Global 2050 Calculator: Assessment of Primary and Secondary Energy Supply

Technical workshop on Fossil fuels and Electricity Generation Technologies

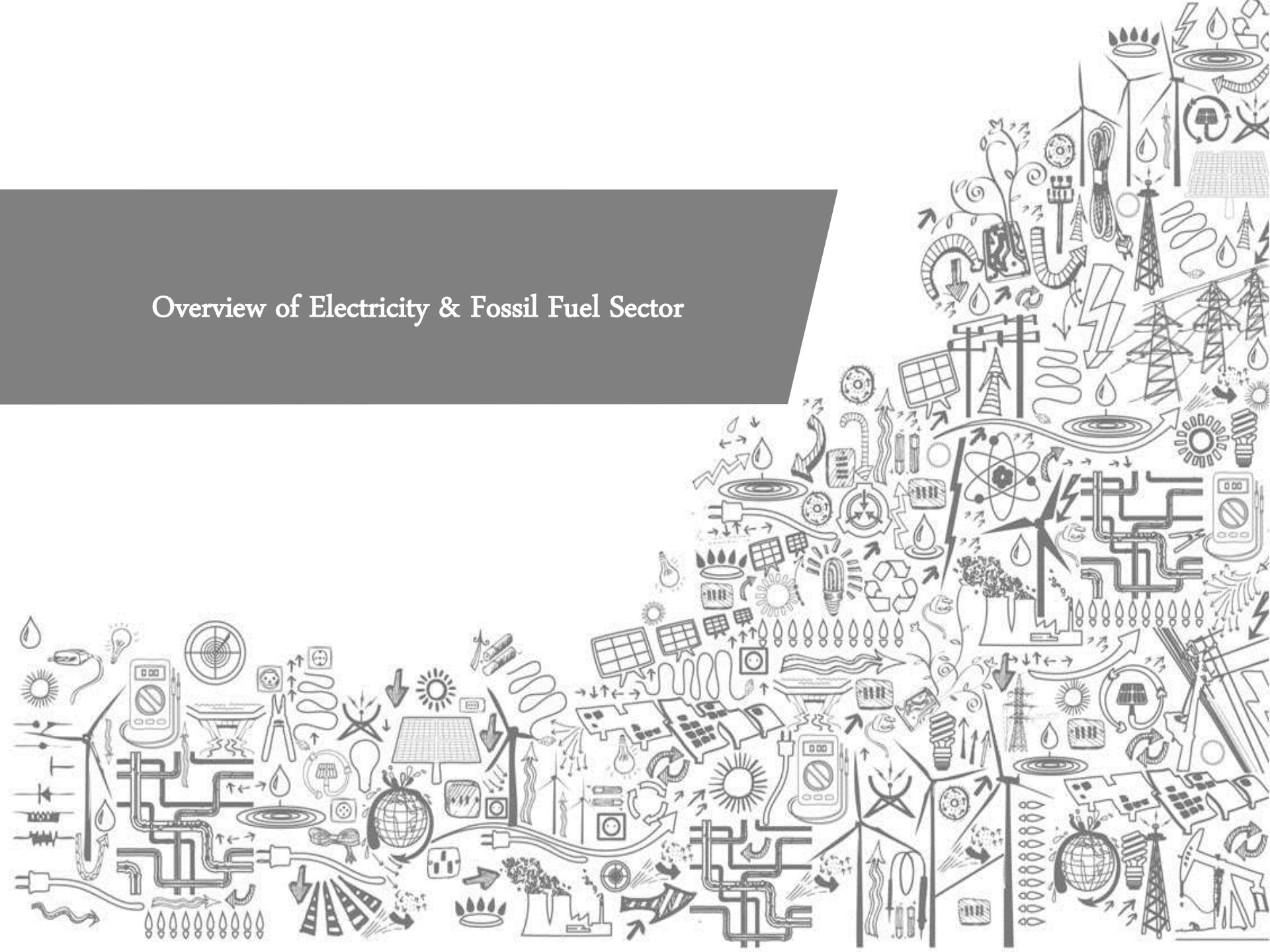
23rd - 24th April, 2014

Gurgaon , India

Content of Presentation – Day 2

- **Model Over view** (repeat session of Day-1)
- **Session-3 : Renewable energy supply**
  - Historic and future pathway of wind energy
  - Historic and future pathway of solar energy
  - Historic and future pathway of marine energy
  - Historic and future pathway of geothermal energy
- **Session-4: Hydro and nuclear energy supply**
  - Historic and future pathway of nuclear
  - Historic and future pathway of hydro power
- **Session-5: Energy balancing and storage**
  - Energy balancing in the model
  - Historic and future pathway of hydrogen energy

Overview of Electricity & Fossil Fuel Sector

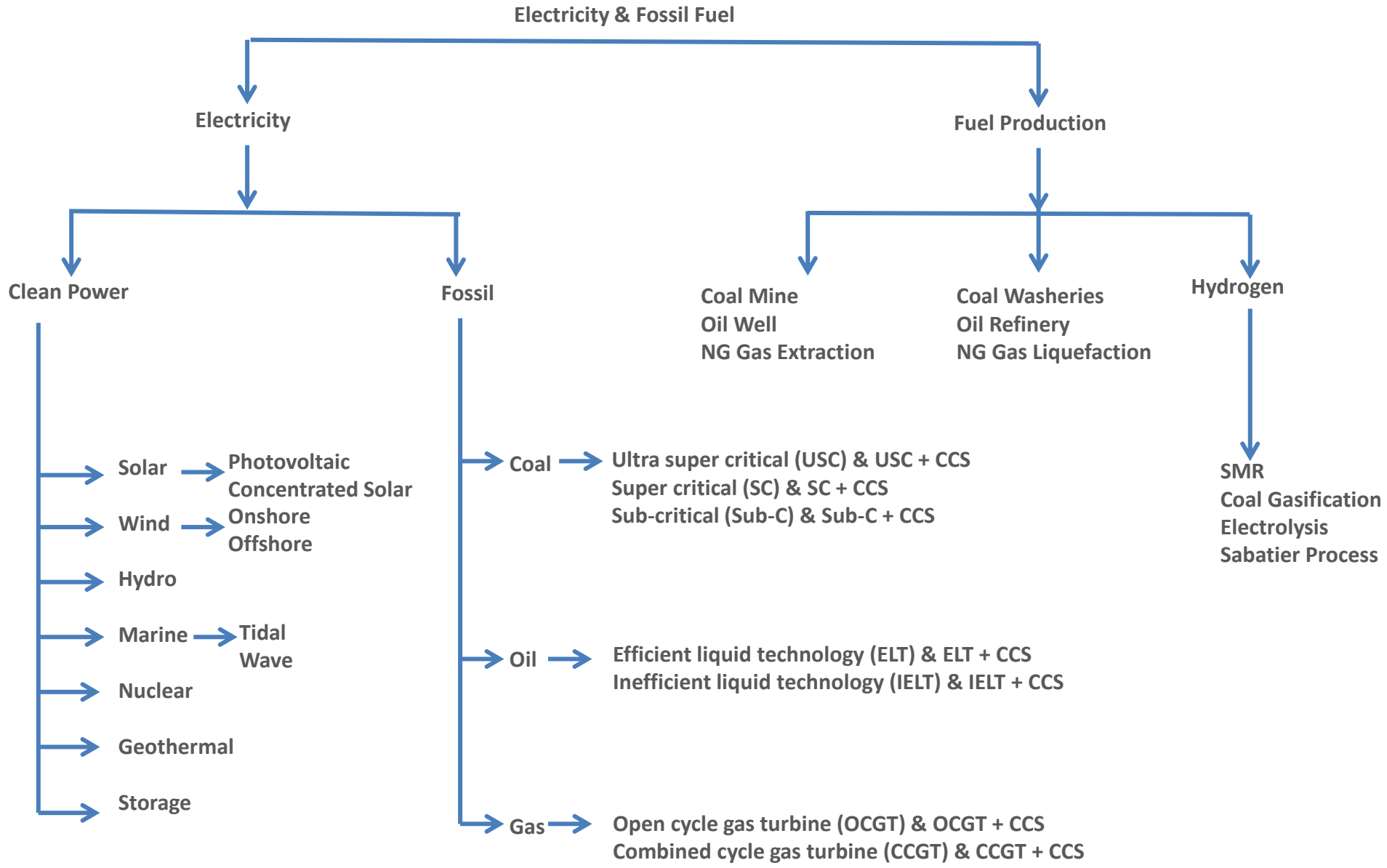


Principles of the Global 2050 Calculator

The Global 2050 Calculator is a simple excel based accounting tool for energy and corresponding emissions which is based only on engineering principle of technology development and adoption and does not contain any constraint in the system during technology deployment.

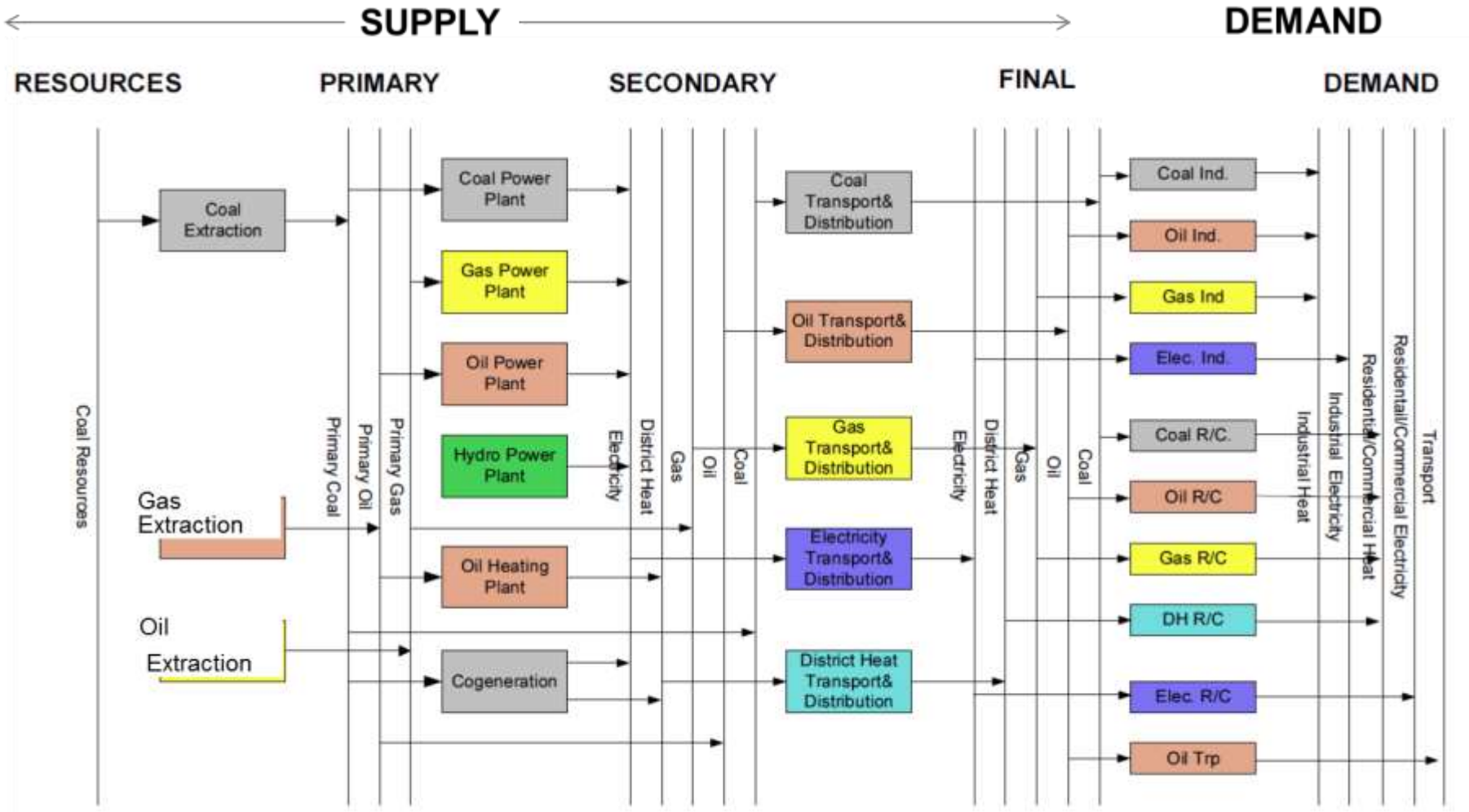
As a matter of fact this tool provides enormous flexibility to the policy and decision makers at all levels to fit their respective surrounding environments in a diversified information platform which can further help them to take informed decisions.

Technology Mapping



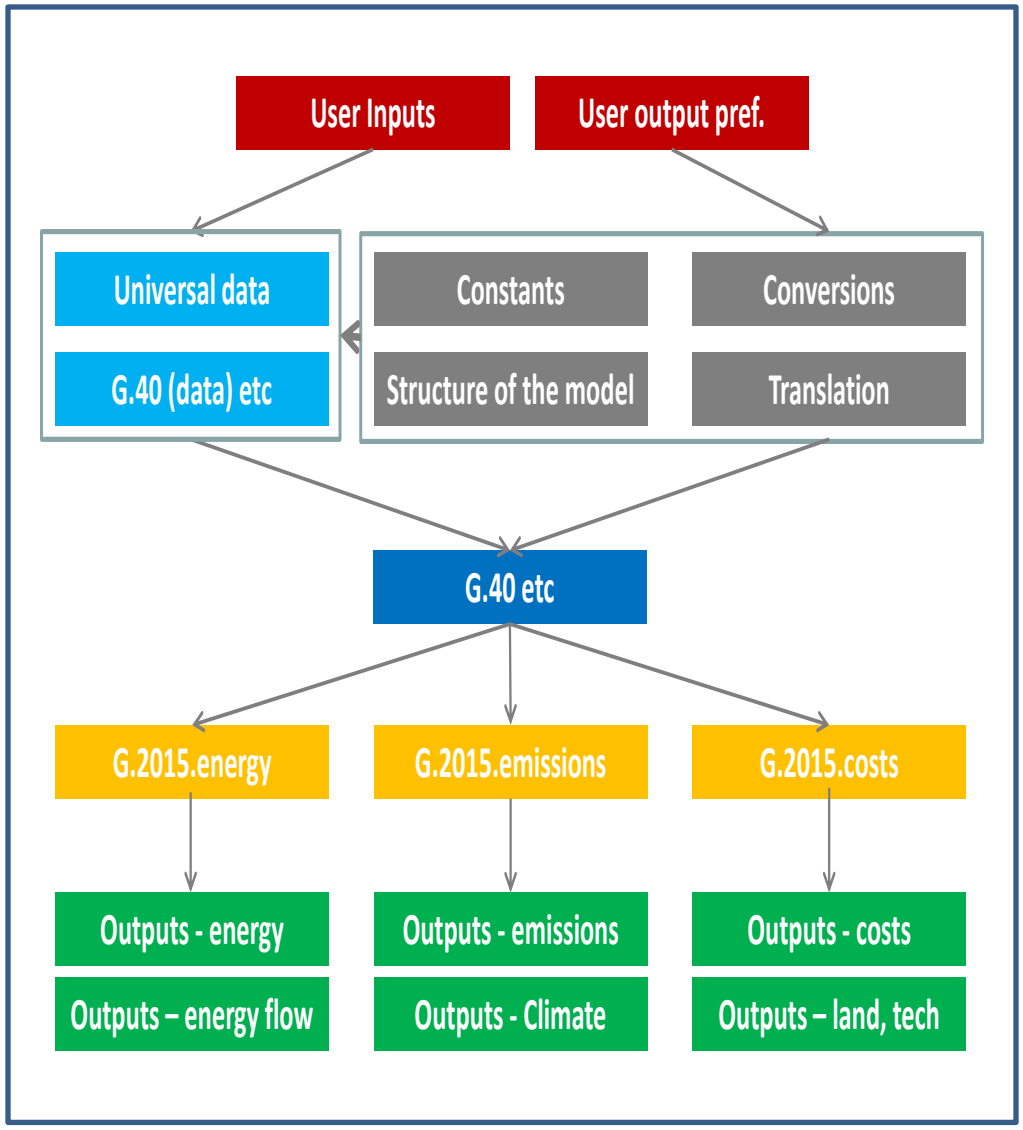
Electricity & Fossil Structure of the Global 2050 Calculator

Indicative flow diagram of the energy system considered in the calculator



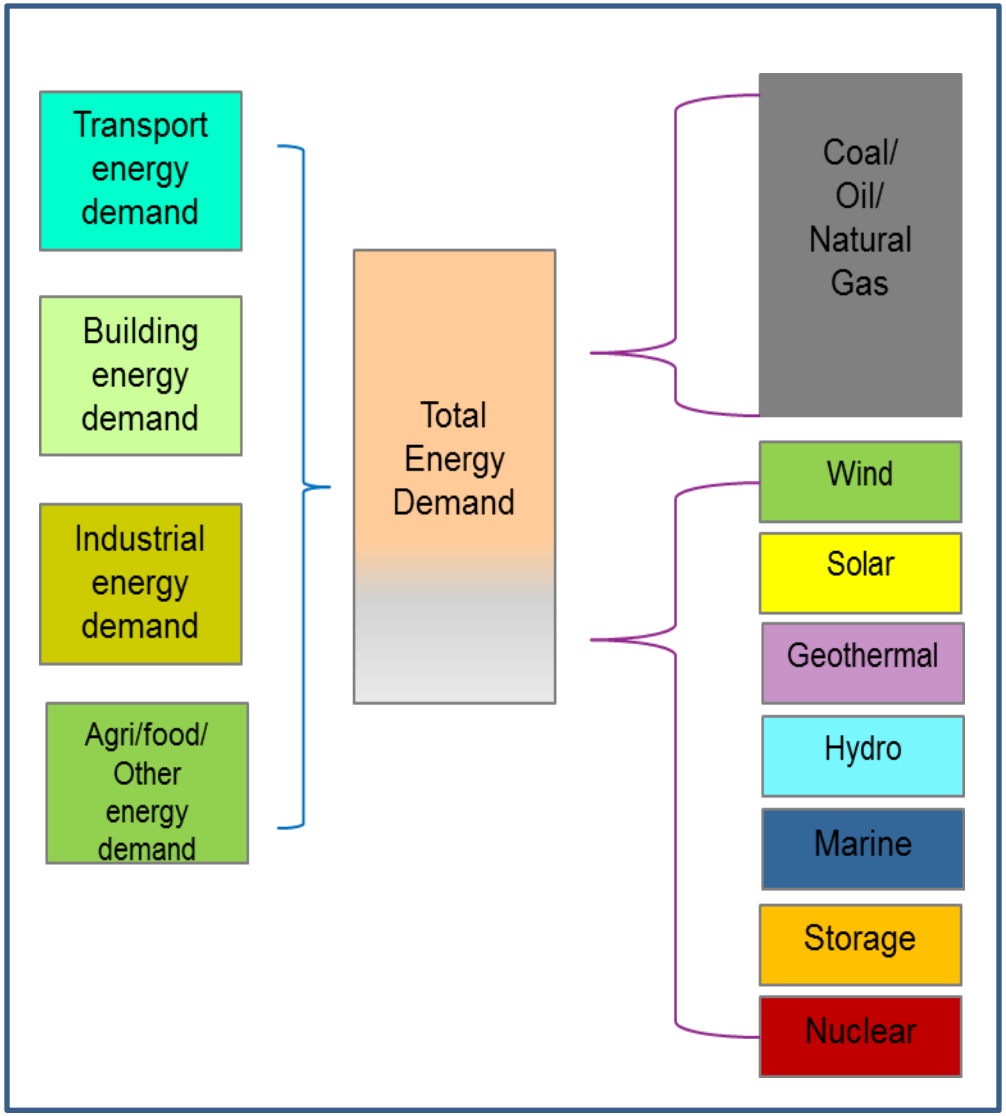
Structure of the Spread Sheets and Linkages

- Different levels of energy systems converted into excel sheets in the model work book
- Users get choices to determine the level of activities under each selected technology which are made user defined in the tool.
- User has options to select levels from 1 energy supply sector (electricity generation) and from 4 different energy demand sectors (transport/ buildings/ manufacturing/ land-food)
- Users get choices to select output units as well.
- Model endogenously determines the total energy demand from each demand sector and then determines the total supply required.

