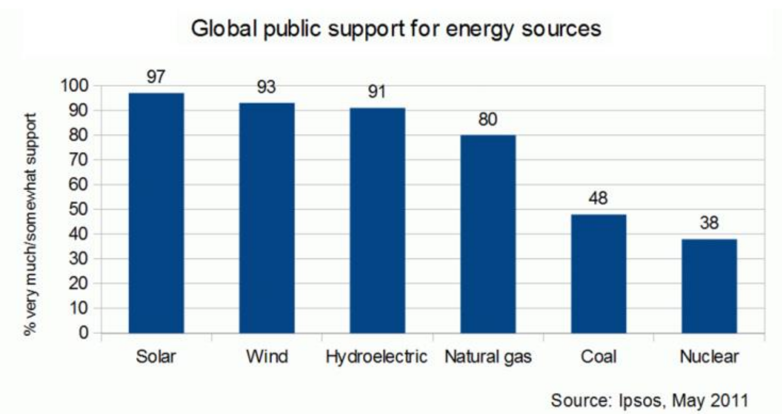
Summary

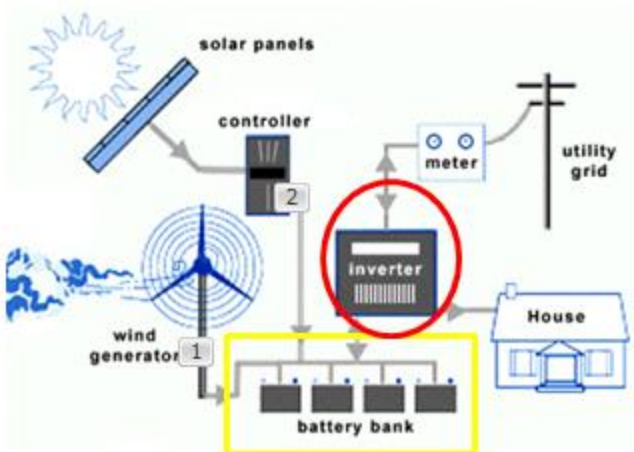




18 Btoe = 209,340 TWh



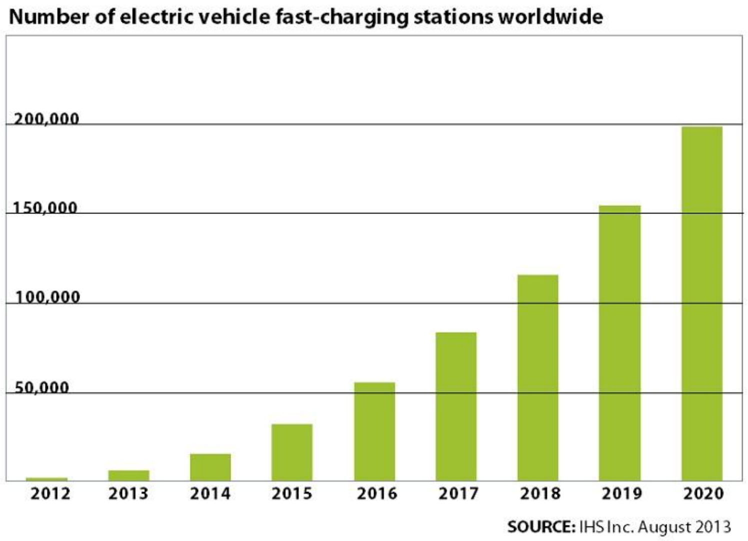


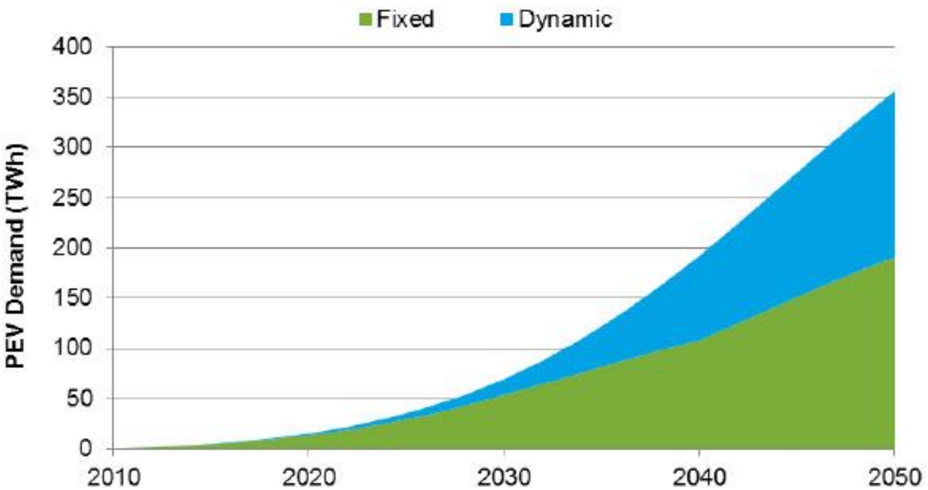


Part-II

New Type of Electrical Loads

Electric Vehicle (EV) Charging
(Tesla, Nissan, BMW, etc.)





EV in New Zealand

Figure 4a: Number of EVs in national fleets internationally[6]

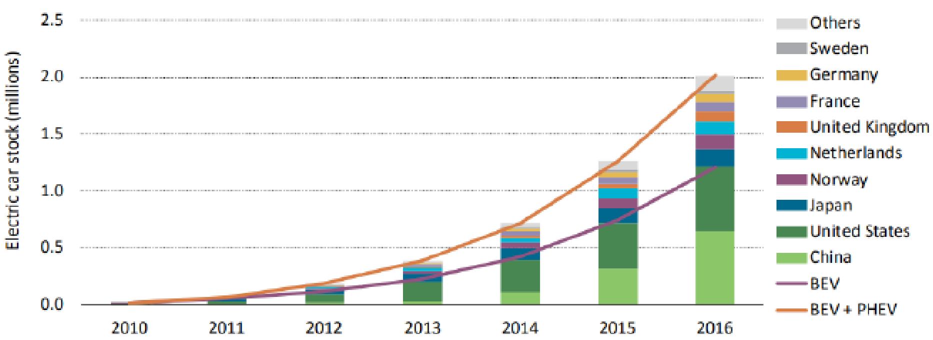


Figure 4b: Number of EVs in national fleet in New Zealand

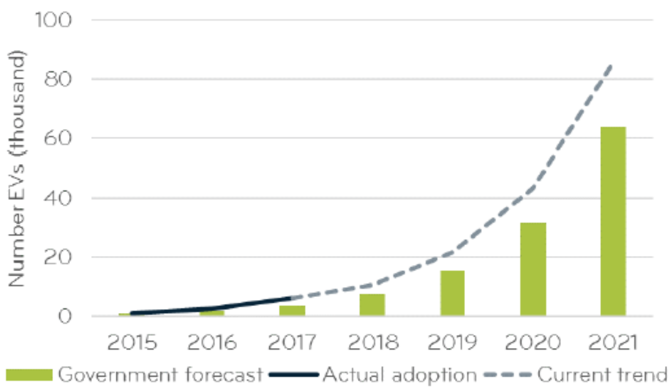


Figure 5: EV penetration in major cities and national averages[8]

