National Modelling and Scenarios

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RFF CMCC European Institute on Economics and the Environment
NAVIGATE
ENGAGE FEASIBILITY OF CLIMATE PATHWAYS
AIM ASIA-PACIFIC INTEGRATED MODEL
NIES JAPAN
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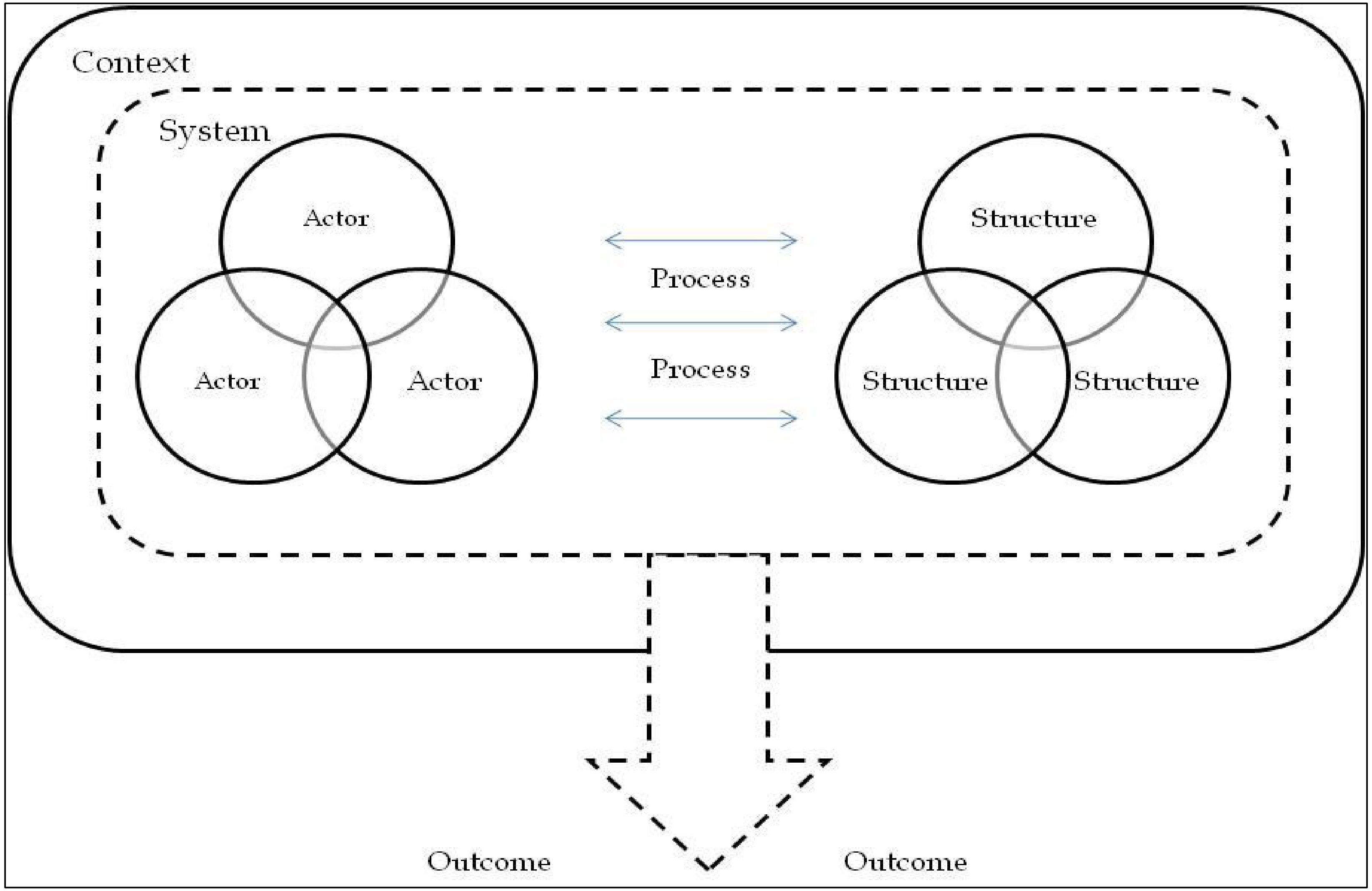
Horizon2020 European Union Funding for Research & Innovation

Structure of the presentation

1. Frameworks
2. Theories
3. Models
4. AIM- Family
5. National Modelling - India

Context


Context
System
Actor
Actor
Actor
Process
Process
Structure
Structure
Structure
Outcome
Outcome

Frameworks

- **Frameworks** can be described as a 'map' developed using a common set of language based on certain assumptions, concepts, values and practices to explain a specific reality.