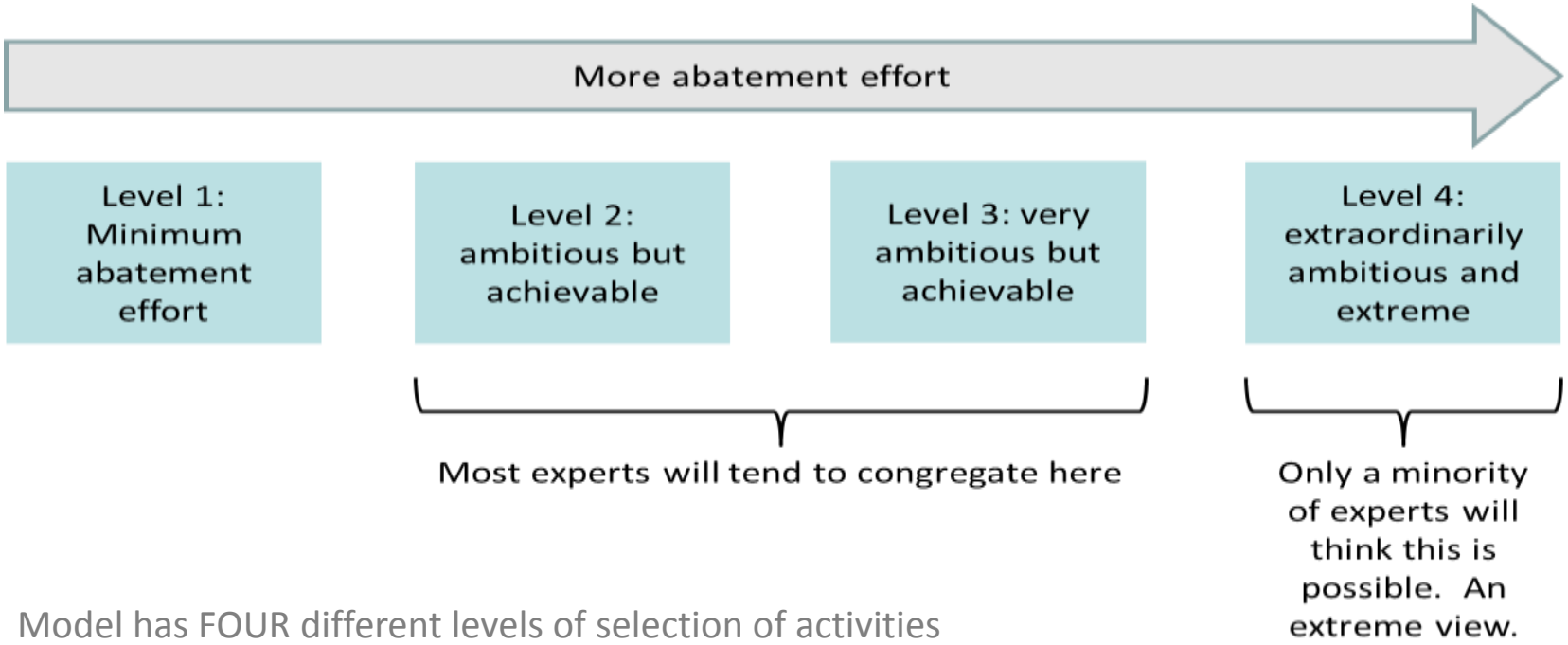


Basic assumptions of electricity supply sector in the model

- Demand = Supply
- Demand meets in a priority order of renewables, nuclear and fossil fuels
- Primary objective of the supply mix is to reduce GHG emissions
- Electricity flows freely from one part to another part of the world- existence of global power grid
- No source of energy is intermittent ..all are firm power



Definition of user defined levels in the model



Model has FOUR different levels of selection of activities

Level-1 : Very pessimistic situation in the future in terms of deploying technology capable of reducing GHG emissions at a global scale.

Level -2 : Cautiously optimistic situation in the future in terms of deploying low emission technology at a global scale.

Level -3: Optimistic situation in the future in terms of deploying low emissions technology at a global scale.

Level -4: Very optimistic situation in the future in terms of deploying low emissions technology at a global scale.

Section 3

Renewable energy supply

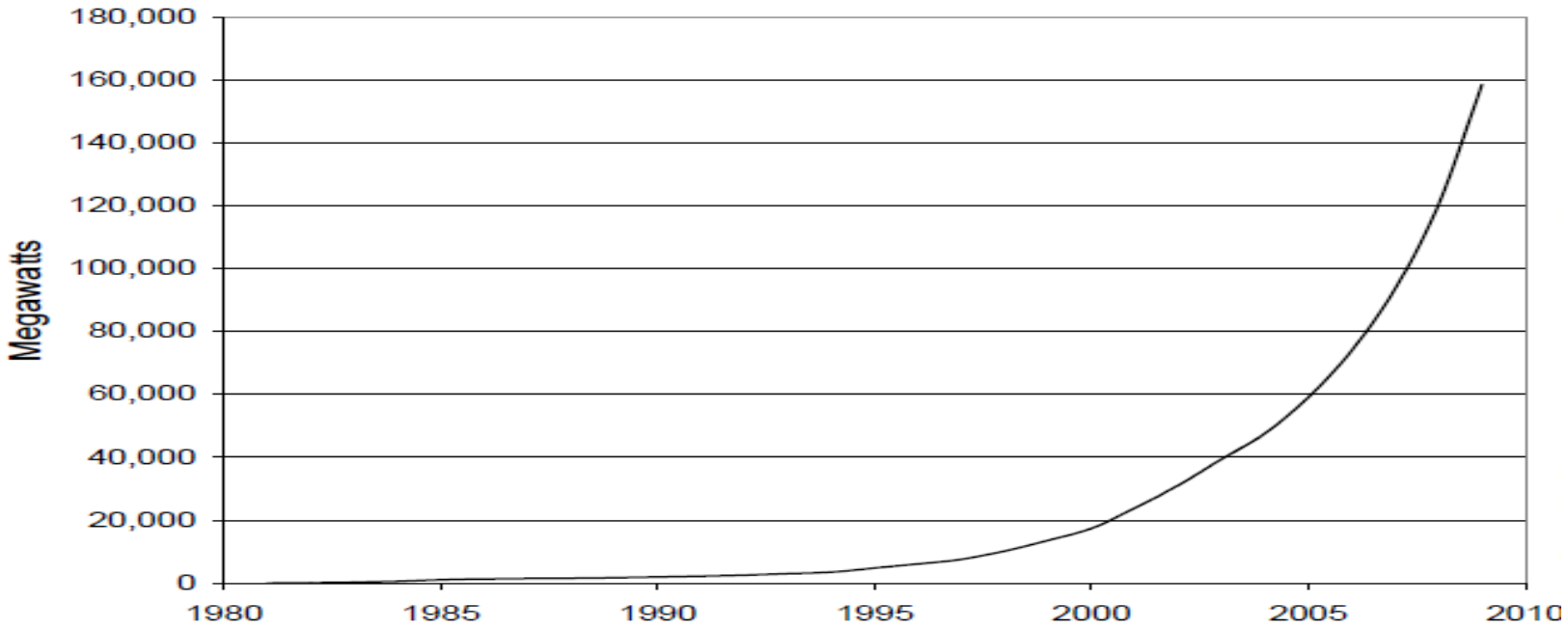
Section 3-1

Wind Energy

Estimated potential of Onshore Wind

- Worldwide, there are nearly 200,000 wind turbines operating in 83 countries, with a total onshore nameplate capacity of 238 GW and offshore capacity of 3.8 GW in 2011 (IEA, 2011).
- World wind generation capacity more than quadrupled between 2000 – 2006 and 2006-2012, doubling about every three years.

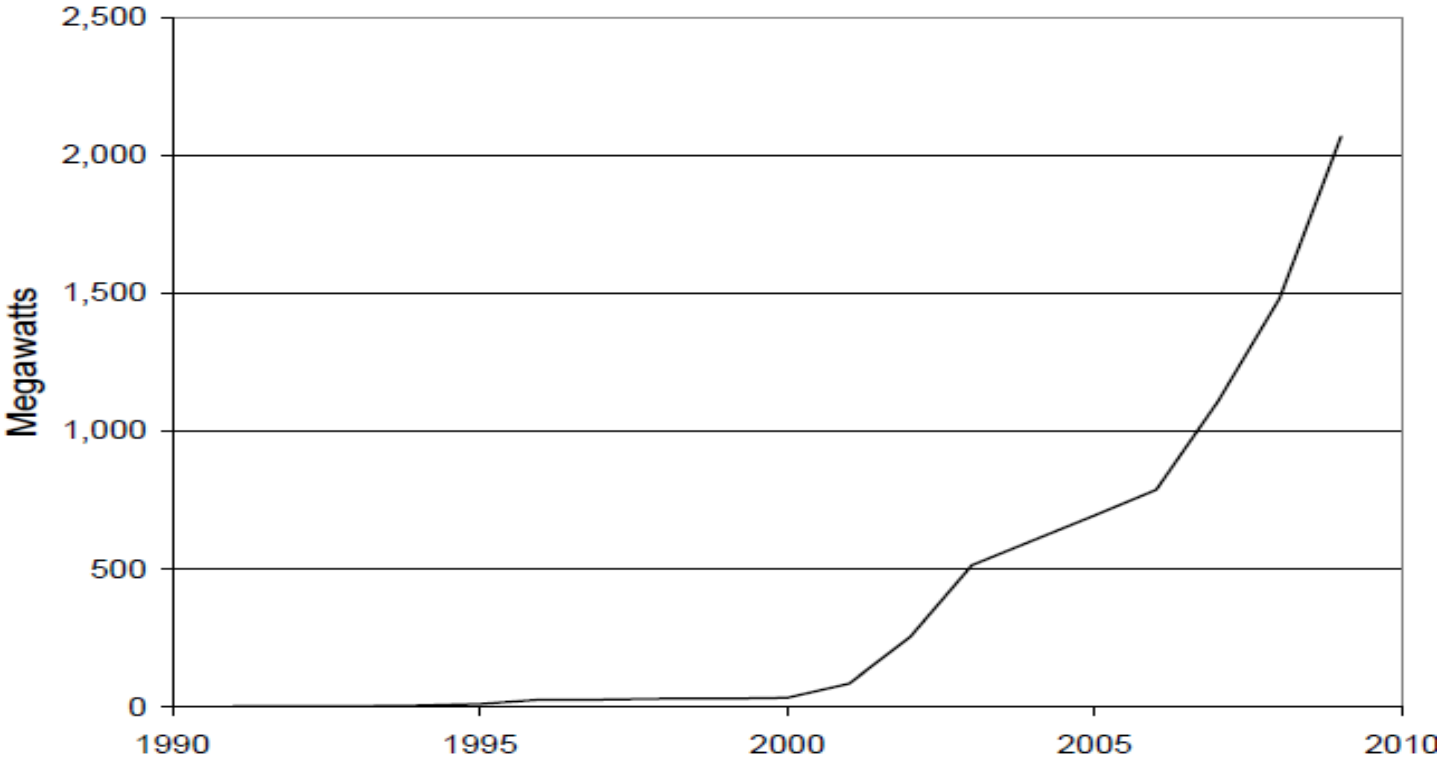
World Cumulative Installed Onshore Wind Power Capacity, 1980-2009



Source: EPI from GWEC, World watch

Estimated potential of Offshore Wind

World Cumulative Installed Offshore Wind Power Capacity, 1991-2009



Source: EPI from 4C offshore, EWEA

Assumptions

- Global capacity factor has marginally improved over a period of time for onshore & offshore generation. The model maintains it constant at 21% and 40 % respectively till 2050. The de-rating of equipment is not considered during its technical lifespan.

- **Built rates of levels for onshore wind electricity**

Level-4: In 2050 there is 5058 GW of onshore wind energy. It is built at a rate of 21% (68 GW/ year) per annum until 2015, 16% (112.4 GW/ year) pa until 2020, 8% (124 GW/ year) pa until 2030, 6% (183 GW/year) pa until 2040 and 2% (91 GW/ year) pa until 2050.

Level-1: In 2050 there is 0 GW of onshore wind energy. It is builds at a rate of 19.64% till 2013, 8% (28 GW/ year) till 2015, 5% till 2020 with decommissioning in tandem.

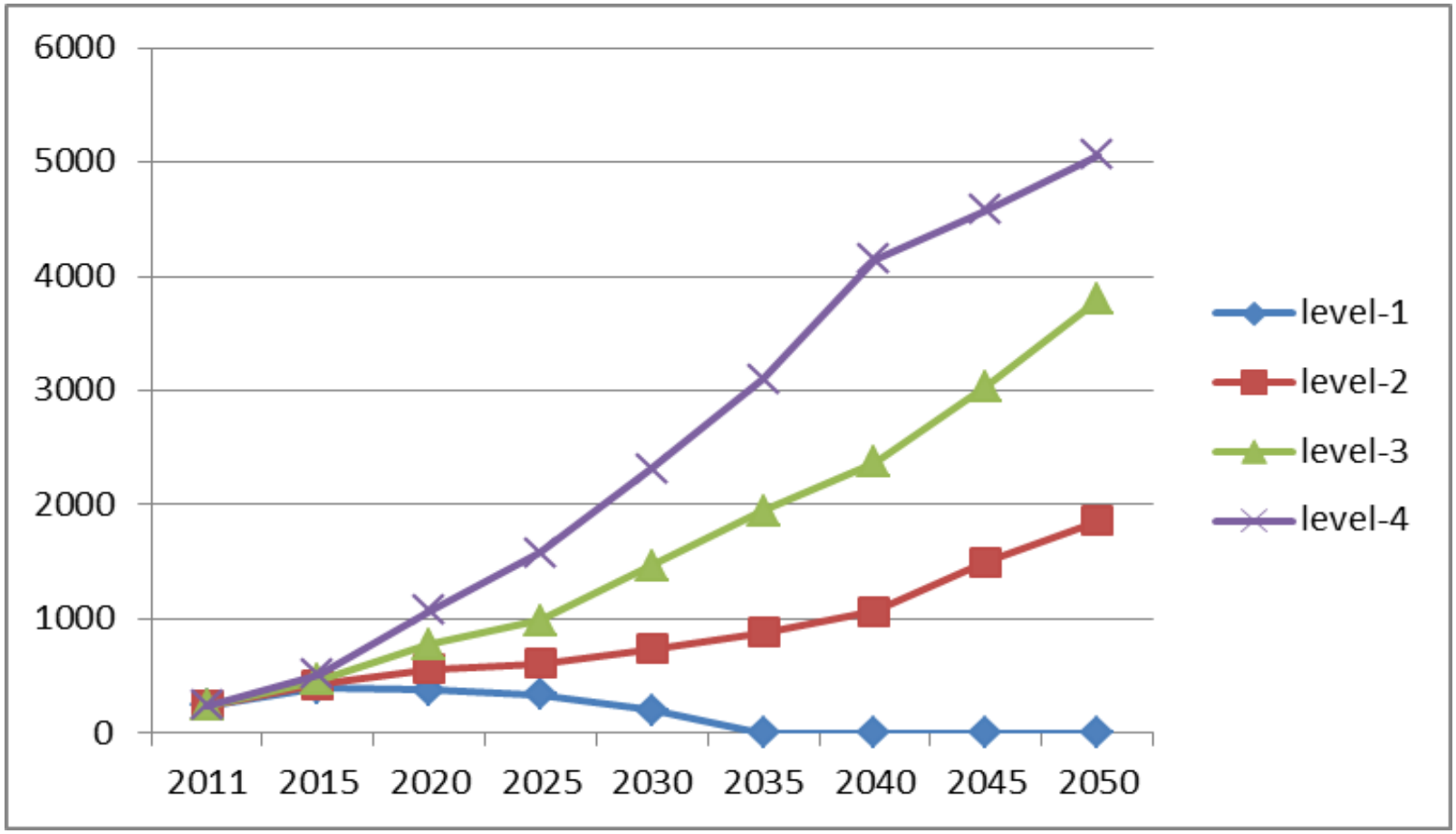
Assumptions…(2)