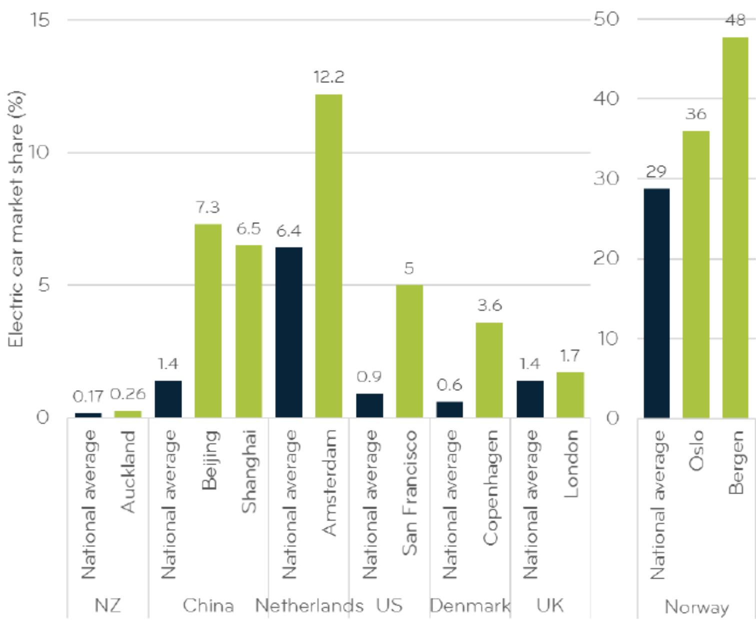
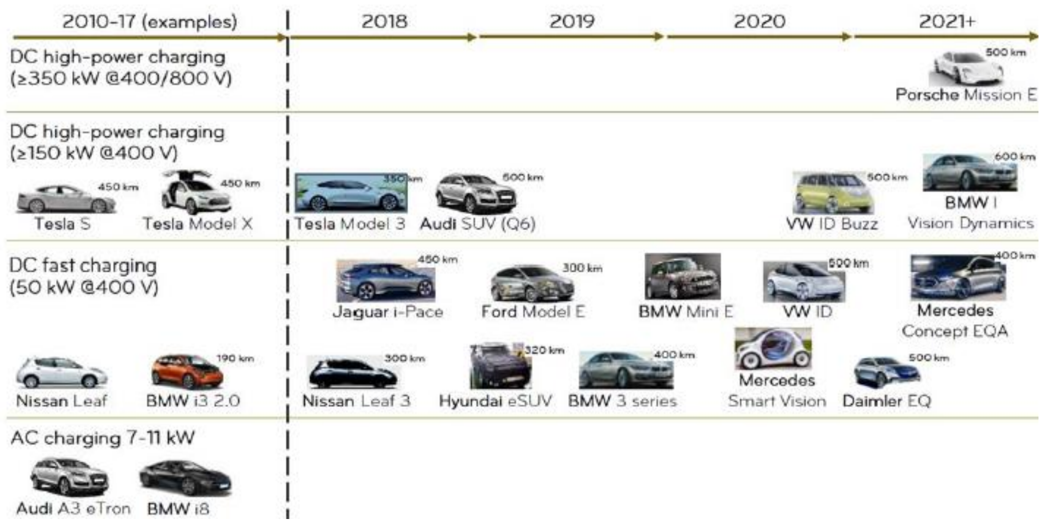


Figure 6: EV models in New Zealand market and compatibility for different charging technologies[9]



[1] Vector, EV Network Integration, 2018.

Problems in EV Integration Studies

- EV charging time is compromised.
- EV sometimes remains at idle mode at charging station.

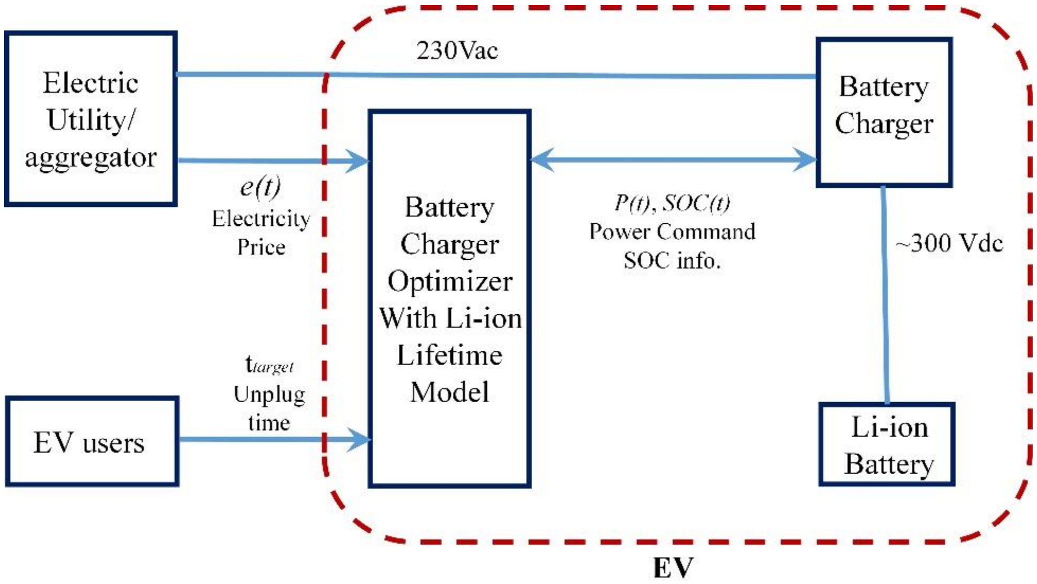
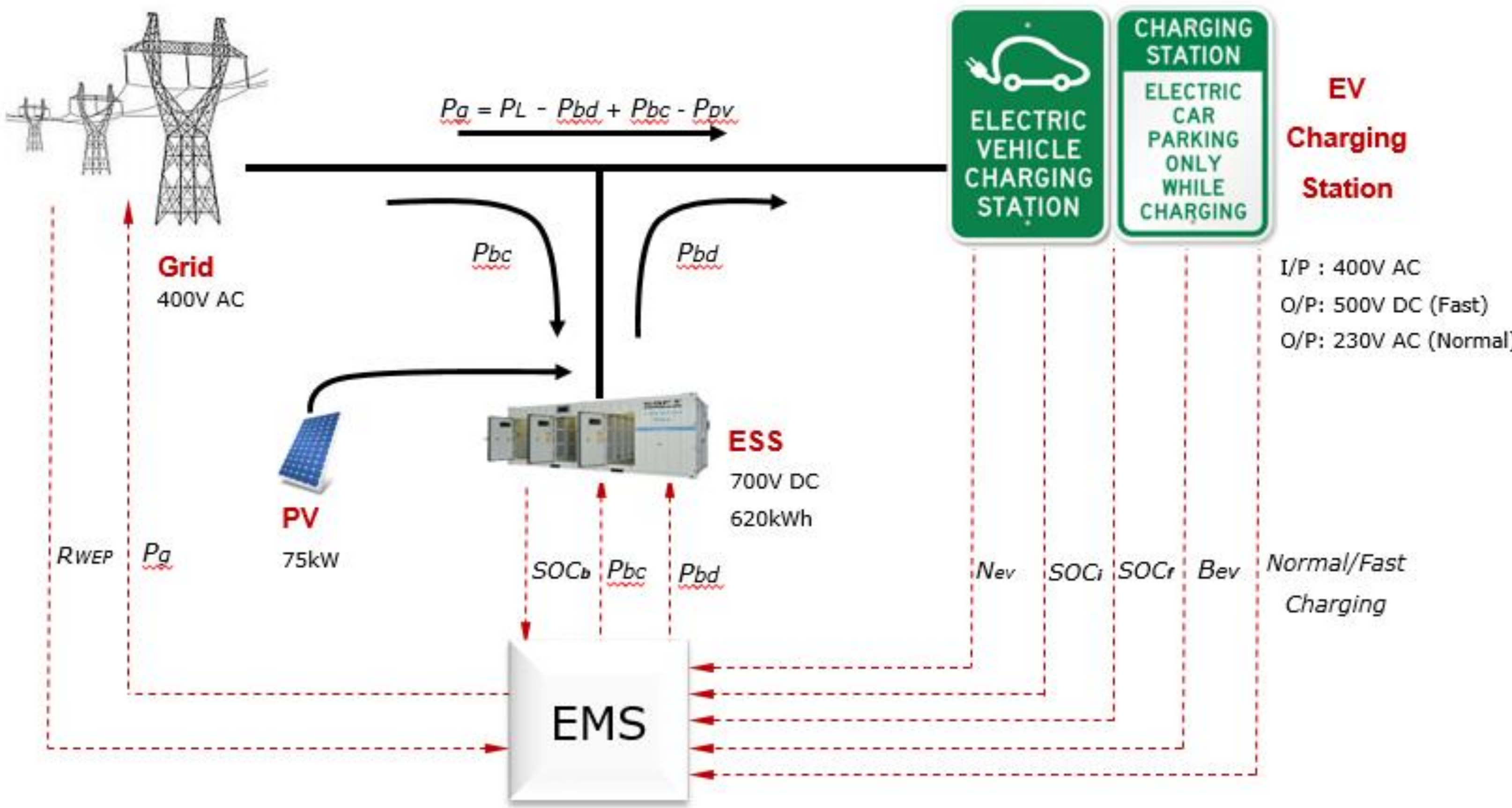


Figure 1. General model followed in most literature [1]

[1] A. Hoke, A. Brissette, K. Smith, A. Pratt, and D. Maksimovic, "Accounting for lithium-ion battery degradation in electric vehicle charging optimization", IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 2, no. 3, pp. 691–700, 2014.
[2] A. S. Subburaj, S. B. Bayne, M. G. Giesselmann and M. A. Harral, "Analysis of Equivalent Circuit of the Utility Scale Battery for Wind Integration," in *IEEE Transactions on Industry Applications*, vol. 52, no. 1, pp. 25-33, Jan.-Feb. 2016.