- **Built rates of levels for offshore wind electricity**

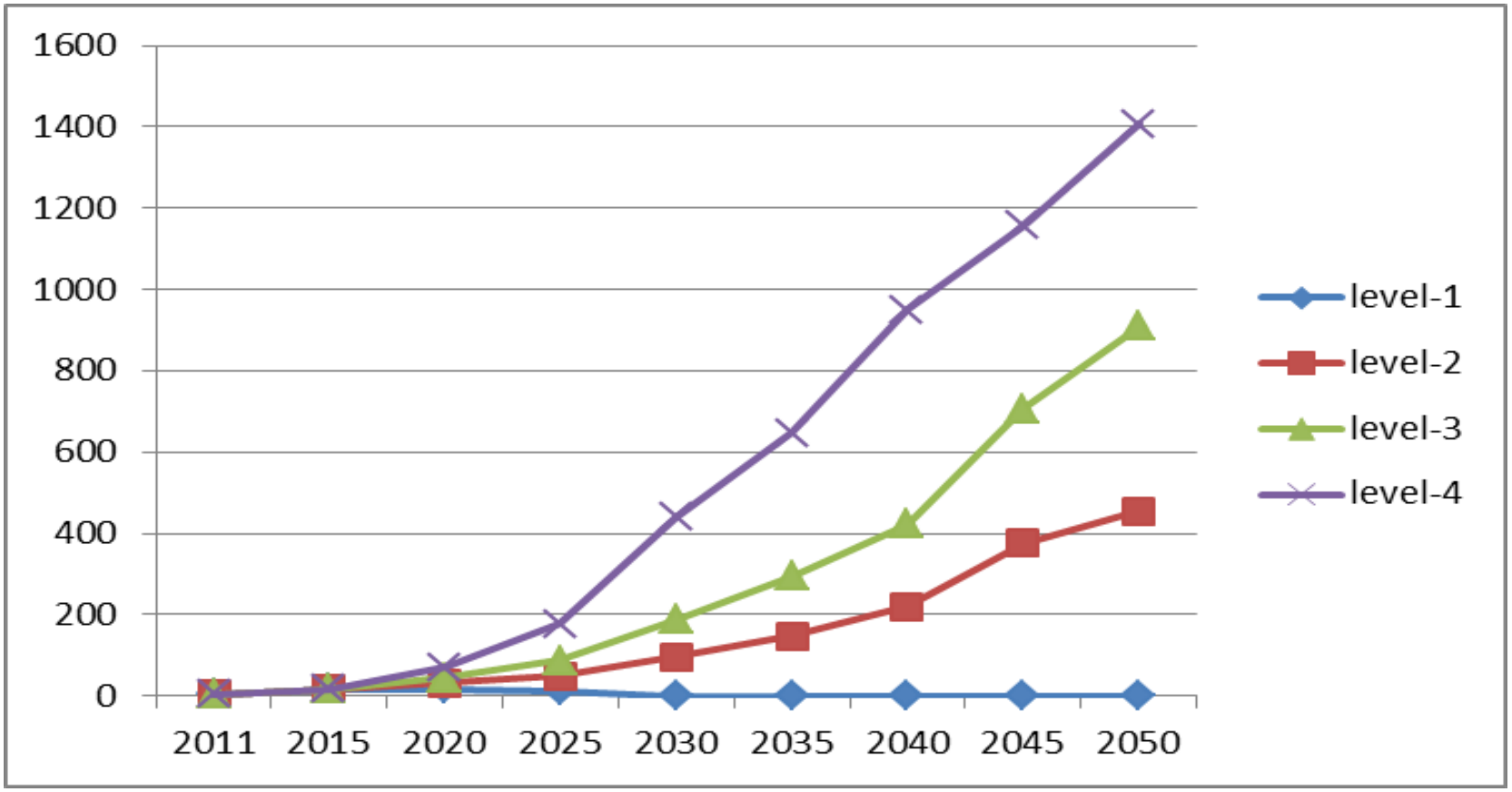
Level-4: In 2050 there is 1408 GW of offshore wind energy which builds at a rate of 34.06% (7.5 GW/year) till 2020, 20% (37 GW/ year) till 2030, 8% (51 GW/ year) by 2040 and 4% (45 GW/ year) by 2050.

Level-1: In 2050 the offshore wind energy is 0 GW with a build rate of 34.06% by 2015. Post 2015 the built rate and decommissioning matches each other till 2020 after which it serves it technical lifespan.

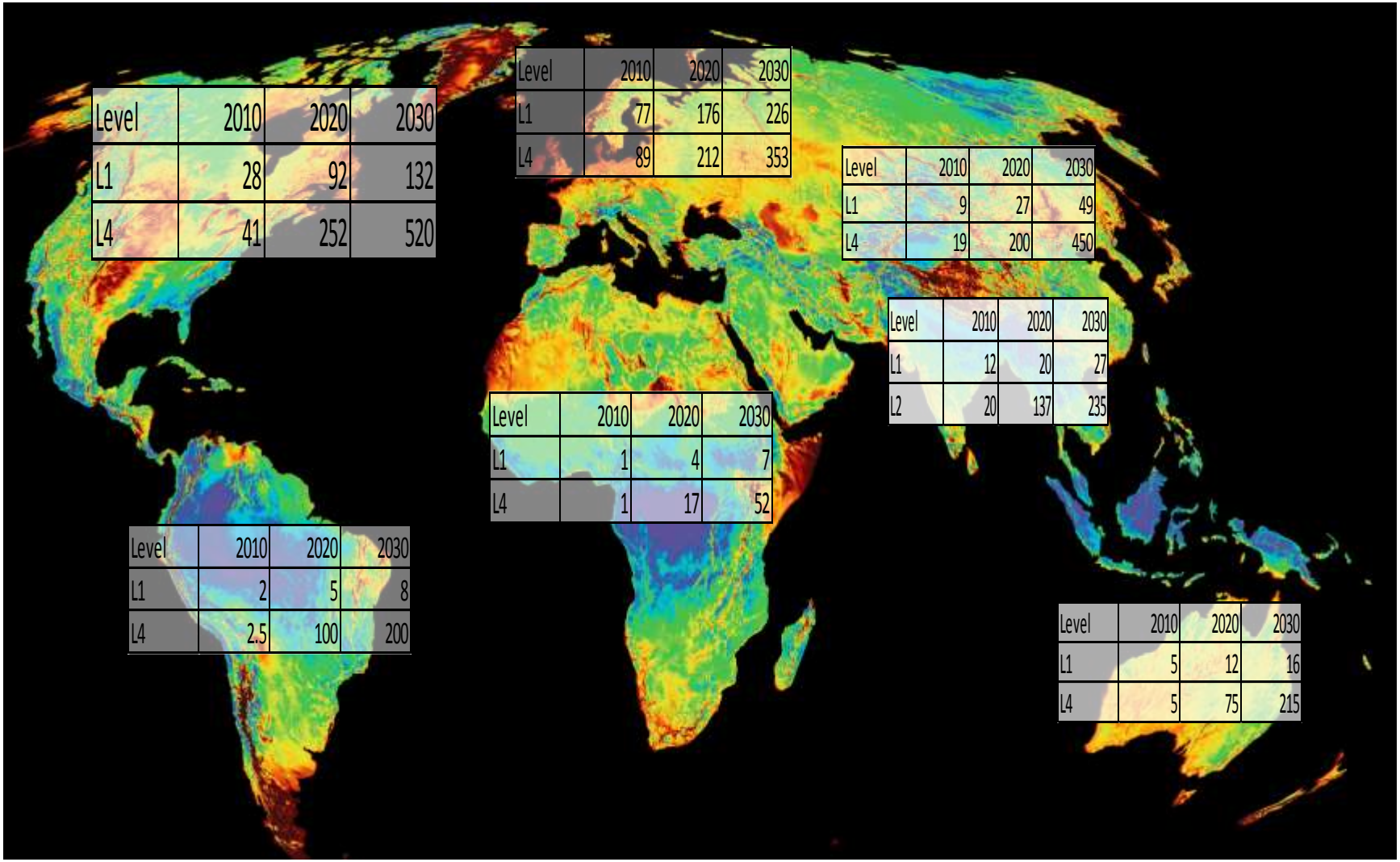
Levels for Onshore Generation (GW)



Levels for Offshore Electricity (GW)



Global distribution of Onshore & Offshore Wind Capacity addition potential



Level	2010	2020	2030
L1	28	92	132
L4	41	252	520

Level	2010	2020	2030
L1	77	176	226
L4	89	212	353

Level	2010	2020	2030
L1	9	27	49
L4	19	200	450

Level	2010	2020	2030
L1	12	20	27
L2	20	137	235

Level	2010	2020	2030
L1	1	4	7
L4	1	17	52

Level	2010	2020	2030
L1	2	5	8
L4	2.5	100	200

Level	2010	2020	2030
L1	5	12	16
L4	5	75	215

Questions to experts on Wind Energy

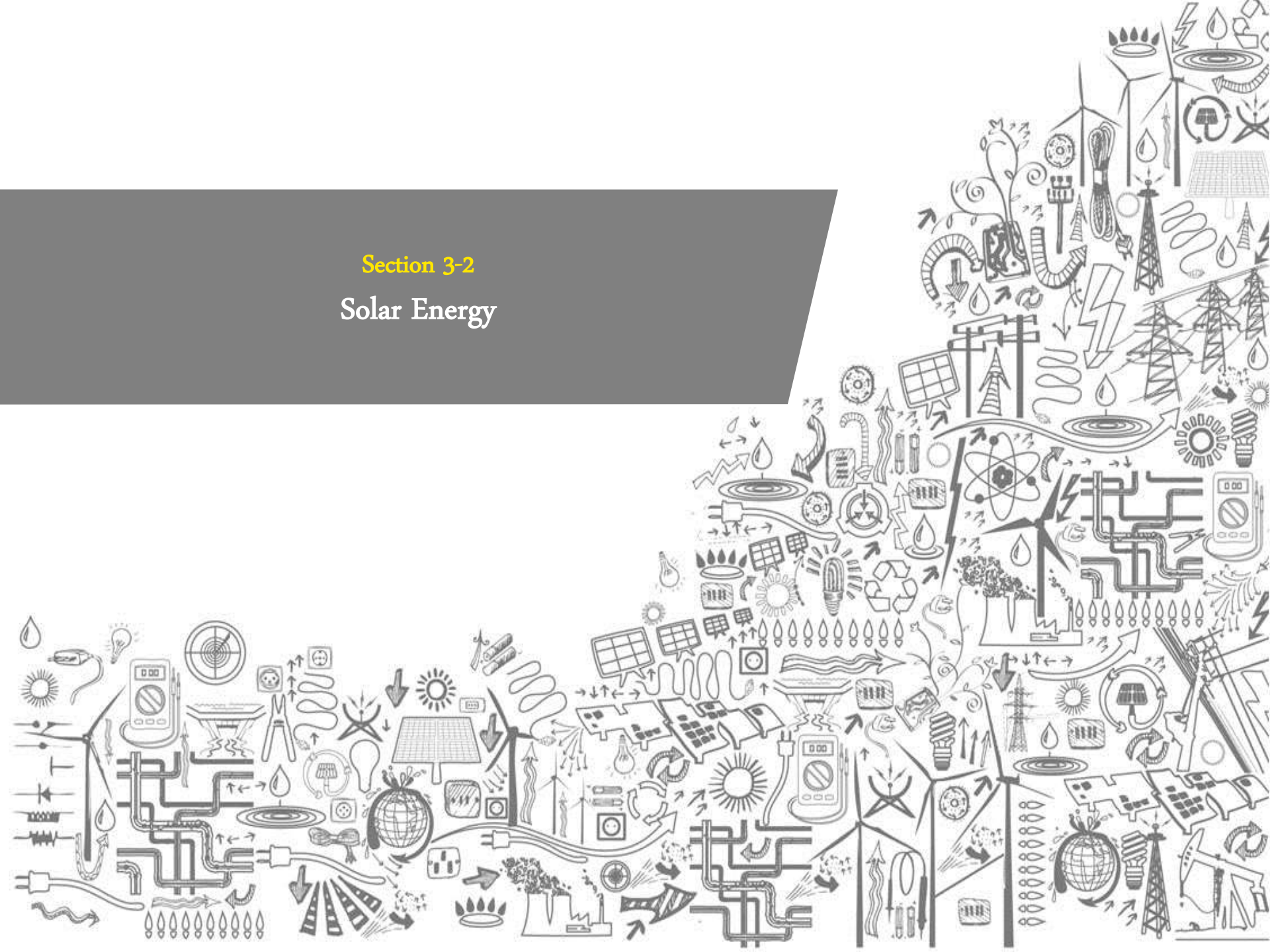
1. Do you think our Level -4 built rates are achievable / reasonable / undermined ?
2. What is your opinion on world can achieve by 2050 closest possible range of 2000 GW ?

Technology	Level-4 by 2050	Global Theoretical Potential
Wind (On shore)	5058 GW	8000 to 80,000 GW*
Wind (off-shore)	1408 GW	

*** http://www.udel.edu/udaily/2013/sep/wind-energy-potential-091012.html**

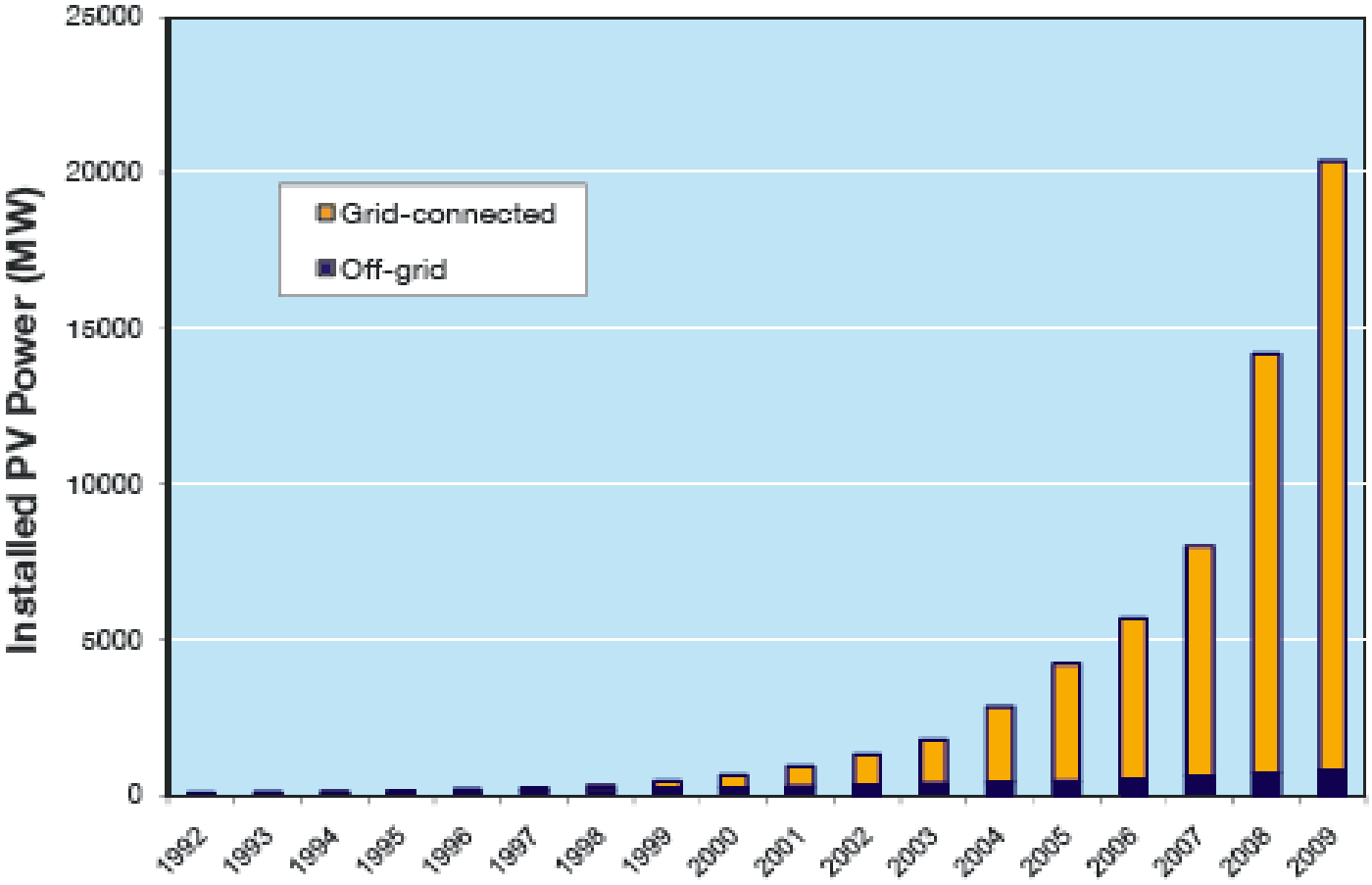
Section 3-2

Solar Energy



Estimated potential of Photovoltaic (GW)

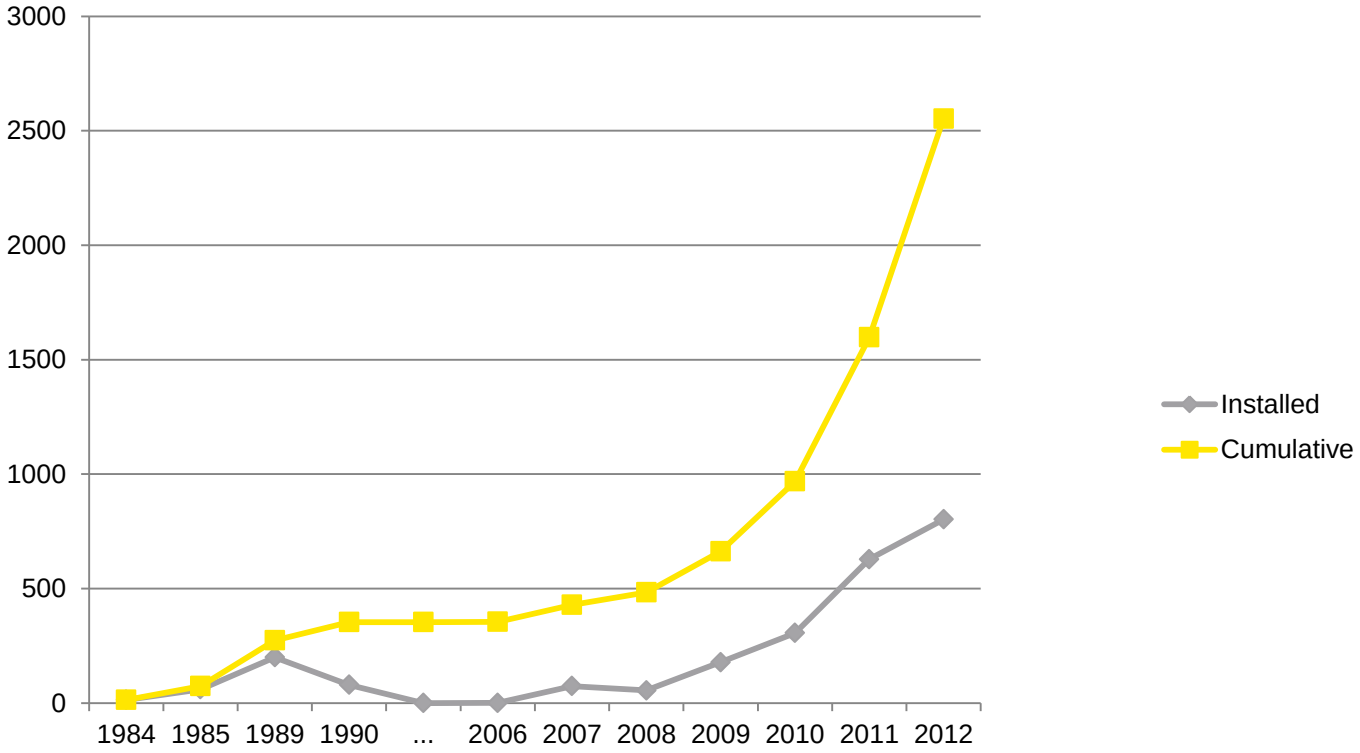
Worldwide, 28 GW of solar photovoltaic till 2011.