EV Energy Management System

A. Ukil/ECSE

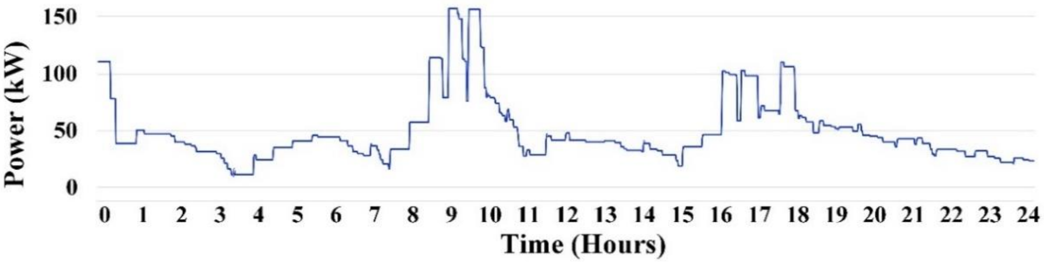


- Benefit of **Time of Use (TOU)** electricity price
- Minimum effect of PV generation variability on loads
- Meeting EV power demands through grid + renewables
- Suitable for peak shaving for dynamic loads such as EV charging

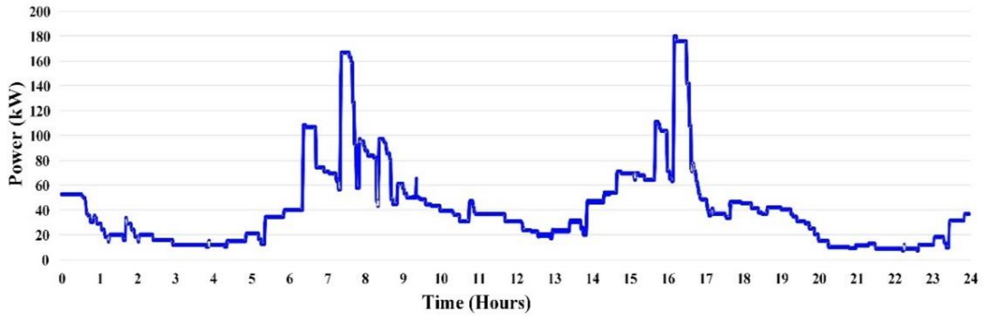
EV Charging: Statistical vs Uncoordinated

EV Charging Load = Σ (Number of Vehicle x How much each vehicle requires charge)

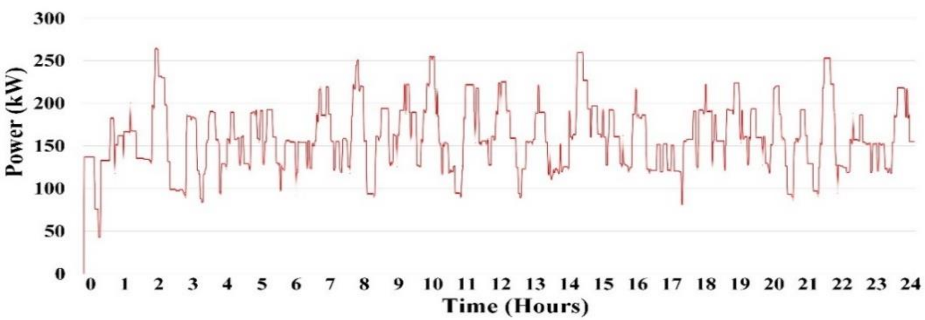
1. Statistical EV charging load
Morning: μ = 8.5, σ = 2
Evening: μ = 17.5, σ = 2



2. Statistical EV charging load
Morning: μ = 7.5, σ = 2
Evening: μ = 16.5, σ = 2



3. Uncoordinated EV charging load



[1] K. Chaudhari, A. Ukil, 17th IEEE International Conf. on Industrial Technology-ICIT, Taipei, Taiwan, Mar. 2016.
[2] K. Chaudhari, A. Ukil, S. K. Kollimalla, U. Manandhar, 42nd IEEE Annual Conf. on Industrial Electronics-IECON, Florence, Italy, Oct. 2016.
[3] K. Chaudhari, A. Ukil, K. Nandha Kumar, U. Manandhar, S. K. Kollimalla, IEEE Trans. on Industrial Informatics, vol. 14, no. 1, pp. 106–116, 2018.

EV Charging: Battery Characteristics

A. Ukil/ECSE

- Charging power for each EV:

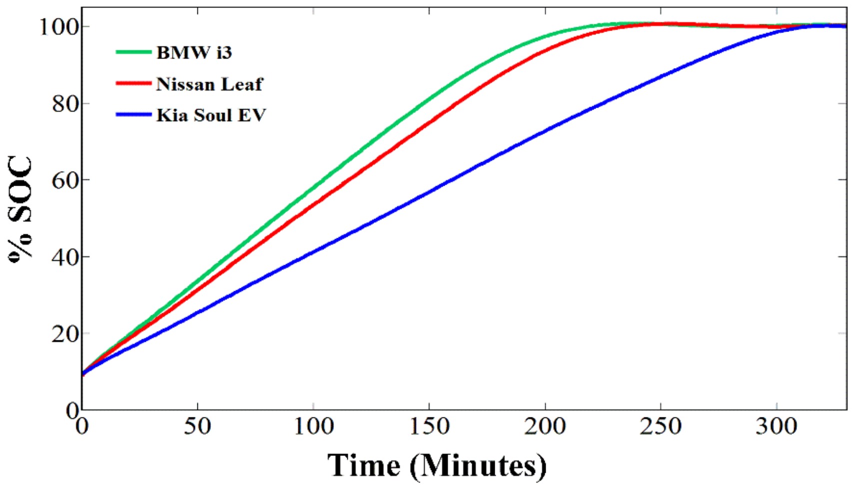
$$P_{ev\,k} = \frac{(SOC_{fk} - SOC_{ik})B_{ev\,k}}{t_{c\,k}} \quad \textbf{(3)}$$

- Total charging power at charging station:

$$P_c(t) = \sum_{k=1}^{N}\left[\frac{P_{ev\,k}(t)}{\eta_{ev}} \pm \frac{\alpha\, P_{ev\,k}(t)}{\eta_{ev}}\right] \quad \textbf{(4)}$$

- Charging station configuration:
  - Capacity: 20 chargers
  - No. of fast chargers: 5
  - No. of normal chargers: 15

Battery charging characteristics for BMW i3, Nissan Leaf and Kia Soul



EV Model	Battery Capacity	Maximum Range
BMW i3	18.8 kWh	160 km
Nissan Leaf	24 kWh	126 km
Kia Soul EV	27 kWh	120 km

[1] K. Chaudhari, A. Ukil, S. K. Kollimalla, U. Manandhar, 42nd IEEE Annual Conf. on Industrial Electronics-IECON, Florence, Italy, Oct. 2016.
[2] K. Chaudhari, A. Ukil, K. Nandha Kumar, U. Manandhar, S. K. Kollimalla, IEEE Trans. on Industrial Informatics, vol. 14, no. 1, pp. 106–116, 2018.