Source: IEA, Trends in solar photovoltaic

Estimated potential Concentrated Solar Power (GW)

Worldwide, 1.59 GW of concentrated solar power was online till 2011.



Source: IEA, Trends in solar photovoltaic

- Global capacity factor has improved over a period of time for solar photovoltaic & concentrated solar power. The model maintains it constant at 20% and 30 % respectively till 2050.

- The de-rating of equipment is not considered for its technical lifespan. Similarly no water or silicon constraints have been taken.

- **Built rates of levels for Solar Photovoltaic (SPV) electricity**

Level-4: In 2050 there is 5539.6 GW of SPV based generation capacity. It builds at a rate of 24.5% (19.2 GW/year) by 2020, 18.4% (88.8 GW/year) by 2030, 11% (200 GW/year) by 2040 and 6% (244.6 GW/year) till 2050, whereas

Level-1: In 2050 there is 0 GW of SPV based generation capacity. It builds at a rate of 19.58% till 2020, serves its technical lifespan and depreciates eventually to 0 GW.

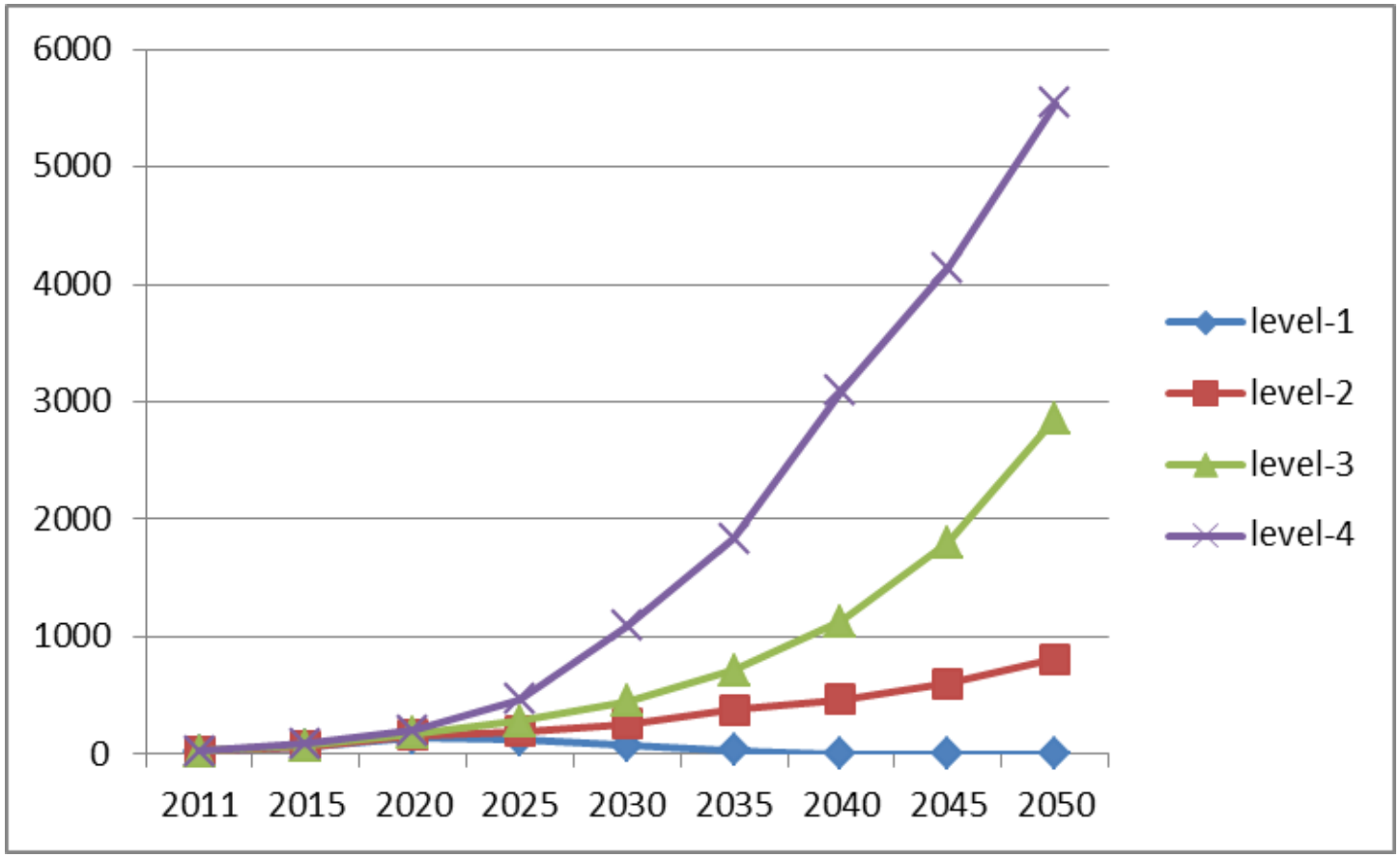
Assumptions…(2)

- **Built rates of levels for Concentrated Solar Power (CSP) electricity**

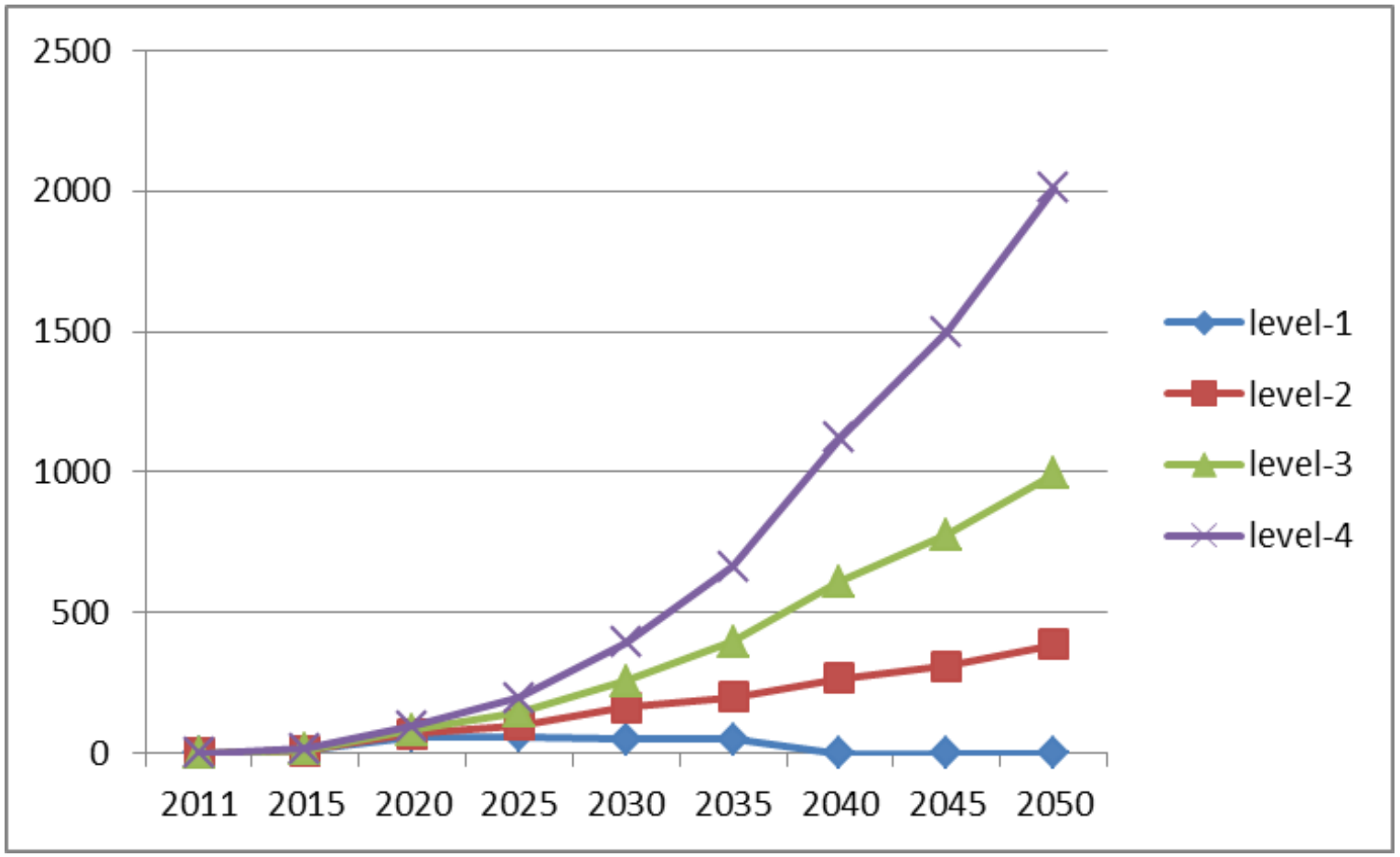
Level-4: In 2050 there is 2007.14 GW of CSP installed capacity which builds at a rate of 58% (10.7 GW/year) till 2020, 15% (29.7 GW/year) till 2030, 11% (72.6 GW/year) by 2040 and 6% (88.6GW/year) by 2050.

Level-1: In 2050 the CSP installed capacity is 0 GW with a build rate of 49.58% by 2020. Post 2020 the built rate and decommissioning matches each other till 2025 after which it serves it technical lifespan and goes to 0 GW installed.

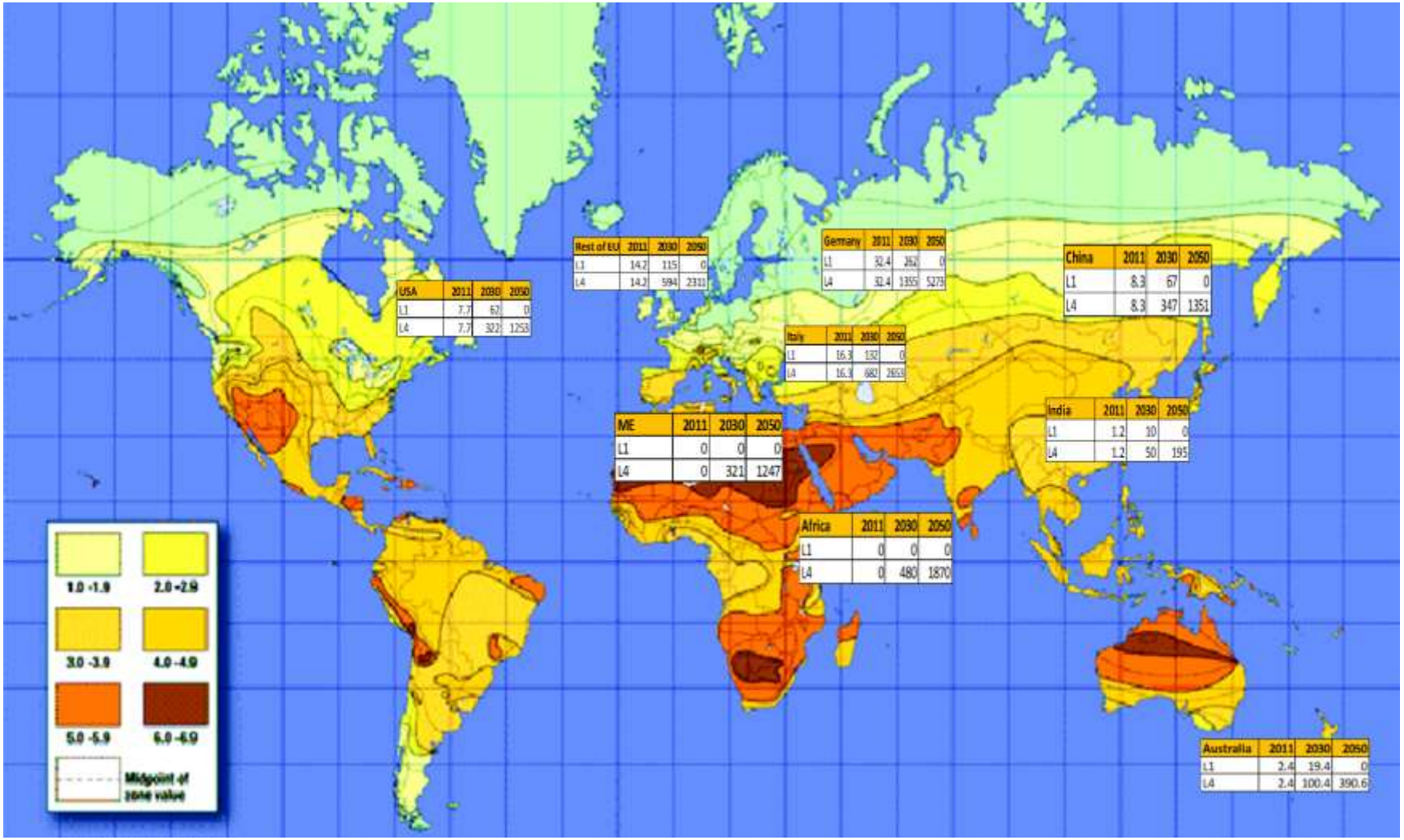
Levels for Solar Photovoltaic (GW)



Levels for Concentrated Solar Power (CSP) (GW)



Global distribution of solar potential



USA	2011	2030	2050
L1	7.7	62	0
L4	7.7	322	1253

Rest of EU	2011	2030	2050
L1	14.2	115	0
L4	14.2	594	2311

Germany	2011	2030	2050
L1	32.4	262	0
L4	32.4	1355	5273

China	2011	2030	2050
L1	8.3	67	0
L4	8.3	347	1351

Italy	2011	2030	2050
L1	16.3	132	0
L4	16.3	682	2653

ME	2011	2030	2050
L1	0	0	0
L4	0	321	1247

India	2011	2030	2050
L1	1.2	10	0
L4	1.2	50	195

Africa	2011	2030	2050
L1	0	0	0
L4	0	480	1870

Australia	2011	2030	2050
L1	2.4	19.4	0
L4	2.4	100.4	390.6

Questions to experts on Solar Energy

1. Do you think our Level -4 built rates are achievable / reasonable / undermined ?
2. What is your opinion on world can achieve by 2050 closest possible range of 4500-490,000 GW ?

Technology	Level-4 by 2050	Global Theoretical Potential
Solar PV	5539.6 GW	4500-490,000 GW
Solar CSP	2007.1 GW	

Ranges of theoretical potential of solar energy

Authors	Technical Power potential (TWe)
DeVries 2007	170-490
Deng et al 2010	57
Rogner et al 2000	50-1580
Grassl et al 2003	33 (sustainable)
Jacobson 2009	170-340
Nakicenovick 2000	>213
Hoogwijk et al. 2008	53.6
Hoogwijk 2004	42.2
Hofman 2002	42
Sorensen 1999	52
Zerta et al 2008	23-46 (sustainable)
This study	**1.75-4.5**

Section 3-3

Marine Energy

Growth assumptions for estimating potential of Wave & Tidal Power

- Worldwide, 0.01 GW of wave and 1 GW of tidal power was online in 2011.
- Built rates of levels for tidal electricity

Level-4: In 2050 there is 292.6 GW of installed tidal capacity. The average built up rate is 12.98% (0.2 GW/ year) till 2020, whereas 15.75% (2.6 GW/ year) till 2040 and 18% (23.7 GW/ year) till 2050.

Level-1: It eventually leads to 0 GW of installed geothermal electricity by 2050. Constant decommissioning rate is considered till it goes zero considering lifespan and other constraints.