EV Results

A. Ukil/ECSE

Cost of electricity for statistical load with SMA in SGD [1]

Statistical Load			
	Cost with ESS Optimisation	Cost With ESS deterministic approach	Cost Without ESS
10th Jan	83.30	89.94	86.30
11th Jan	97.80	102.37	104.56
12th Jan	88.23	88.54	95.03
13th Jan	116.01	118.46	142.43
14th Jan	88.56	90.79	98.72
15th Jan	74.89	76.65	75.75
16th Jan	64.60	65.13	74.68

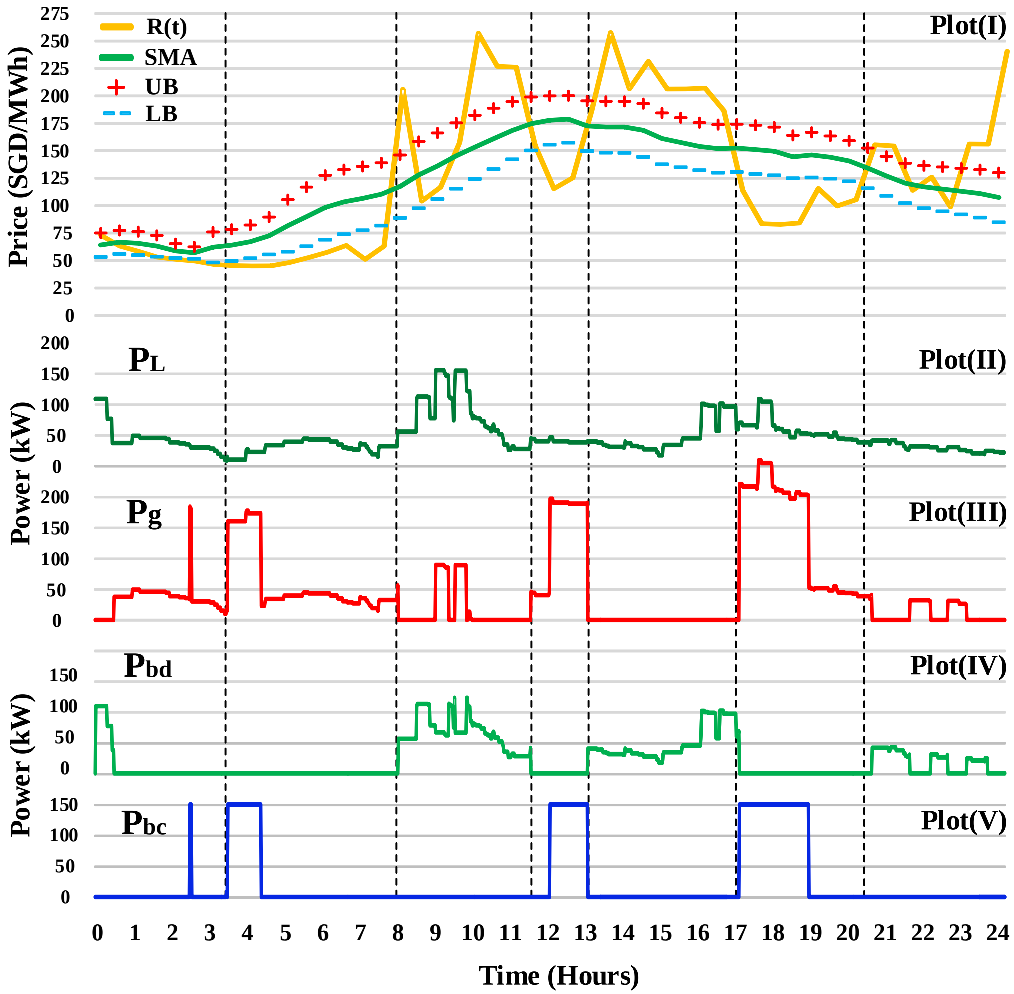


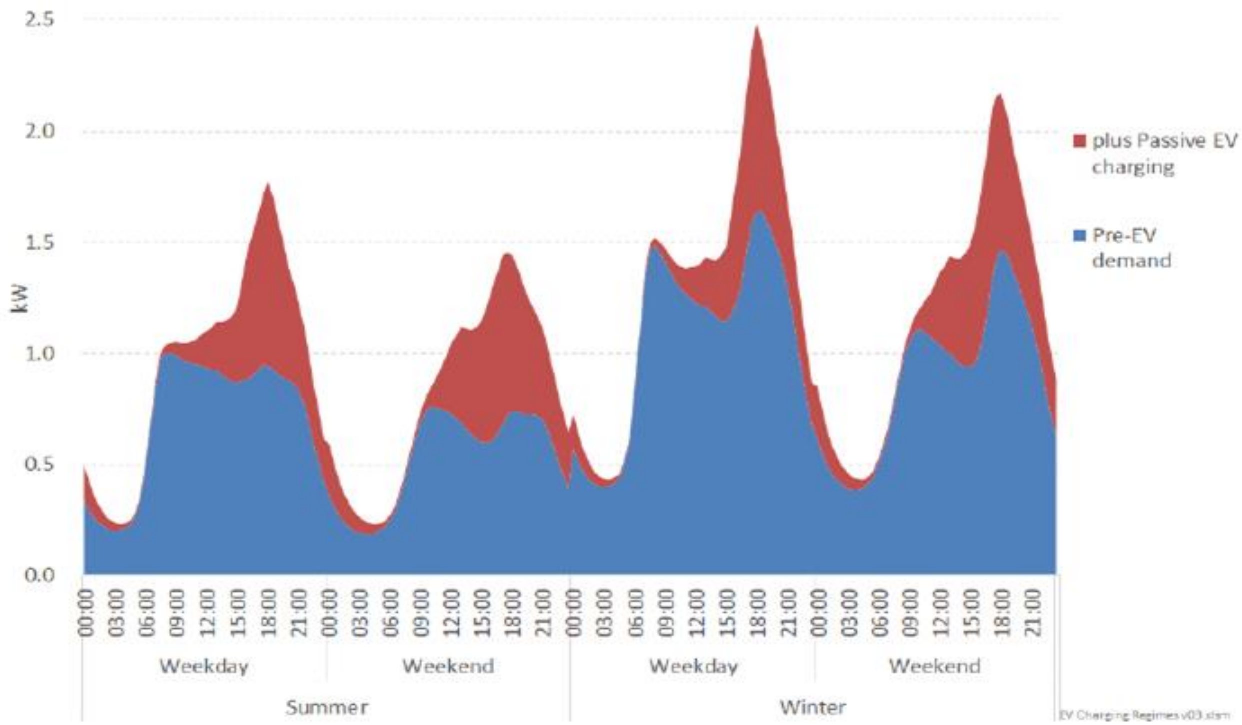
Figure 14. Hourly power plot for one day, Plot (I) Electricity Price, Plot (II) Load requirement, Plot (III) Grid power, Plot (IV) Battery discharge power, Plot (V) Battery charging power for Statistical Load and SMA. [1]

[1] K. Chaudhari, A. Ukil, K. Nandha Kumar, U. Manandhar, S. K. Kollimalla, *IEEE Trans. on Industrial Informatics,* vol. 14, no. 1, pp. 106–116, 2018.

Challenges in EV: Home Charging

THE UNIVERSITY OF AUCKLAND
Te Whare Wānanga o Tāmaki Makaurau
NEW ZEALAND
A. Ukil/ECSE

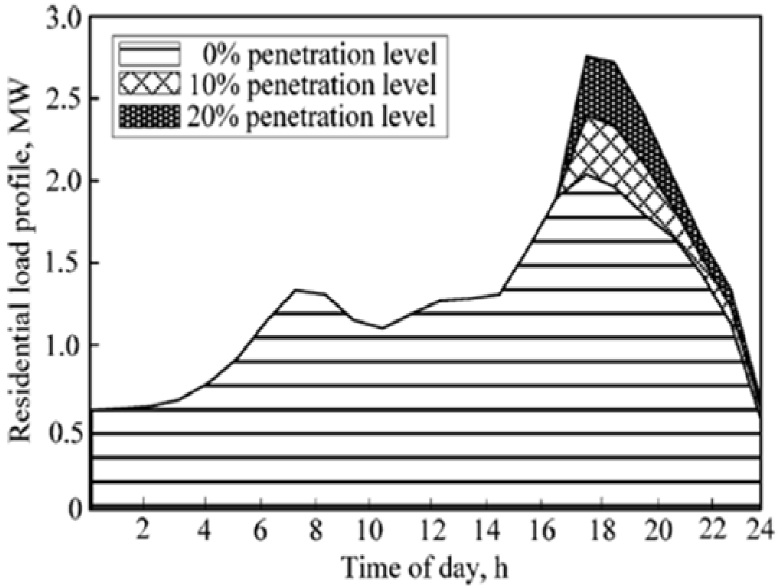
- Almost all private EVs will be charged at home in most first world countries
- If different strategies are not implemented then the load demand curve for residential areas will have very high peaks
- Strategies such as time of use and smart charging will have to be deployed to keep peaks under control

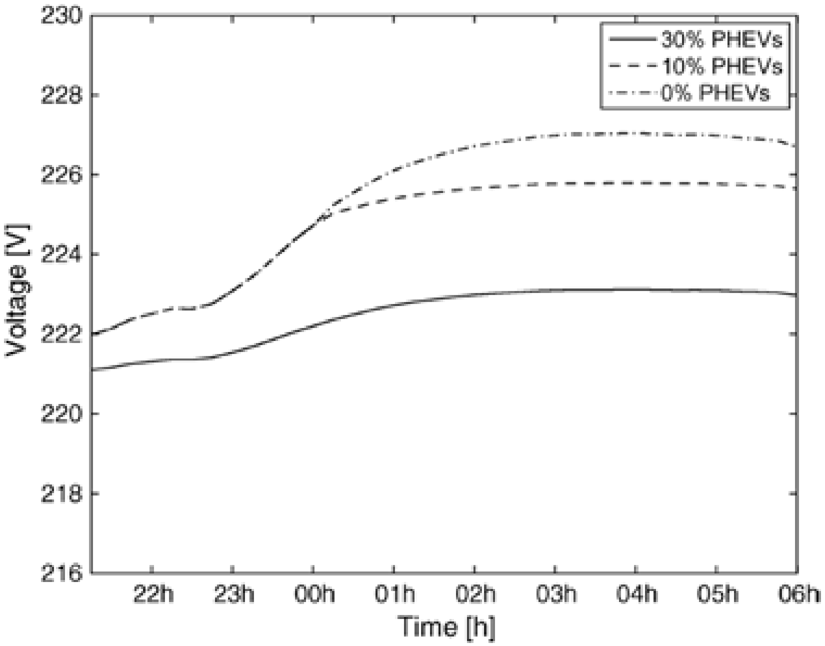


[1] K. Clement-Nyns, E. Haesen, and J. Driesen, "The impact of charging plug-in hybrid electric vehicles on a residential distribution grid," IEEE Transactions on Power Systems, vol. 25, pp. 371–380, Feb 2010.

Challenges in EV: Distribution Systems

- EVs could have impact on distribution systems, like load peaks, power quality
- EV charging would cause voltage deviations and harmonics
- Most studies considered at least two charging scenarios: G2V, V2G
- All the studies looked at found that coordinated/smart charging prevented new peak loads occurring



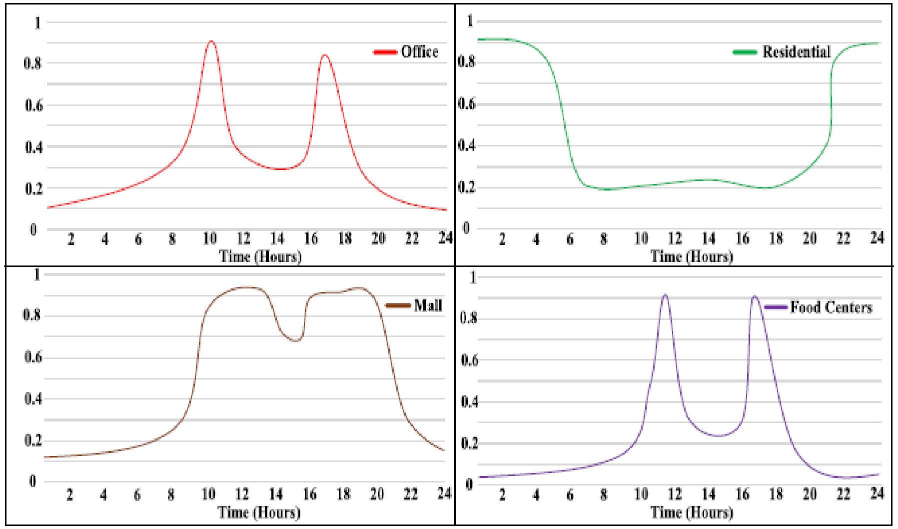


[1] K. Clement-Nyns, E. Haesen, and J. Driesen, “The impact of charging plug-in hybrid electric vehicles on a residential distribution grid,” IEEE Transactions on Power Systems, vol. 25, pp. 371–380, Feb 2010.

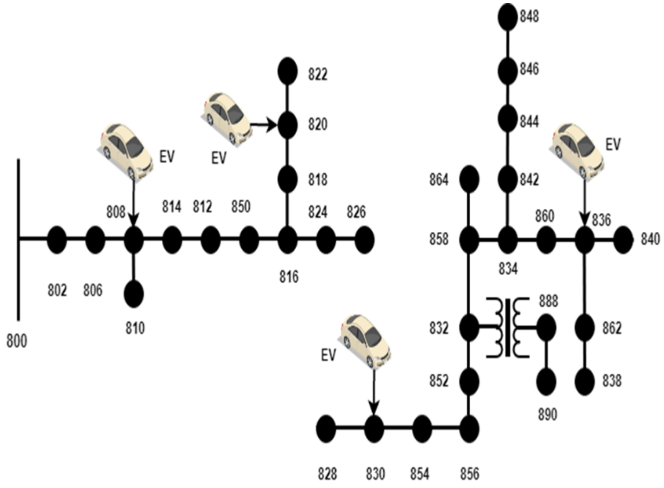
Challenges in Distribution System

A. Ukil/ECSE

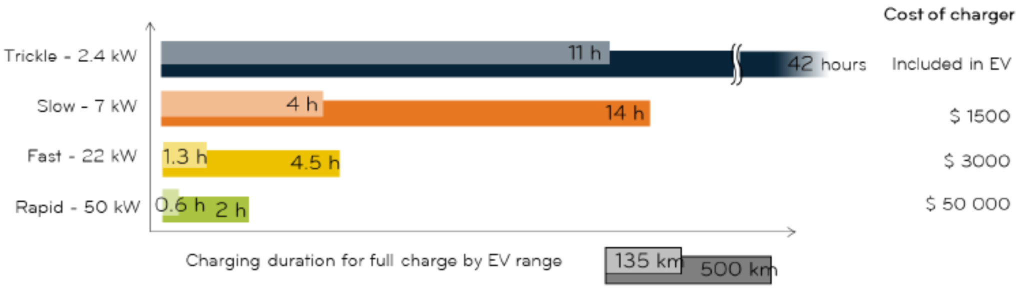
Typical Probability of EV Charging at Different Locations in a City