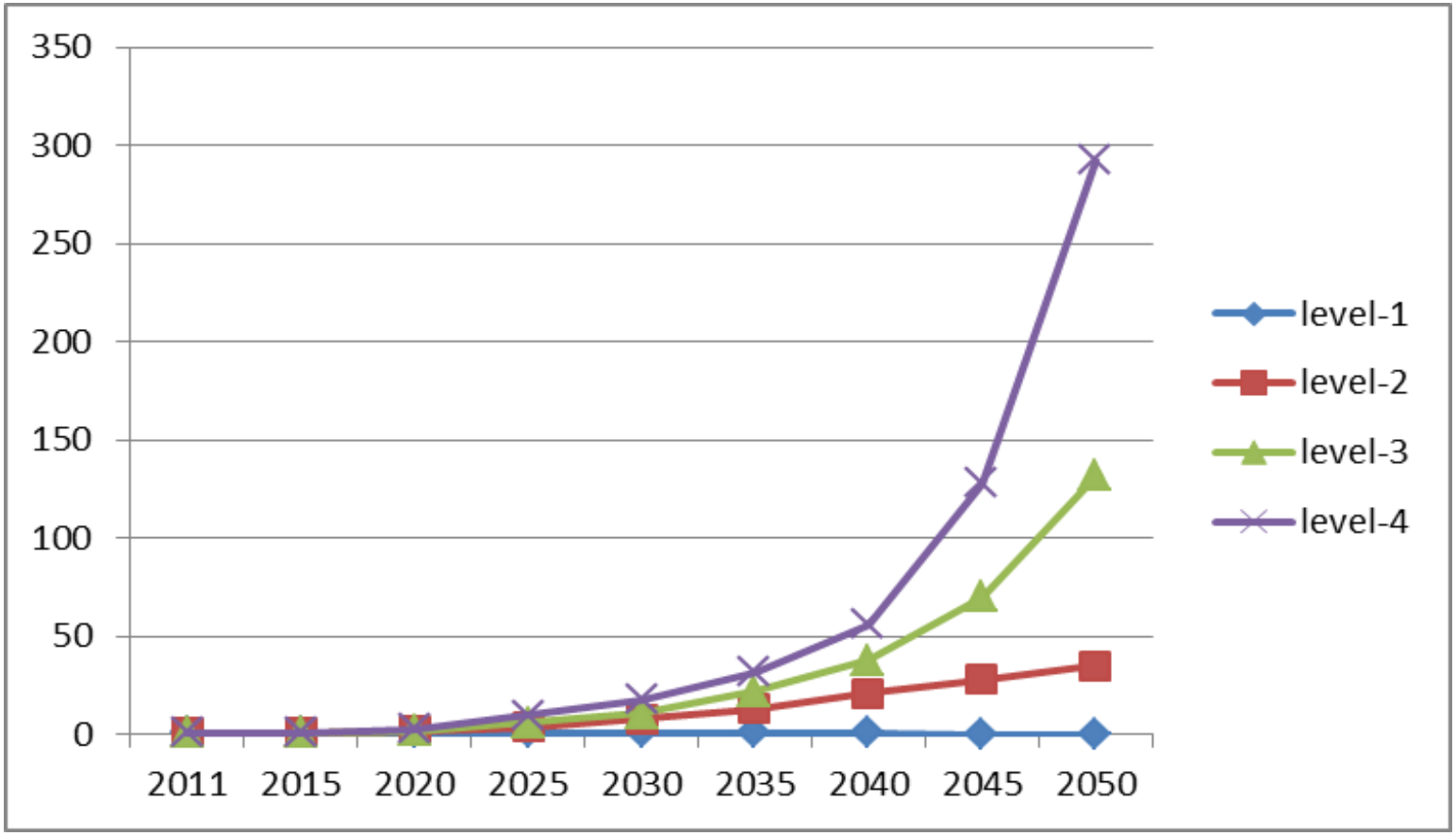
Growth assumptions for estimating potential of Wave & Tidal Power

- **Built rates of levels for wave electricity**

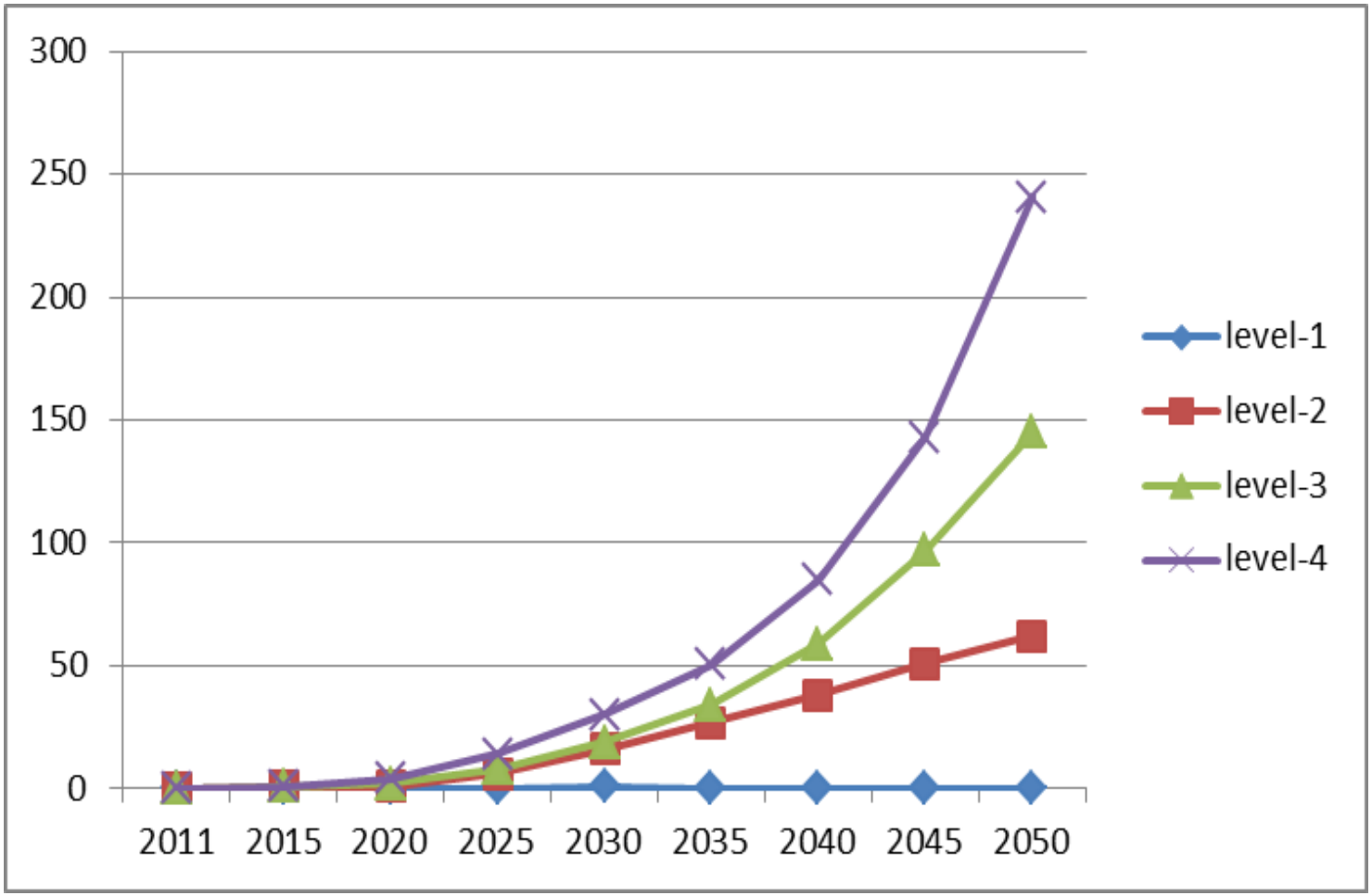
Level-4: In 2050 there is 240.8 GW of installed wave capacity. The average built up rate is 94.58% (0.44 GW/ year) till 2020, whereas 22.32%% (2.6 GW/ year) till 2030 and 10.97% (10.5 GW/year) up till 2050.

Level-1: It eventually leads to 0 GW of installed wave capacity by 2050. It initially grows at a high rate of 24.9% till 2020 and then constant decommissioning rate is considered till it goes zero considering lifespan and other constraints.

Levels for Tidal Energy (GW)



Levels for Wave Energy (GW)



Questions to experts on Marine Energy

1. Do you think our Level -4 built rates are achievable / reasonable / undermined ?
2. What is your opinion on world can achieve by 2050 closest possible range of 4000-5000 GW ?

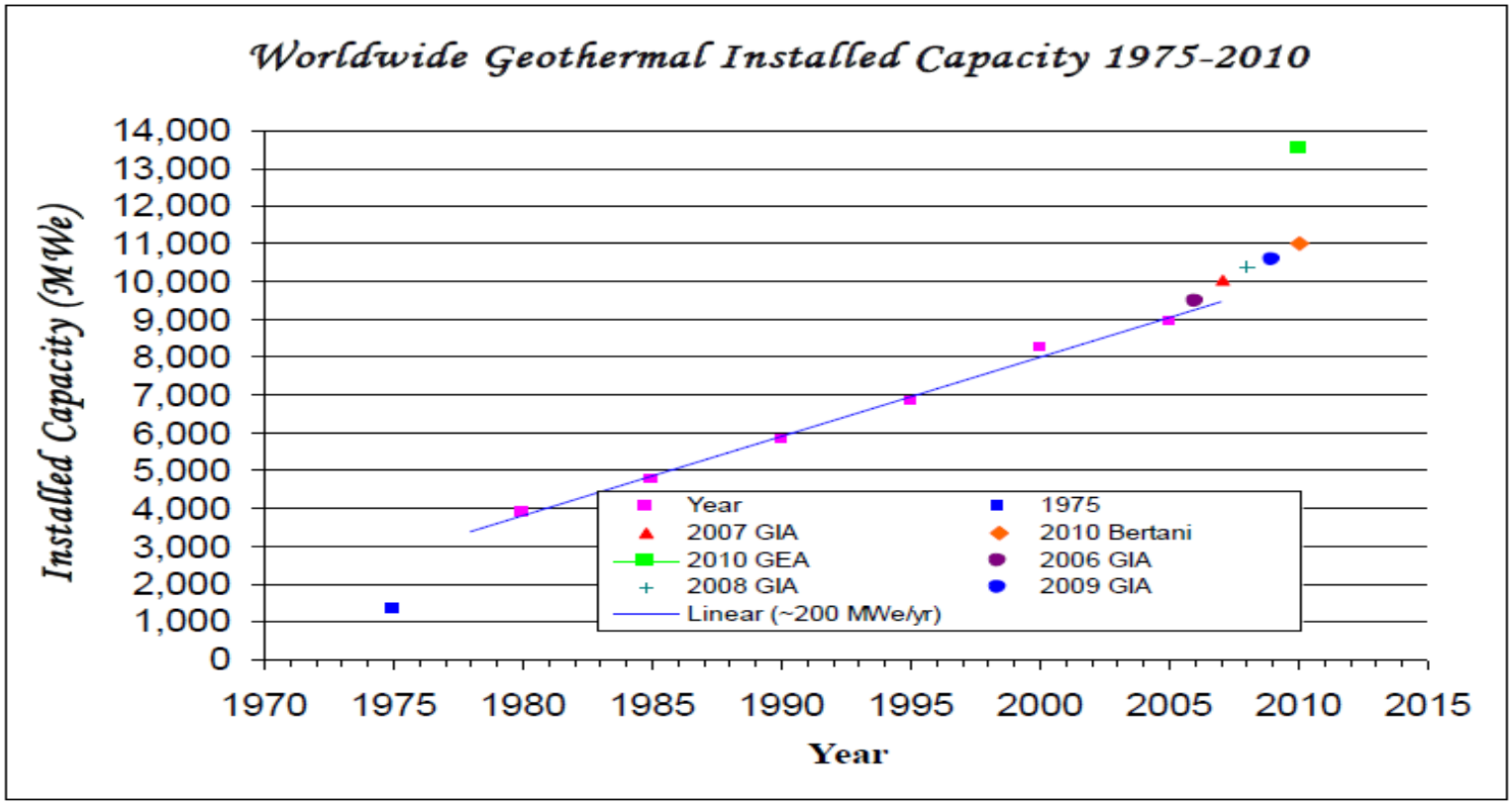
Technology	Level-4 by 2050	Global Theoretical Potential
Tidal Energy	292.6 GW	3000 to 4000 GW
Wave Energy	240.8 GW	2700 to 5000 GW

Section 3-4

Geothermal Energy

Estimated potential of Geothermal

- Worldwide, 11.6 GW of geothermal power was online in 24 countries in 2011.



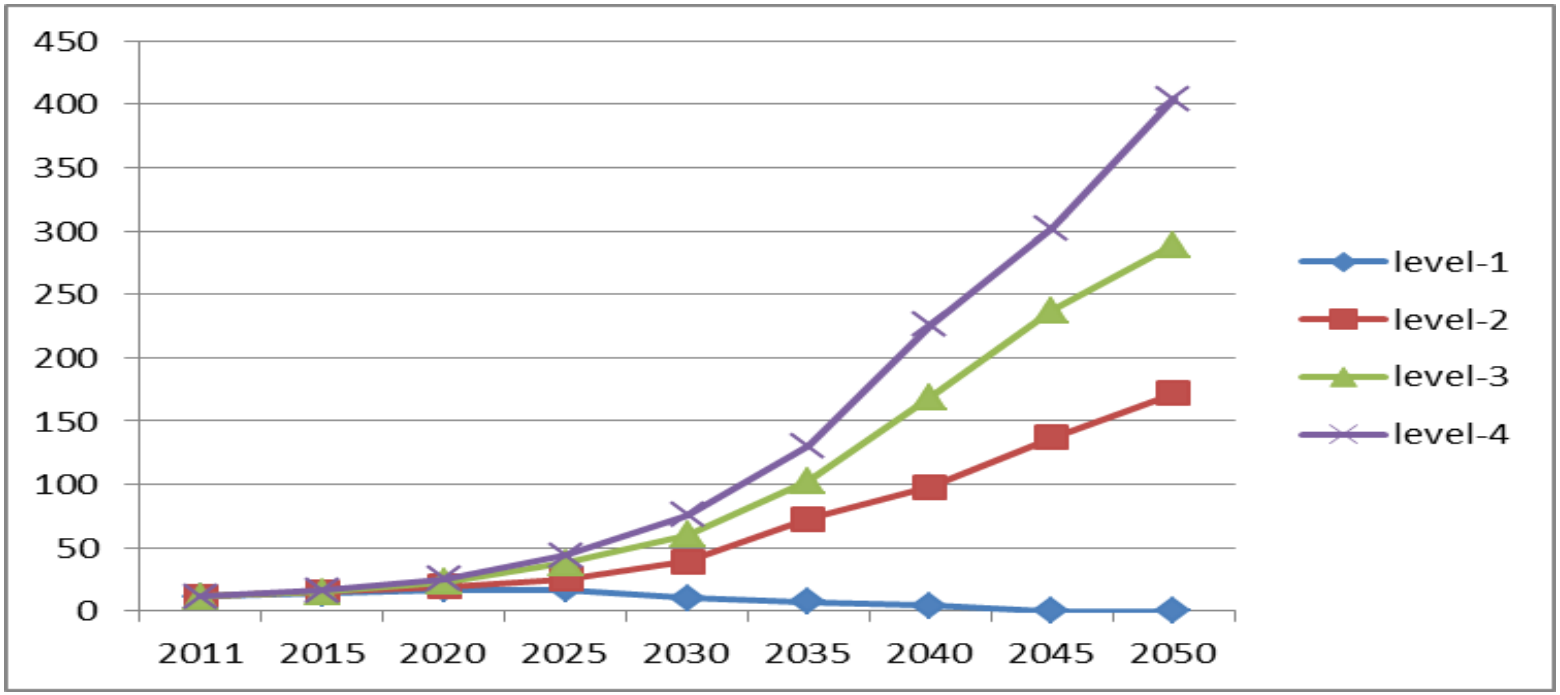
Source: IEA-GIA, 13th Annual Report

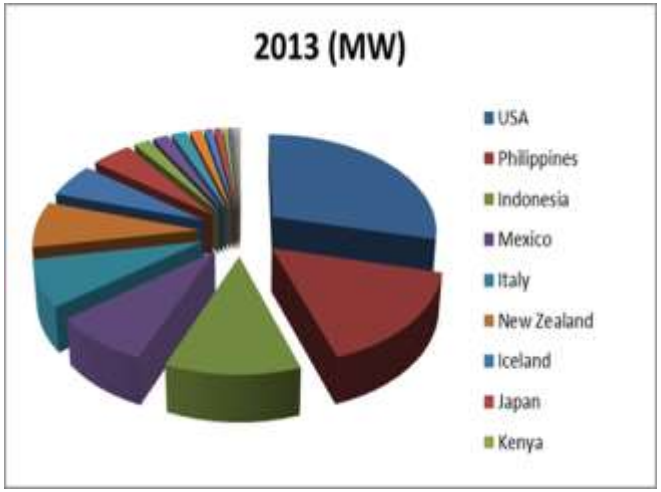
- **Deeper drilling considered**: Standard global average of drilling depth is 3 km , but we considered up to 10 km to enhance the energy availability.
- Built rates of levels for geothermal electricity

Level-4: In 2050 there is 404 GW of installed geothermal electricity. The average built rate is 9% (1.6 GW/year) till 2020, whereas 11.55% (10 GW/ year) till 2040 and 6% (18 Gw/ year) up till 2050.

Level-1: It eventually leads to 0 GW of installed geothermal electricity by 2050. The average built up rate is 4.34% (0.6 GW / year) till 2020, whereas a constant decommissioning rate is considered till it goes zero considering lifespan and other constraints.