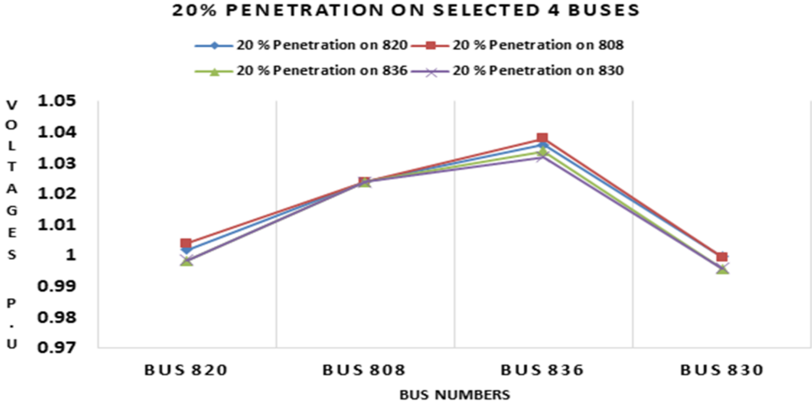


EV Integration in IEEE 34-Bus System



Classification of EV chargers



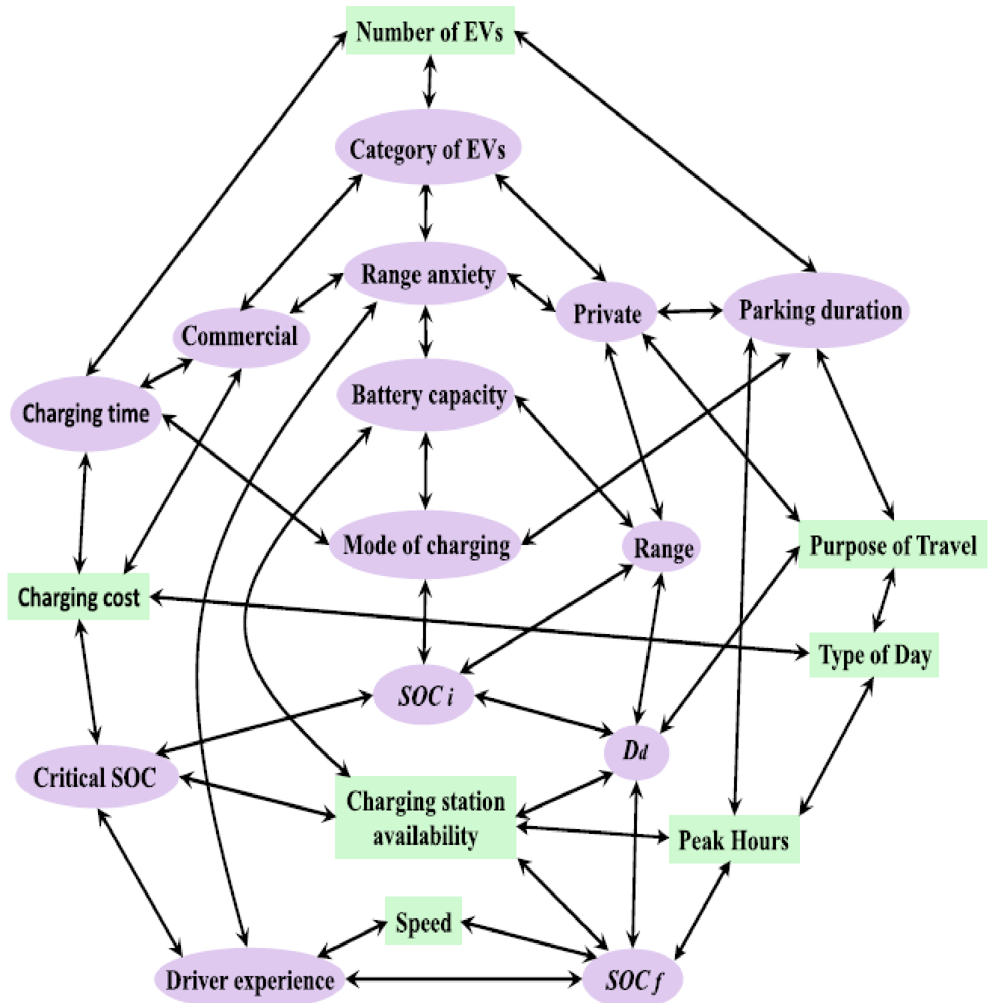


[1] K. Chaudhari, K. Nandha Kumar, A. Krishnan, A. Ukil, H.B. Goomalla, "Agent Based Aggregated Behavior Modelling For Electric Vehicle Charging Load," IEEE Transactions on Industrial Informatics, vol. 15, no. 2, pp. 856–868, 2019.

[2] M. Aqib, A. Ukil, "Voltage Sensitivity Analysis and Demand Dispatch Option of Electric Vehicle in Smart Grid," IEEE Innovative Smart Grid Tech -ISGT, Chengdu, China, May 2019.

Major Factors:
Data Analytics, User Behaviour

Interdependency of Various Factors for Large Scale EV Integration

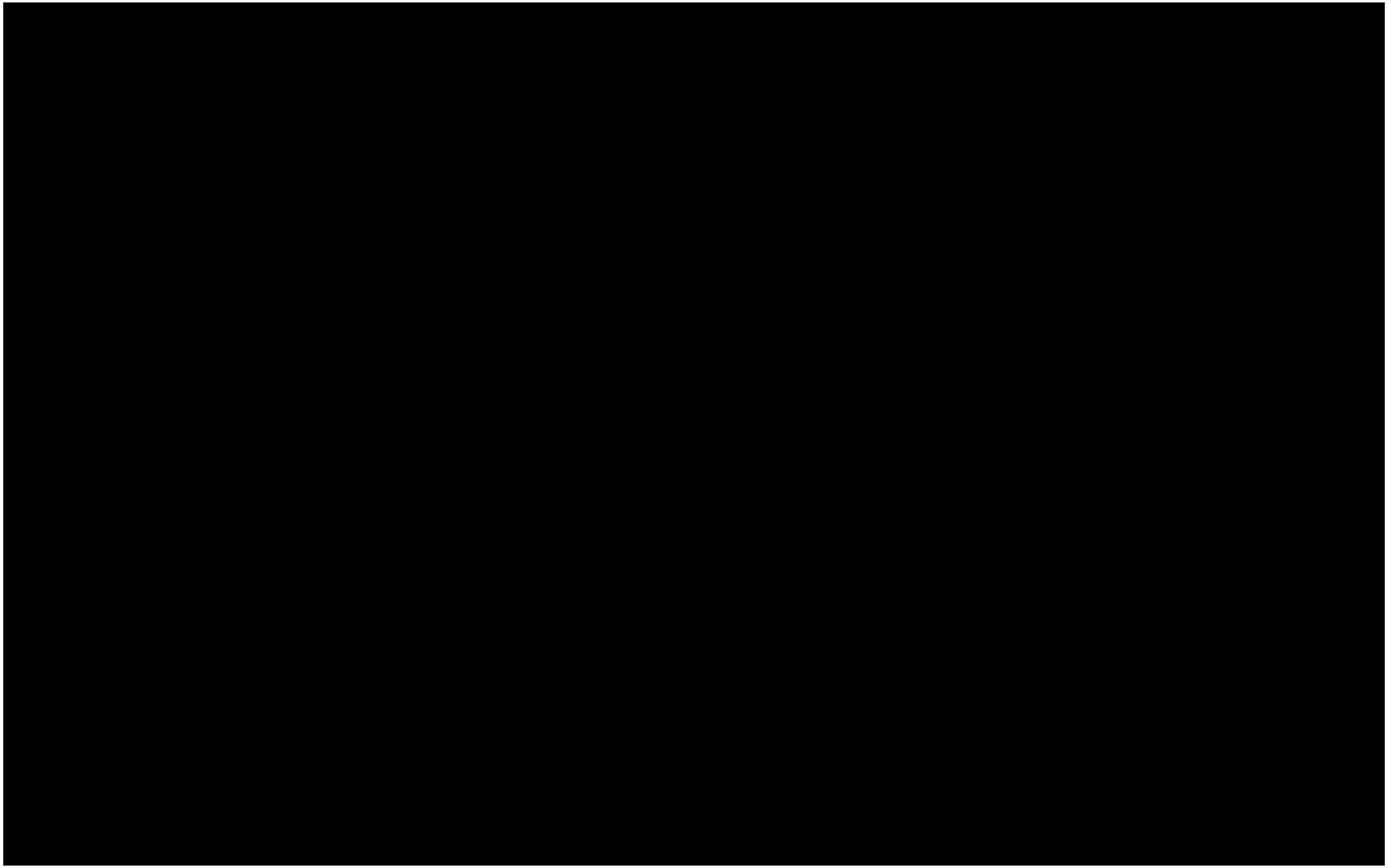


[1] K. Chaudhari, K. Nandha Kumar, A. Krishnan, A. Ukil, H.B. Goomalla, IEEE Transactions on Industrial Informatics, vol. 15, no. 2, pp. 856–868, 2019.
[2] M. Aqib, A. Ukil, IEEE Innovative Smart Grid Tech -ISGT, Chengdu, China, May 2019.