Levels for Geothermal Electricity

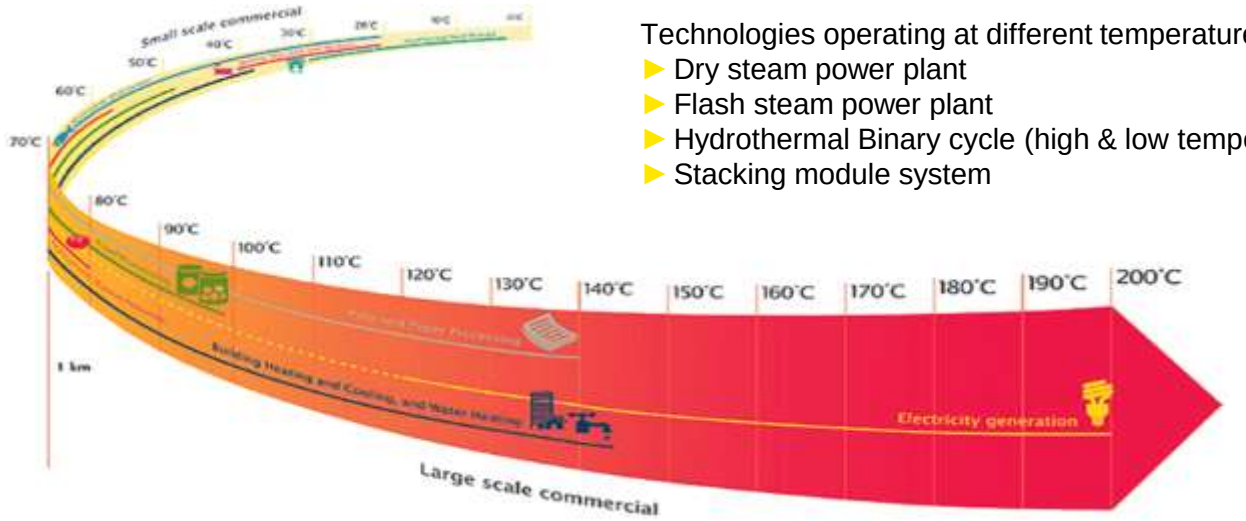




Questions to experts on Geothermal Electricity

1. Do you think our Level -4 built rates are achievable / reasonable / undermined ?
2. What is your opinion on world can achieve by 2050 closest possible range of 2000 GW ?

Technology	Level-4 by 2050	Global Theoretical Potential
Geothermal Electricity	404 GW	35 to 2000 GW

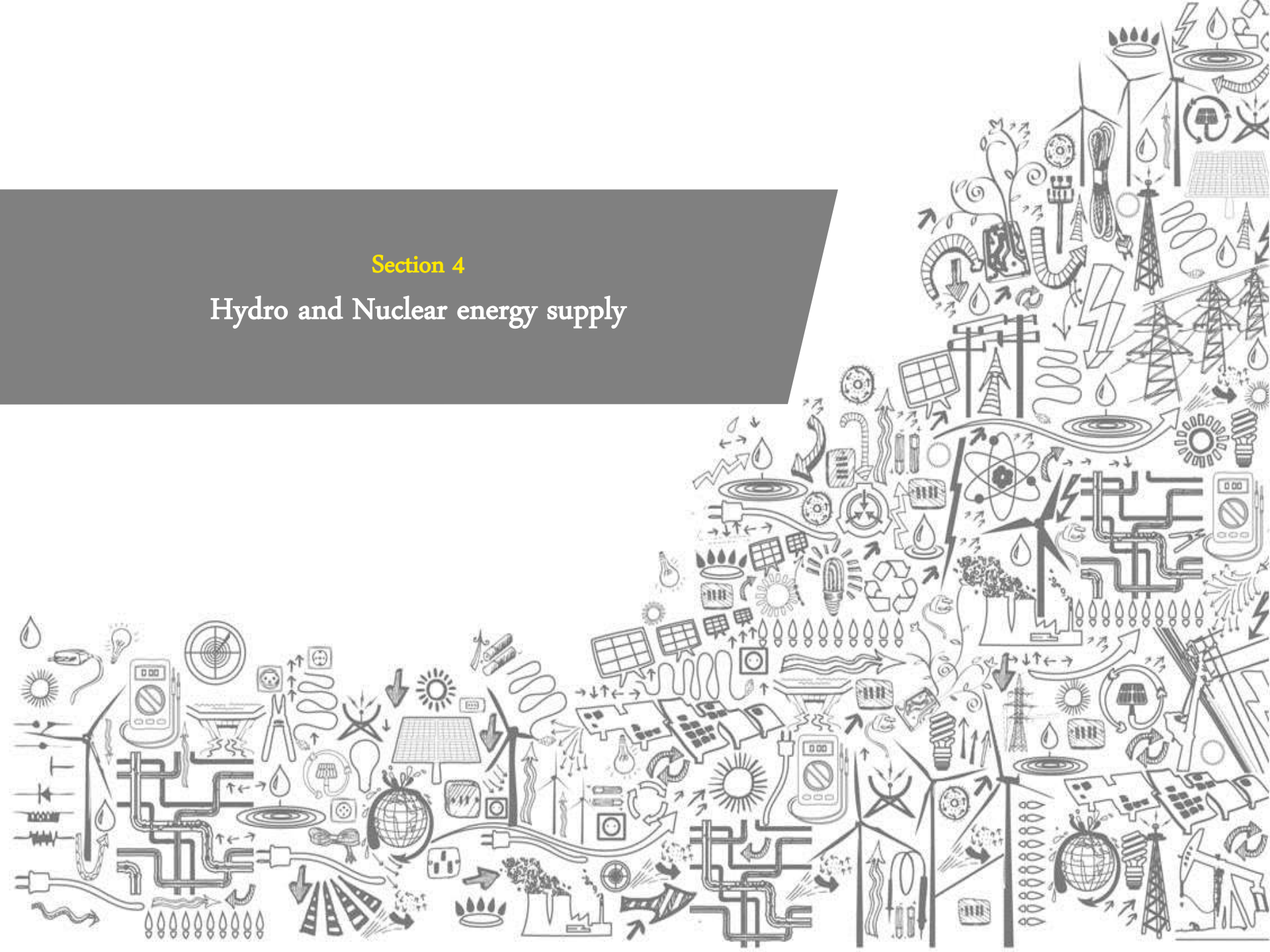


Technologies operating at different temperature:

- Dry steam power plant
- Flash steam power plant
- Hydrothermal Binary cycle (high & low temperature)
- Stacking module system

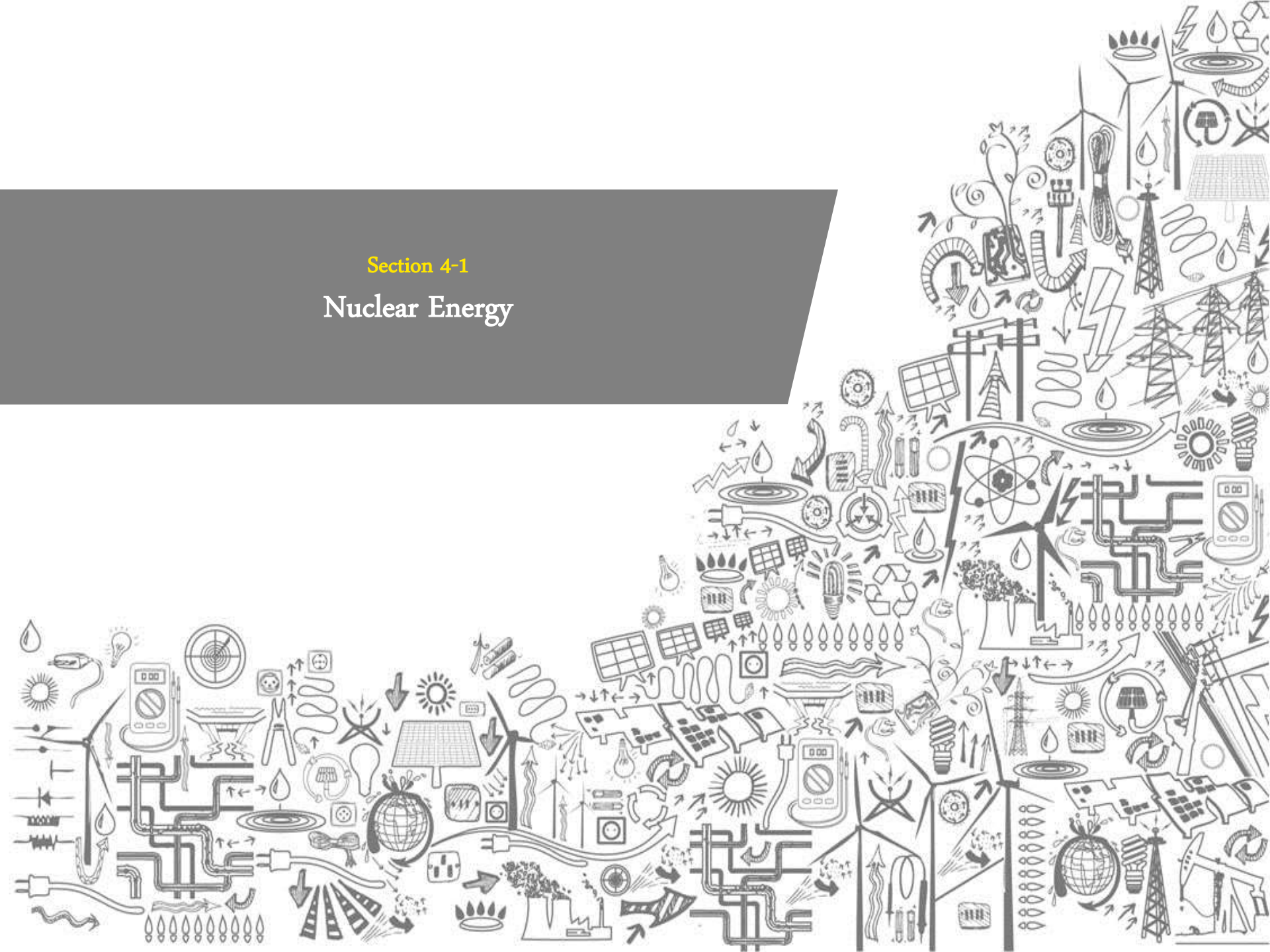
Section 4

Hydro and Nuclear energy supply



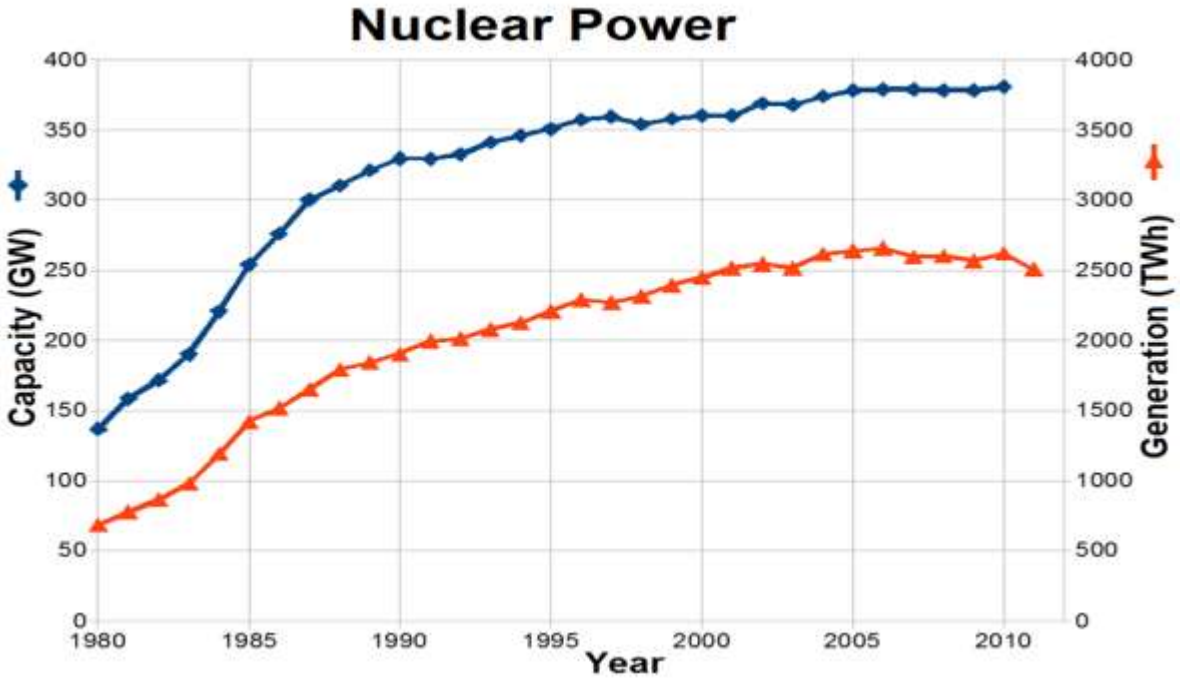
Section 4-1

Nuclear Energy



Growth assumptions for estimating potential of Nuclear Energy

- Worldwide, 369 GW of nuclear power was online in 2011. Nuclear fission has been considered for formulation of levels up till 2050 while nuclear fusion contribution will be marginal.
- No fuel material constraint is considered for defining levels. Decommissioning has not been considered as impediment



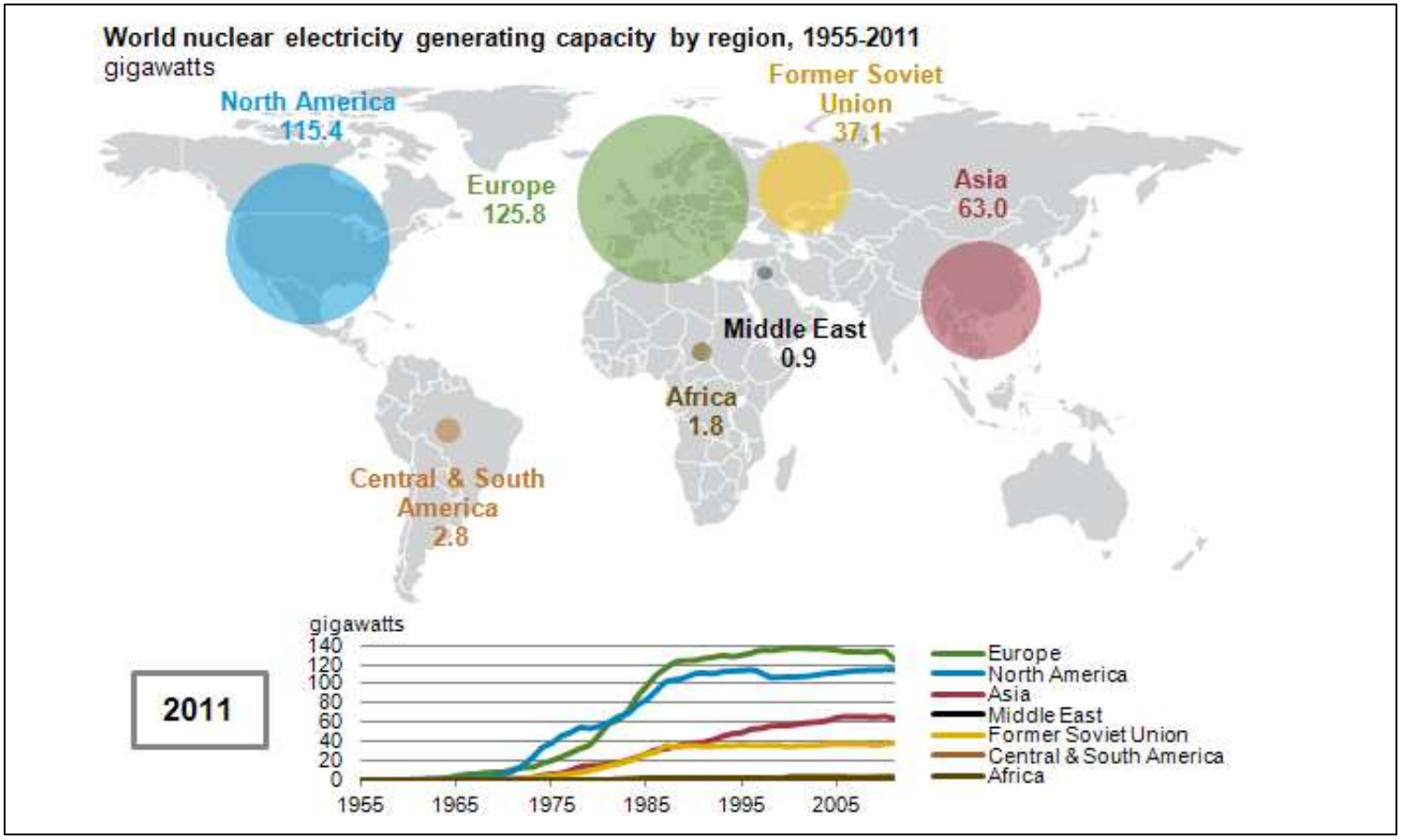
Built rate of levels for Nuclear

Level-4: In 2050 there is 6667.69 GW equivalent of installed nuclear capacity. The average built up rate is 10.30% (58 GW/year) till 2020, 12% (187.8 GW/year) till 2030, 6% (219 GW/year) till 2040 and 3% (170.6 GW/year) until 2050.

Level-1: In 2050 there is 0 GW equivalent of active nuclear capacity. Phased decommissioning of various installations would be under progress.

Source: EIA

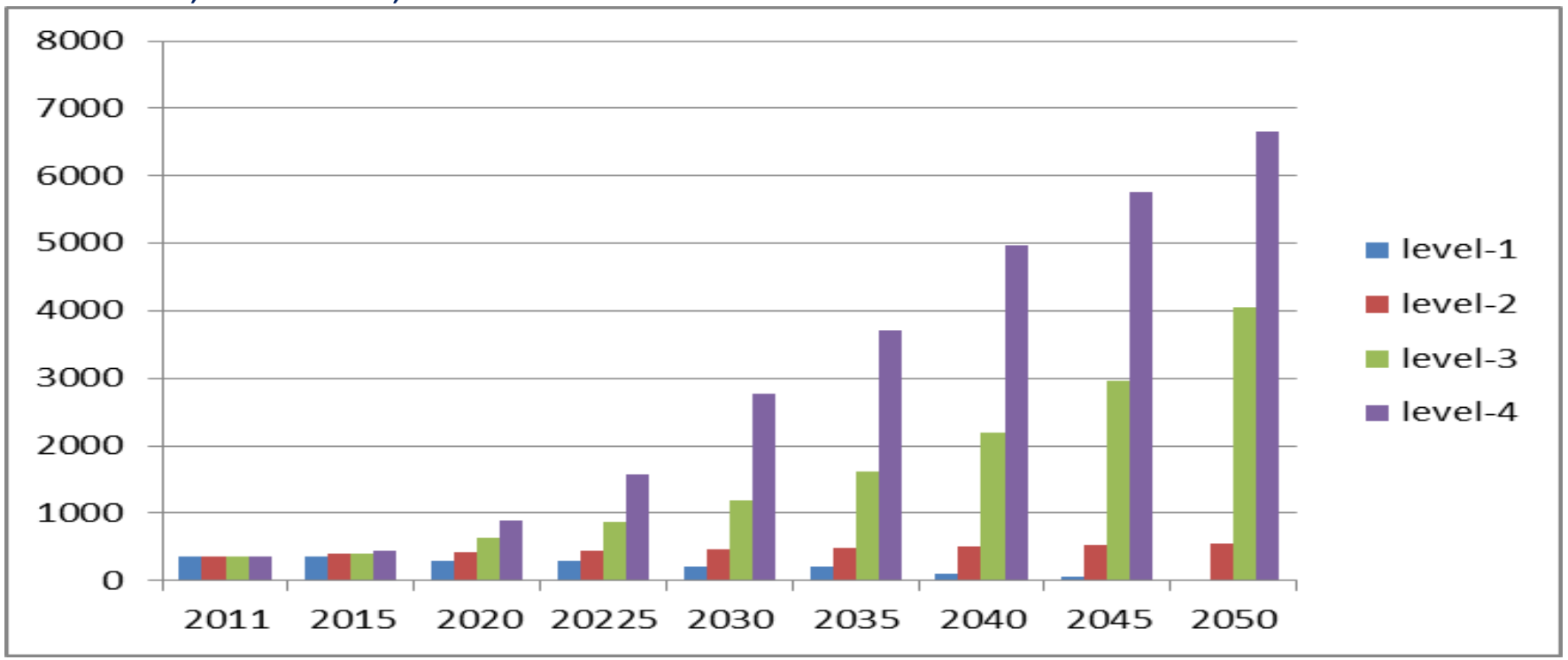
Growth assumptions for estimating potential of Nuclear Energy



Source: EIA

Nuclear Levels

- There are 31 countries operating nuclear power plants in the world. A total of 429 reactors combine an installed capacity of 364 GW in 2012. These figures assume the final shutdown of the ten Fukushima reactors.
- Various technologies and fuel options have been studied like uranium, plutonium, thorium, deuterium, etc.



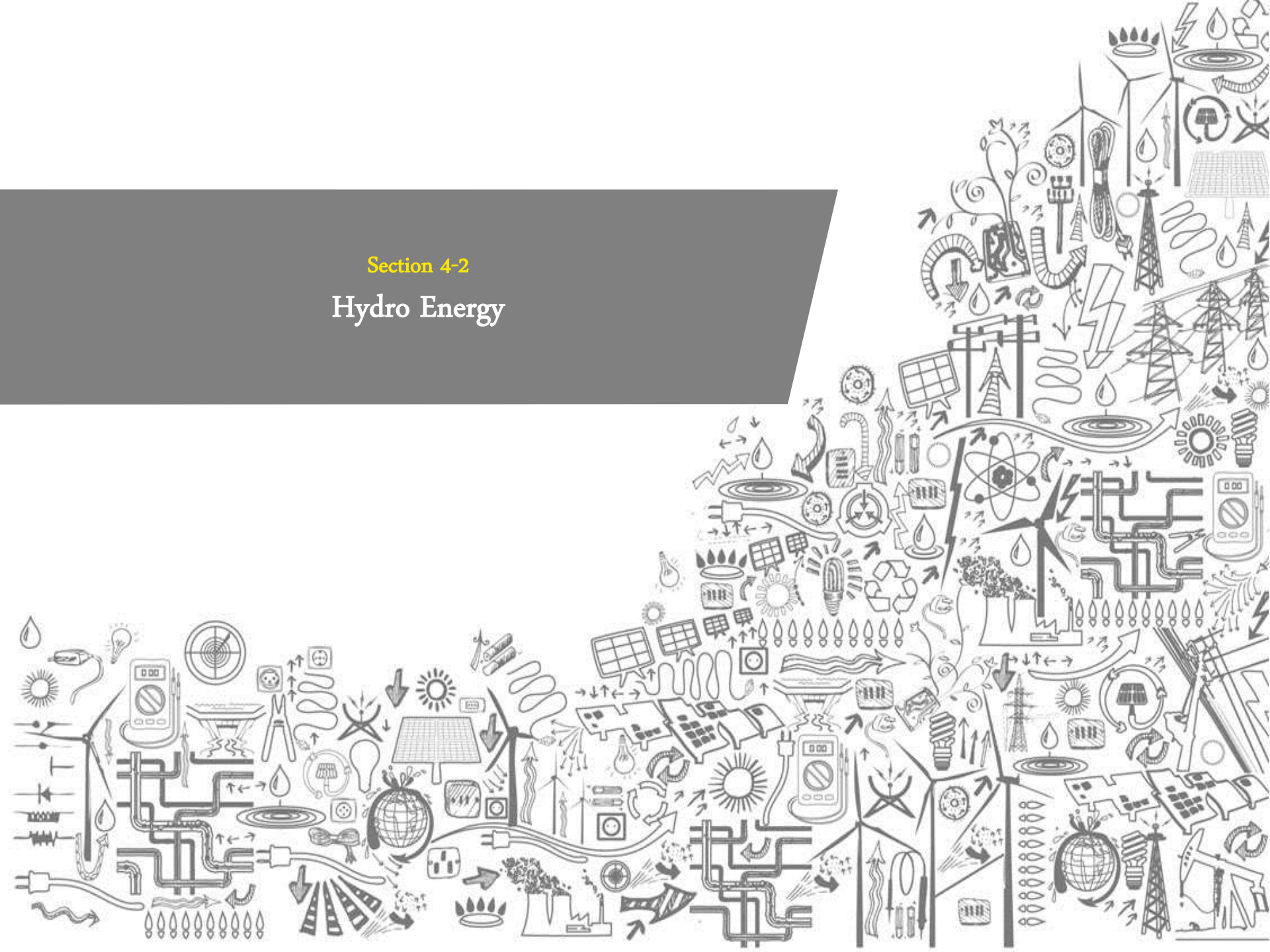
Questions to experts on Nuclear Power

1. Do you think our Level -4 built rates are achievable / reasonable / undermined ?
2. Countries drifting away from nuclear based generation like Japan, France, Germany and others.
3. Should capacity addition of nuclear vessels till 2050 be incorporated in the levels? Is it going to be substantial?
4. In 1973-1974, the IAEA gave a forecast of installed nuclear capacity of 3,600-5,000 GW worldwide by 2000. What is your opinion on world can achieve by 2050 in terms of installed GW ?

Technology	Level-4 by 2050	Global Theoretical Potential
Nuclear Power	6667.69 GW	Not available

Section 4-2

Hydro Energy



Growth assumptions for estimating potential of Hydro Energy

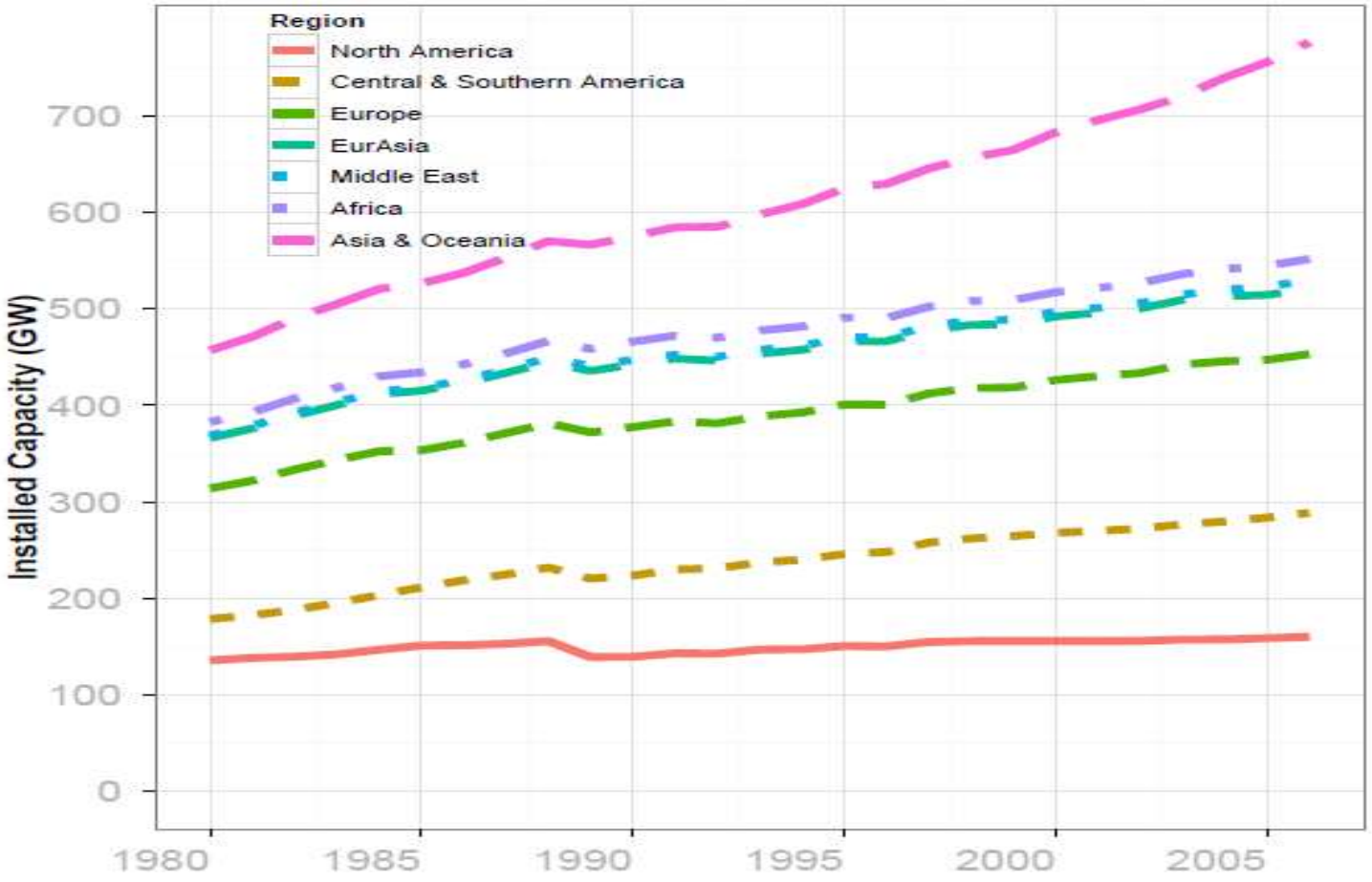
- Worldwide, 970 GW of hydro power was online in 2011. Five countries namely China, Brazil, United States, Canada and Russia accounts for nearly half of global hydro capacity.

- **Built rate of levels for Hydro**

  Level-4: In 2050 there is 3053 GW equivalent of installed hydro capacity. The average built up rate is 2.93% till 2020 and 3% until 2050.

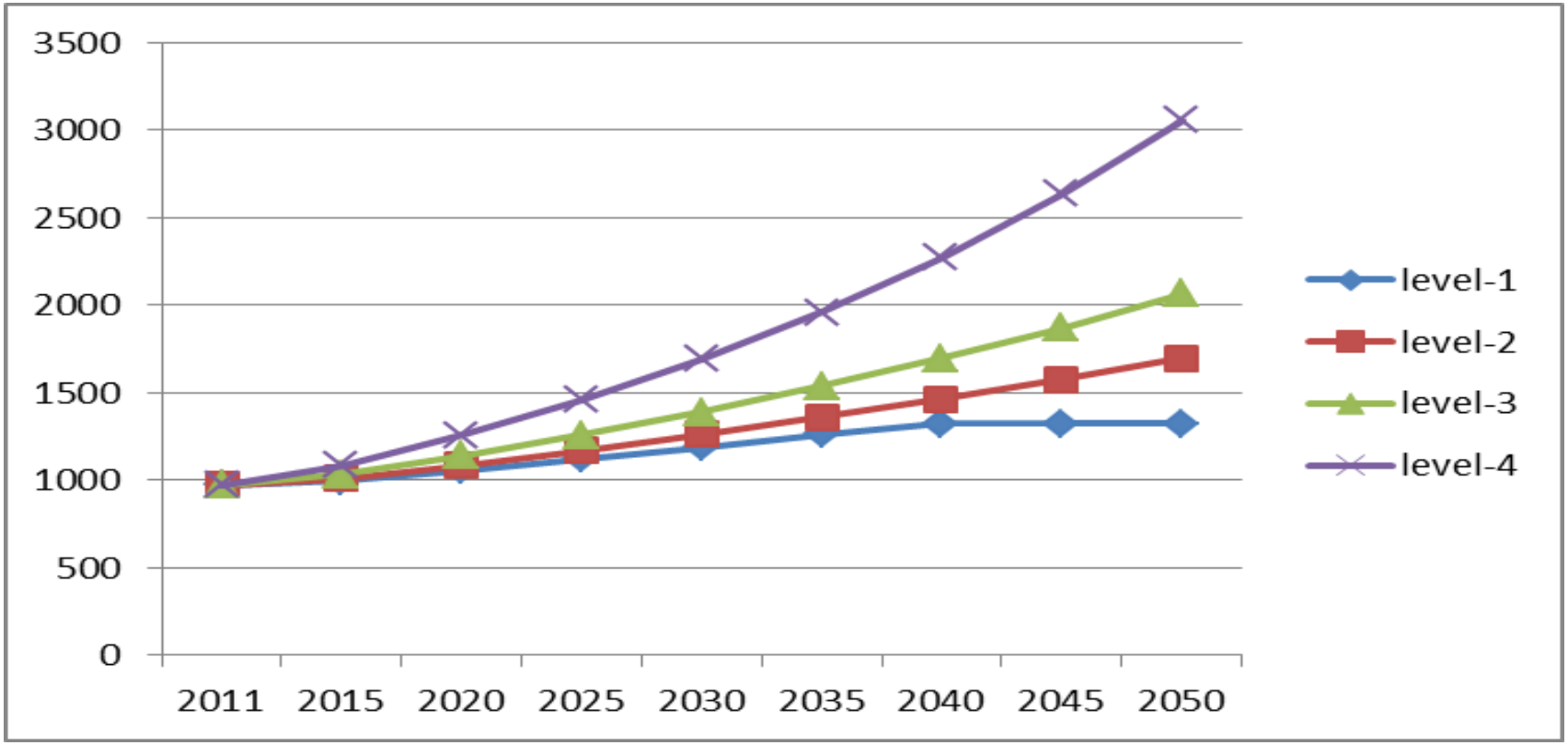
  Level-1: In 2050 there is 1324 GW equivalent of installed hydro capacity. The average built up rate is 0.92% till 2020, 1.2% till 2030 and 1.08% until 2050.

Global Installed Hydropower Capacity 1980-2006



Levels for Hydro Energy

- The countries which may significantly contribute towards hydro capacity addition based on the technology & resource base are China, Brazil, United States, Canada, Russia, India and others.



Questions to experts on Hydro Power

1. Do you think our Level -4 built rates are achievable / reasonable / undermined ?
2. What is your opinion on world can achieve by 2050 closest possible range of 5000 GW ?

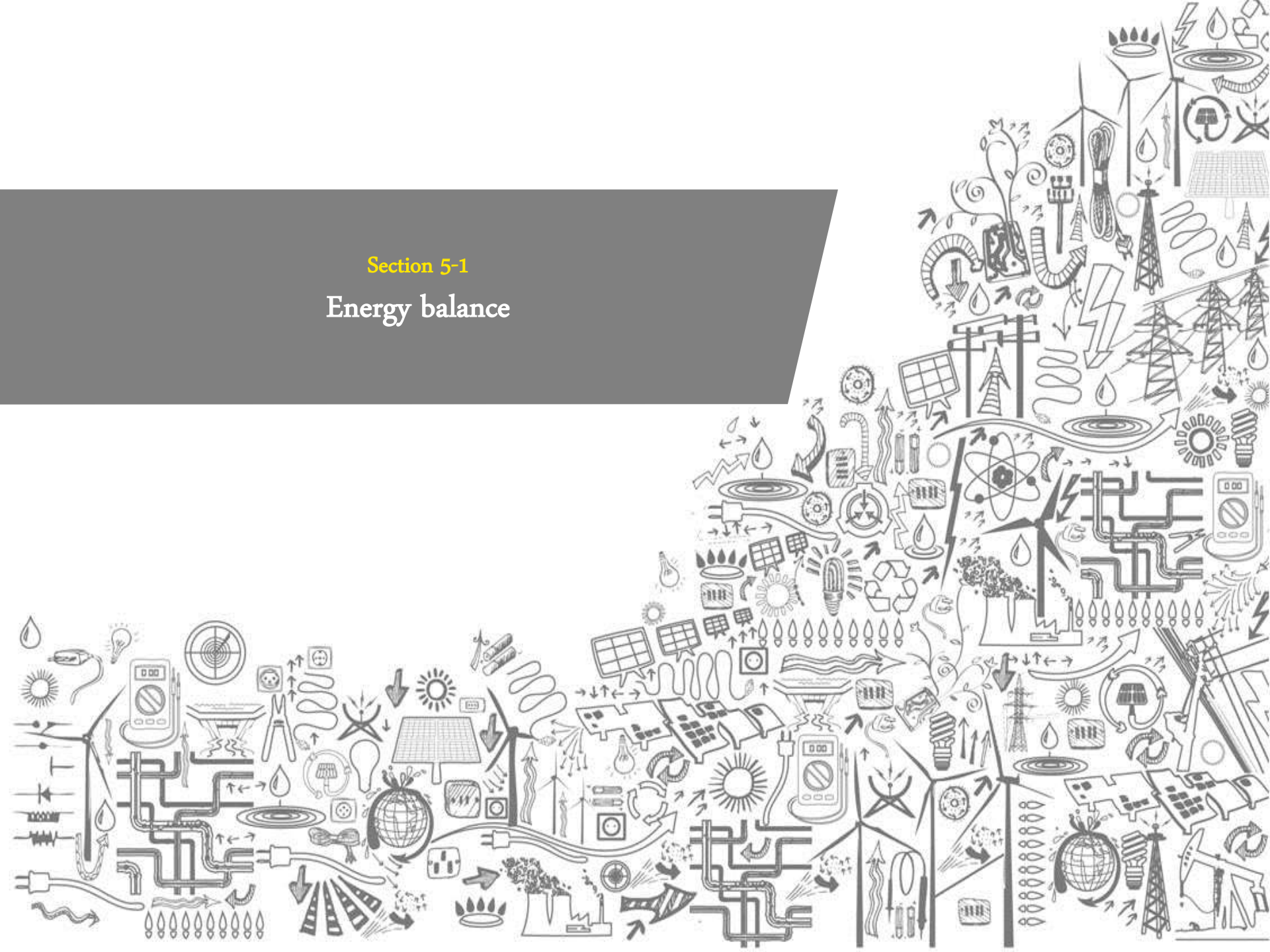
Technology	Level-4 by 2050	Global Theoretical Potential
Hydro Power	3053 GW	3500 - 5000 GW

Section 5

Energy balancing and storage

Section 5-1

Energy balance



Electricity balancing in the Global Calculator

Tom Bain
UK Department of Energy and Climate Change

Structure

The issues and complexity of balancing

The current approach in country calculators and the Global Calculator

How we propose to model balancing in the Global Calculator

Group discussion

Key issues for you feedback

- Does our proposal seem simple yet sufficiently useful?
- Who else should we consult?
- Which sources / documentation should be consulted?
- Would you like to be involved more on this issue?