EV Challenges: Summary

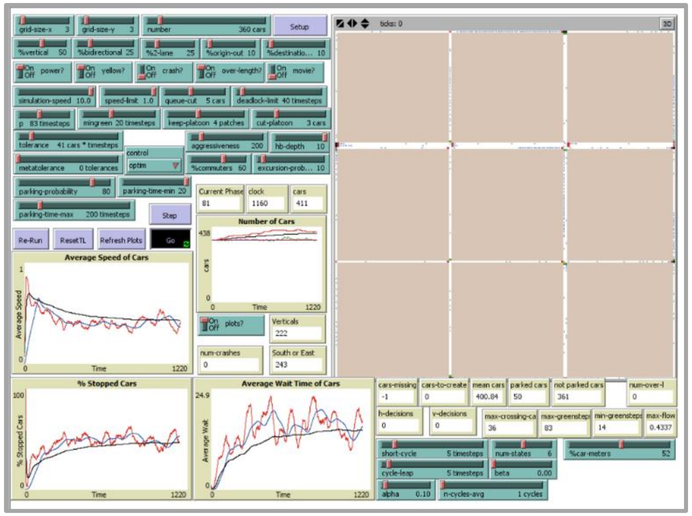
A. Ukil/ECSE

https://www.youtube.com/watch?v=MsvR2FpyU1w



Complexity Driven Human Behaviour Model: Predicting EV Load

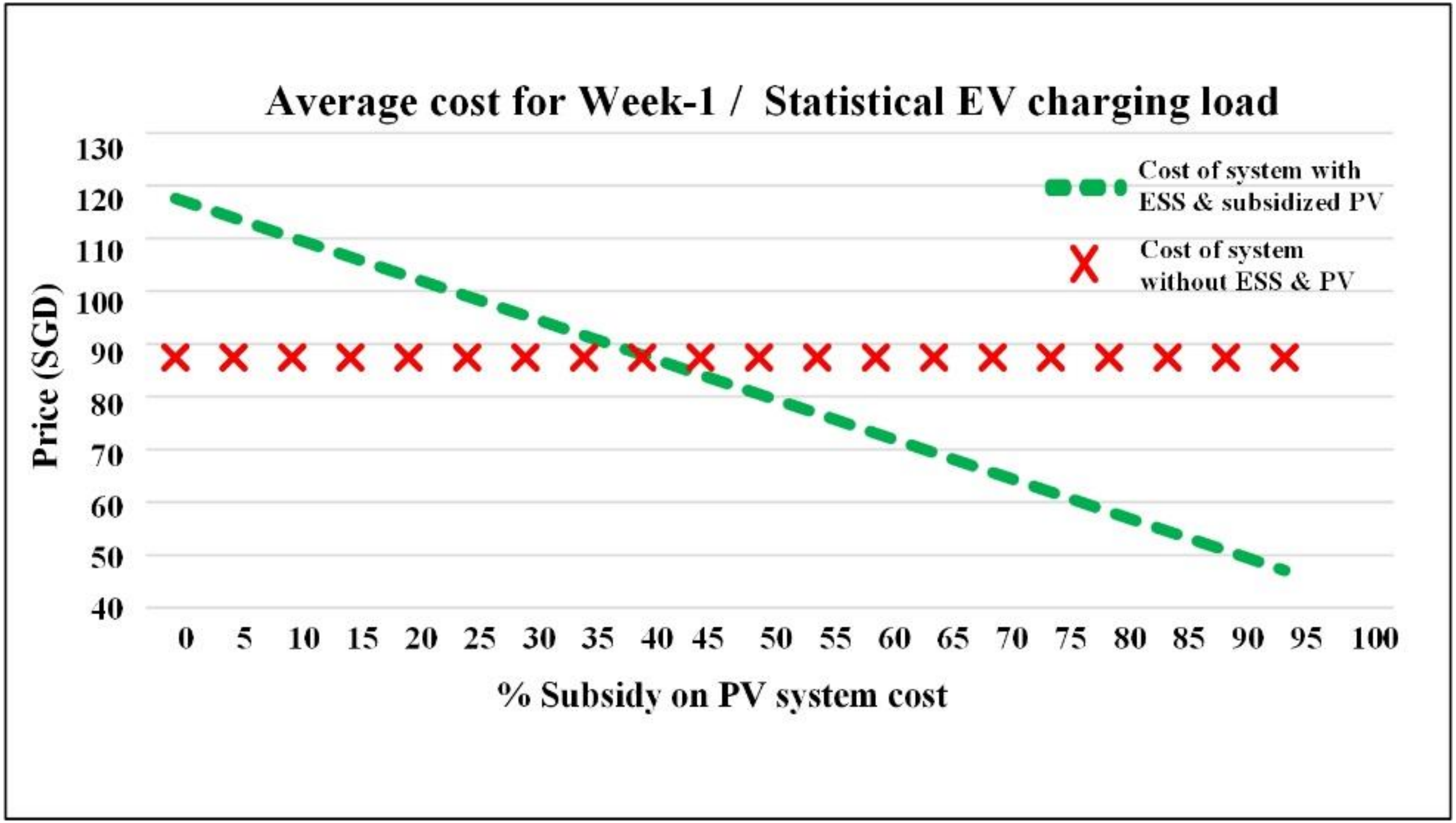
- Agent Based Modelling using **Netlogo**.
- Identify decision variables affecting arrival and departure time using
  - Type of charger
  - EV battery capacity and charge characteristics.
  - Parking time.
  - Parking probabilities.
  - Carpark availability data.
  - Traffic data.
  - Driving statistics and EV user behavior.
  - Refueling statistics and EV user behavior.



- Create real life environment using ABM and decision variables, and generate EV charging load demand at every minute.
- Netlogo based models could be used for traffic prediction, congestion management as well.

Policy Factor: Role of PV+ESS Subsidy on EV Integration

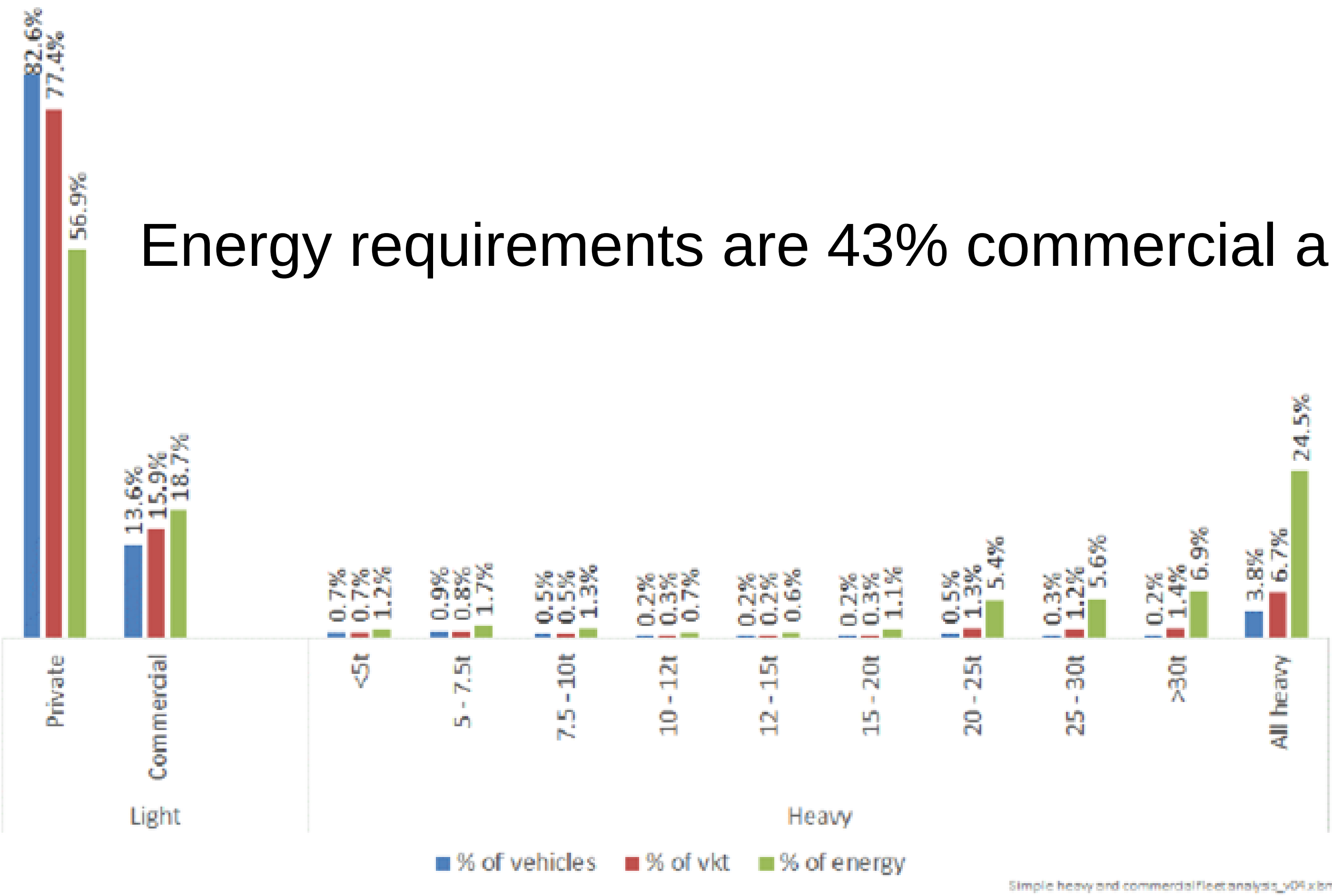
A. Ukil/ECSE



Type of Vehicle: Commercial vs Private

A. Ukil/ECSE

Energy requirements are 43% commercial and 57% private



Electrification of Heavy Vehicles

A. Ukil/ECSE

- Unlike cars (low power), electrification of heavy trucks is challenging
- Cars use less power (torque), shorter distance, trucks have large torque requirement over long distance
- Special design for drivetrain is required for heavy vehicles

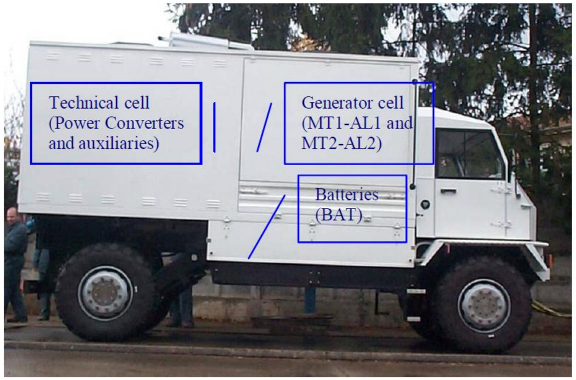
Nissan Leaf
Synchronous electric motor
80 kW (110 hp) and 280 N·m
Energy supplied by a 24 kWh lithium ion battery

Nissan e-NT400 (concept)
100 km, 6 Ton load
110 kW (148 hp) and 350 N-m
Energy supplied by a 72 kWh (3 Leafs)

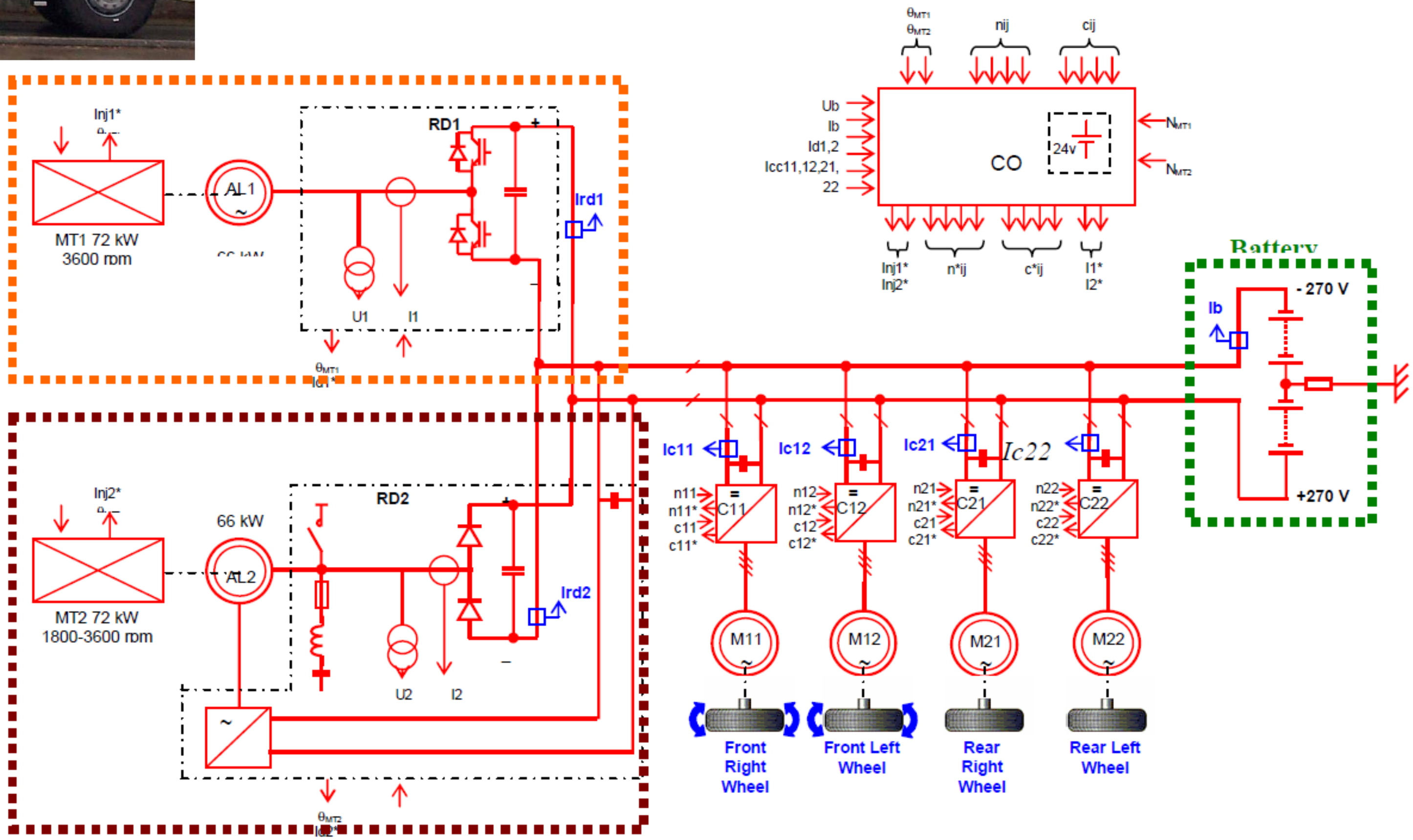
- **Typical 5-6 Ton Diesel Trucks use: Average 4.21 kWh/km**
- **Electric Trucks use: 1.25 kWh/km (i.e. 3.37 times less energy consumption)**

[1] Nissan Press Release: e-NT400.

Heavy Electric Vehicles



12 ton Concept Electric Truck
4x30 kW for wheels
Li-ion battery at 540V



[1] K. El Kadri, A. Berthon, “Energy Management Operating Modes Concerning a Hybrid Heavy Vehicle,” IEEE EUROCON, 2007.

Heavy Duty Electric Trucks: State-of-Art

A. Ukil/ECSE

Table 1
Specifications of some electric trucks.

Manufacturer	Commercial name	Type	Maximum weight	Battery capacity (kW h)	Range (km)	Energy consumption (kW h/km)	Charging power (AC/DC kW)
Mitsubishi	eCanter	medium duty	7.5t	82.8	120	0.69	
BYD	T7	medium duty	11t	175	200	0.88	100/150
Freightliner	eM2 106	medium duty	12t	325	370	0.88	260
Volvo	FL Electric	rigid	16t	100–300	100–300	1.00	22/150
Renault	D Z.E.	rigid	16t	200–300	300	1.00	22/150
eMoss	EMS18	rigid	18t	120–240	100–250	1.00	22/44
Mercedes-Benz		rigid	26t	212	200	1.06	
Renault	D WIDE Z.E.	rigid	26t	200	200	1.00	22/150
Tesla	Semi	semitrailer	36t		480–800	< 1.25	
BYD	T9	semitrailer	36t	350	200	1.75	100/150
Freightliner	eCascadia	semitrailer	40t	550	400	1.38	260

[1] H. Liimatainena, O.V. Vlietb, D. Aplynb, Applied Energy, vol. 236, pp. 804-814, 2019

Summary

A. Ukil/ECSE

- Electric Vehicles are growing exponentially worldwide
- EVs can introduce challenges in creating new peaks
- Public EV charging stations with renewable + ESS is required to balance
- Effective planning for future power distribution system is needed
- EVs encompass a lot of interdependent variables, e.g. carpark availability data, traffic data, EV user charging behavior
- Agent-based modeling helps to effectively design the EV charging infrastructure
- Compared to cars, trucks have large torque requirement over long distance
- Special design for drivetrain is required for heavy duty electric trucks (strong R&D focus)
- Policy required: increased use of EVs in public transport, subsidy for energy storage in charging stations, effective time-of-use