The issues and complexity of balancing

The current approach in country calculators and the Global Calculator

How we propose to model balancing in the Global Calculator

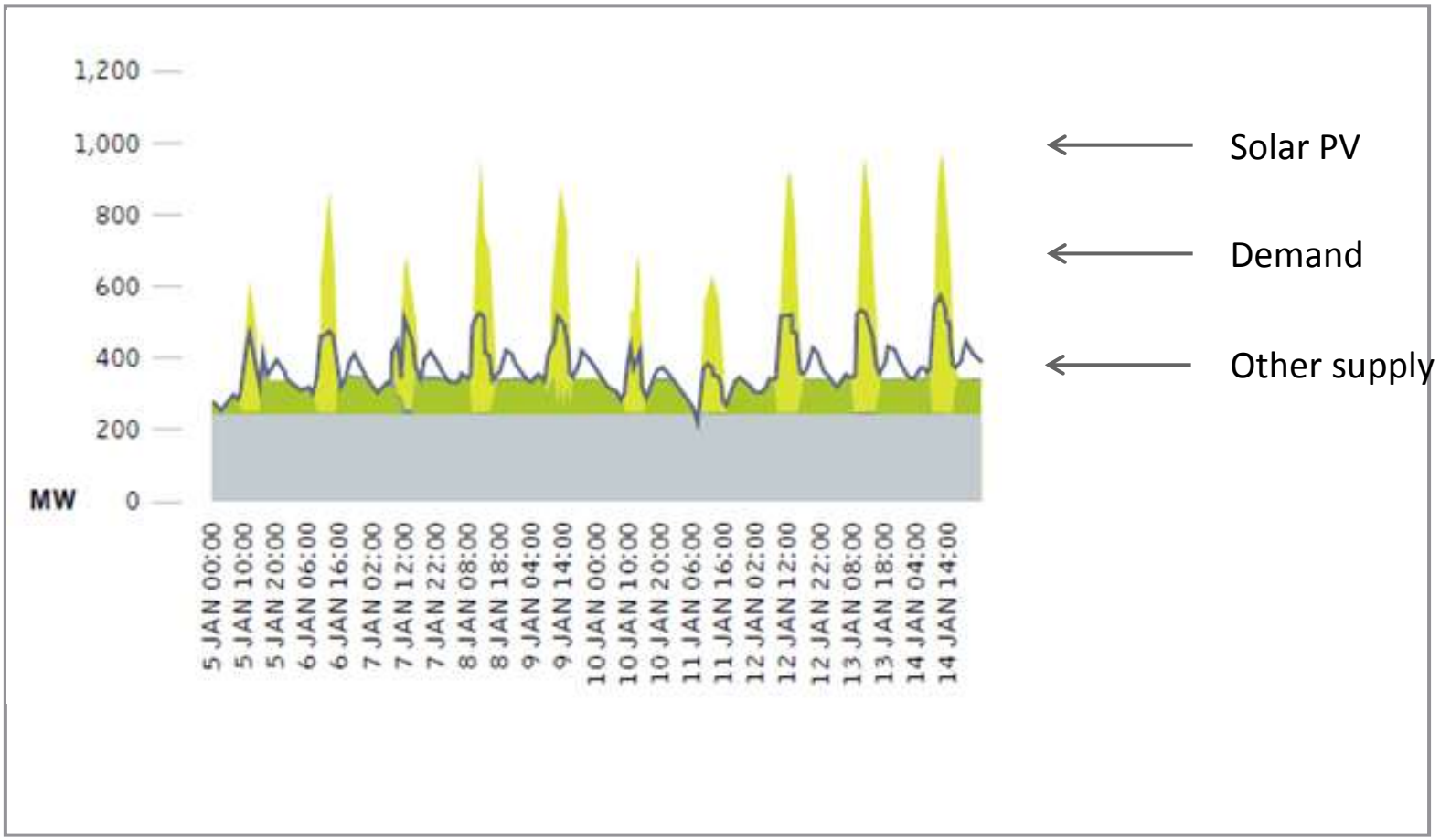
Group discussion

In the real world electricity supply and demand must match every second and on every grid

Here are some associated complexities:

- Intermittent renewables may necessitate backup capacity
- Intermittent renewables may lead to curtailment and energy implications
- Any technology can “fail” (e.g. natural disaster)

Case study: curtailment in Germany 1997



Green Peace, “Renewables 24/7: Infrastructure needed to save the climate” (page 29)

Case study: managing excess generation in Portugal 2012

4,517 MW of wind power capacity installed (20% energy penetration) leading to excess generation in times of low loads and high wind. Managed by:

- **controlling** production from run-of-river hydro plants
- **exporting** excess power to the Spanish energy market
- halting the **import** of electricity from France through Spain

1 NREL, "Wind and Solar Curtailment" (2013) http://www.nrel.gov/docs/fy13osti/60245.pdf

The issues and complexity of balancing

The current approach in country calculators and the Global Calculator

How we propose to model balancing in the Global Calculator

Group discussion

Other 2050 Calculators manage to capture the main impacts in a simple way

UK Calculator

- backup capacity for a cold, windless day (less wind, solar, wave, more demand for heat)
- less gas backup capacity if the user chooses storage / interconnection / demand shifting

India Calculator ("IESS 2047")

- Flat demand and supply and a single grid
- Stress tests by Lawrence Berkeley National Laboratory to assess the technical feasibility of some of the key energy pathways and to broadly identify the storage and balancing electricity requirement

At a global level simplification is needed

We currently take a very simple approach

- Model at a yearly level
- Model at a global level for each year
- Flat supply and demand and no specification of location of demand and supply
- For each year the model matches supply to demand for electricity

Simplicity is the “unique selling point” of the Global Calculator

The issues and complexity of balancing

The current approach in country calculators and the Global Calculator

How we propose to model balancing

Group discussion

We need to choose somewhere between the extremes

"Ideal" approach

- Model every grid
- Model every second
- Model every wind turbine, solar panel etc
- Model the load curve for every electric heater, electric car etc
- Incorporate the feedback from climate impacts to generation

Simplest approach

- Do not address balancing
- Global grid
- No volatility
- Caveat the results

We propose to start with a simple approach – we may add complexity if it's worthwhile

We can't ignore the issue - our model would

- underestimate fossil fuel consumption
- underestimate emissions
- underestimate installed capacity
- underestimate costs

But our methodology has to be simple because

- difficulty in obtaining data
- we are modelling in Excel
- we are modelling at a yearly, global level
- limited time and resource

We will check our results using other example pathways

We will start with a simple approach to capture the capacity implications

1. Treat the **world as a single region** in the Global Calculator

2. Using load curves from example regions – estimate the "typical" ratio of the peak electricity demand to the yearly total

3. For each year in the Global Calculator:
    a. scale the annual electricity demand using this "year to peak ratio" to estimate the **peak demand**
    b. simulate a **"worst case" supply** (0-10% (?) availability factor for intermittent renewables (solar PV, wind, tidal, wave) and 75%(?) availability for base load)

4. Have the model "build" **backup capacity to cover the difference** between the peak and the "worst case" supply, after storage and dispatchable technologies (hydro, electric cars, concentrated solar with storage, gas plants, etc), which are treated as 100% available

We will start with a simple approach to capture the energy implications

1. Focus on **curtailment**

2. Use an **existing energy model** to inform us on the relationship between installed capacity of different technologies etc and the associated curtailment

3. Use the energy curtailment reported by this existing model:
    a. to **increase the use of fossil fuels** in the absence of storage, and;
    b. to give us a **value for energy available for storage** (if chosen by the user)

We will allow the user to explore the impacts of demand smoothing and storage

(1) Lever on "storage" [more on this later]

- Affect the level of backup capacity installed by the model
- Affect the curtailment / associated use of fossil fuels

(2) Lever on "demand smoothing"

- Affect the size of the peak to affect the backup capacity

We can't capture all the complexities - some of them will have to be caveated and "flagged" to the user

We feel that the following are out of scope:

- reporting the number / duration / scale of blackouts
- interconnection changing over time
- transmission failures / curtailment from insufficient transmission capacity (we will have to assume transmission will be in place and estimate the costs)
- the smoothing impact of greater geographic spread of renewables
- load curves at a technology level

Chatzivasileiadis, Ernst, Andersson: "The Global Grid"

The issues and complexity of balancing

The current approach in country calculators and the Global Calculator

How we propose to model balancing in the Global Calculator

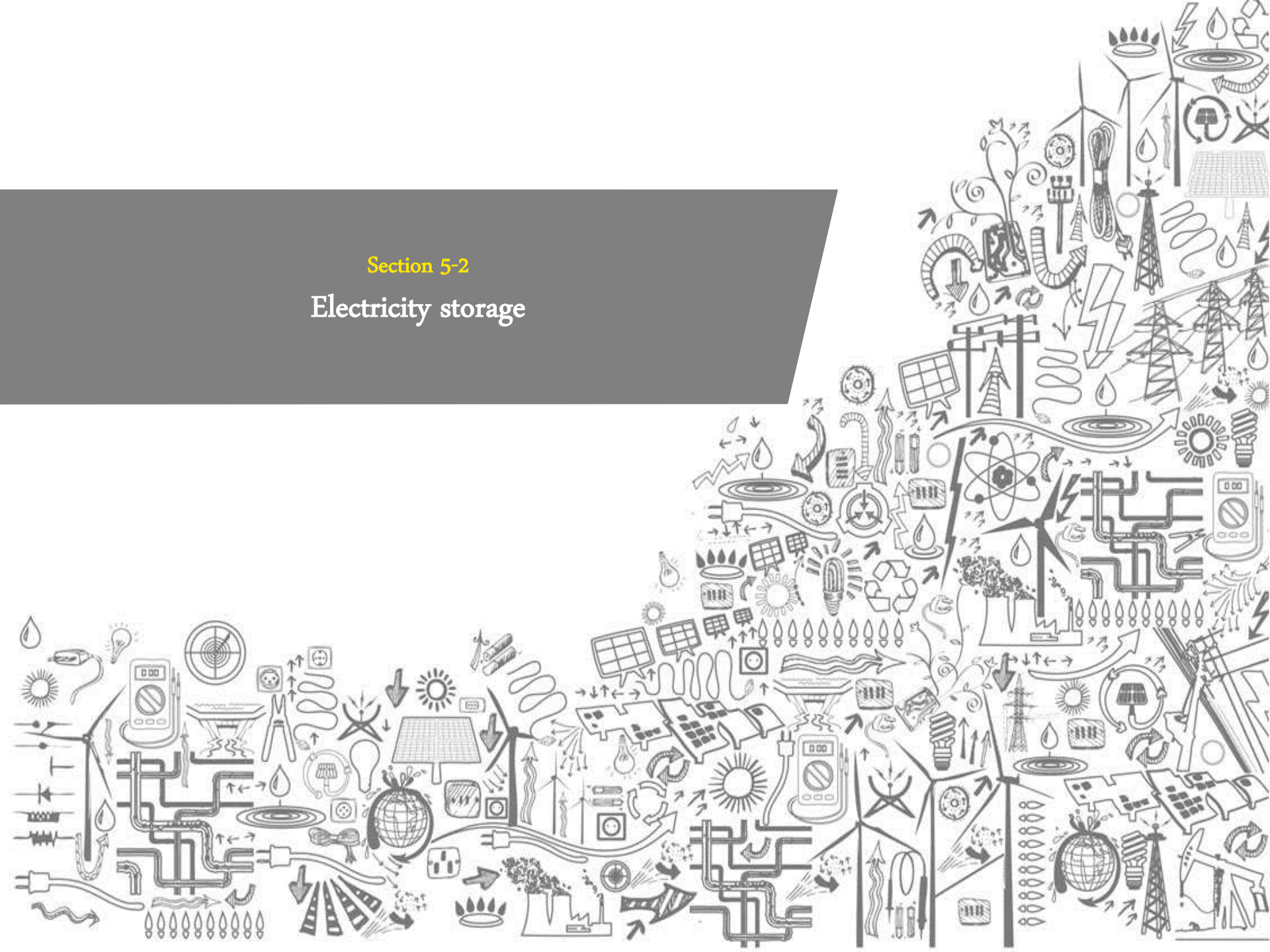
Group discussion

Your further help and feedback would be most appreciated

- Does our proposal seem simple yet sufficiently useful?
- Who else should we consult?
- Which sources / documentation should be consulted?
- Would you like to be involved more on this issue?

Section 5-2

Electricity storage



Growth assumptions for estimating potential of Electrical Storage

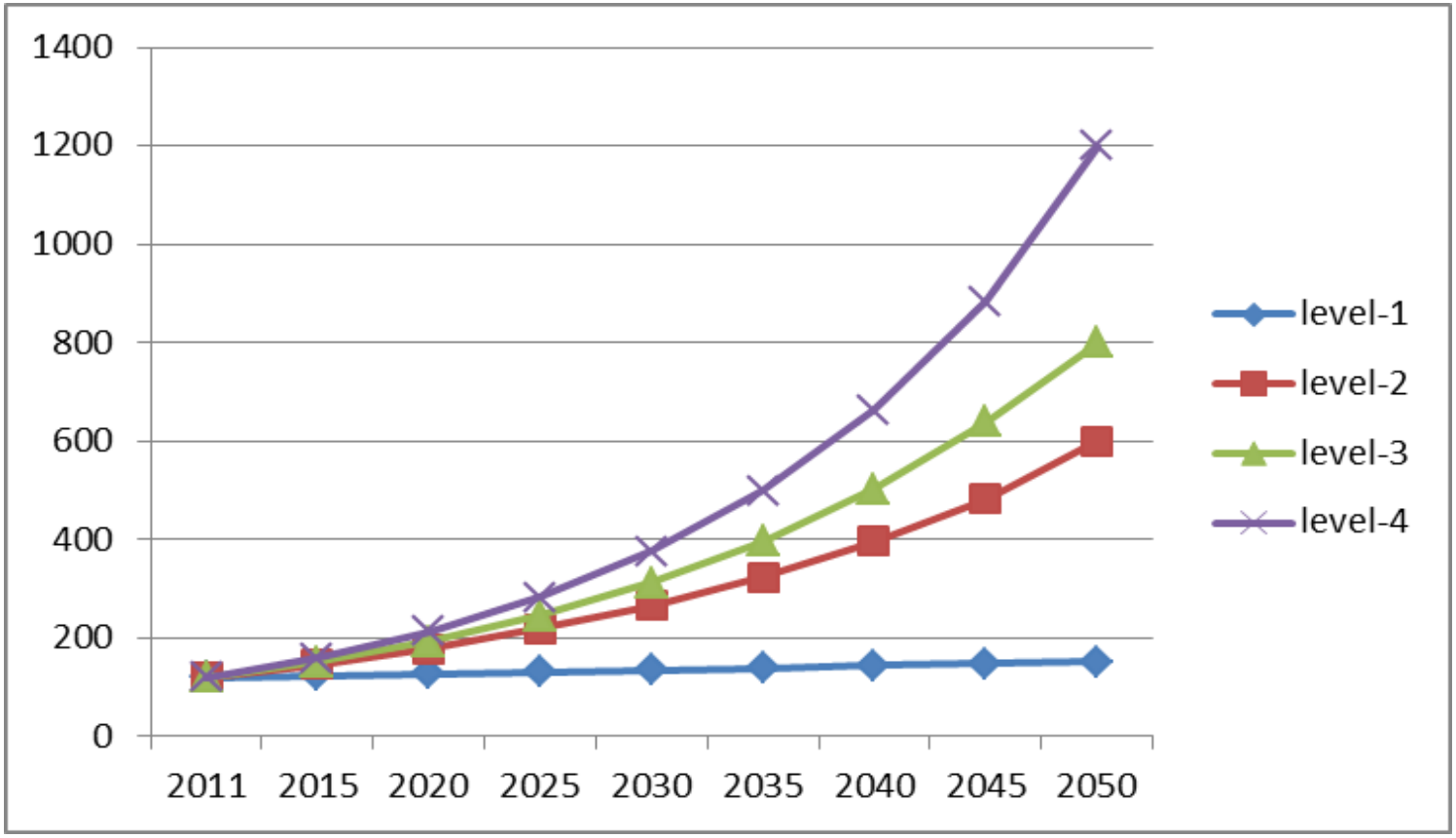
- **Built rate of levels for electrical storage**

Level-4: In 2050 there is 1200 GW of installed electrical storage capacity. The average built up rate is 6.54% (10.3 GW/year) till 2020, whereas 5.87% (22.6GW/year) till 2040 and 6.09% (53.6GW/year) up till 2050.

Level-1: In 2050 there is 152 GW of installed electrical storage capacity. It builds at rate of 0.65% till 2020 and 0.59% up till 2050.

Levels for Electrical Storage (GW)

- Energy storage technologies would include Pumped Storage, Compressed Air, NaS Batteries, Advanced Lead Acid, Batteries, Flow Batteries, and Lithium Ion Batteries for Utility-Scale Storage.



Questions to experts on Electrical Storage

1. Do you think our Level -4 built rates are achievable / reasonable / undermined ?
2. What is your opinion on world can achieve by 2050 closest possible range?

Thank You