- The **complexity of a situation or phenomenon** is dealt by integrating various disciplines that will help to comprehend each of the variables, the relationships and interactions between the variables that produce a certain outcome.

- Frameworks can be of many types, such as conceptual, analytical, action-oriented, activity theory-oriented, distribution cognition oriented, and procedural.

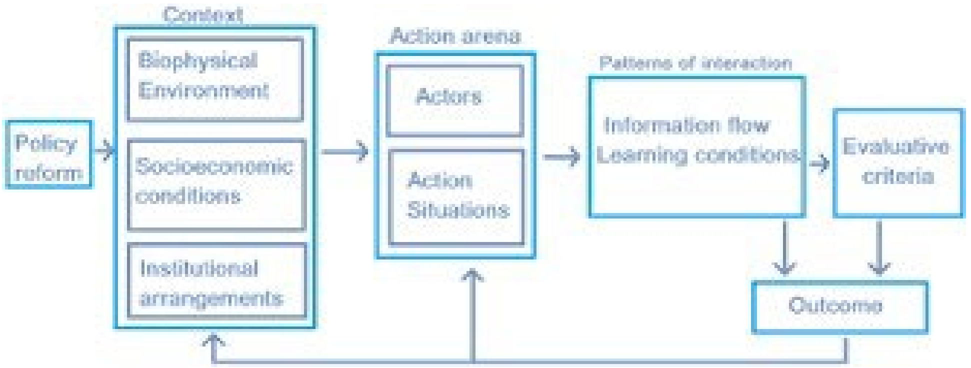
SES Framework - Types

S⇒E		E⇒S	S⇔E
Anthropo	Ecocentric	Anthropo	Anthropo
DPSIR TNS SESF	ES ESA MEFA	SLA TVUL	HES MTF
Policy	**Ecocentric**	**Vulnerability**	**Integrative**
DPSIR Driver, Pressure, State, Impact, Response	ES Ecosystem Services	SLA Sustainable Livelihood Approach	HES Human Environment Systems Framework
SESF Social-Ecological Systems Framework	ESA Earth Systems Analysis	TVUL Turners Vulnerability Framework	MTF Management and Transition Framework
TNS The Natural Step	MEFA Material and Energy Flow Analysis		

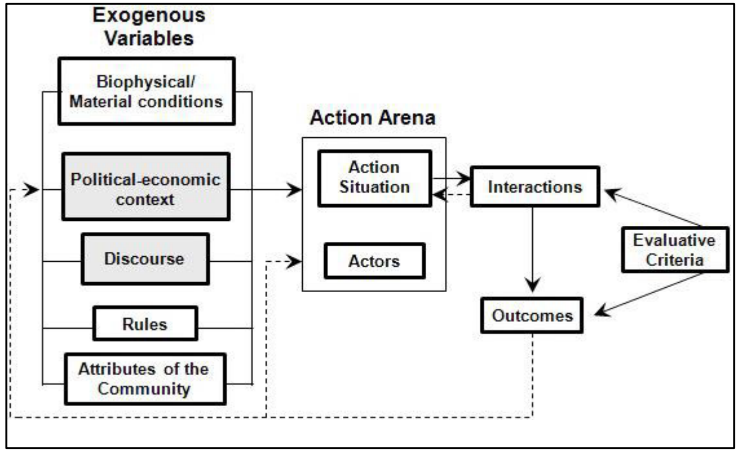
Source: Binder, C. R. et al. (2013)

IAD Framework

Institutional Analysis and Development (IAD) Framework

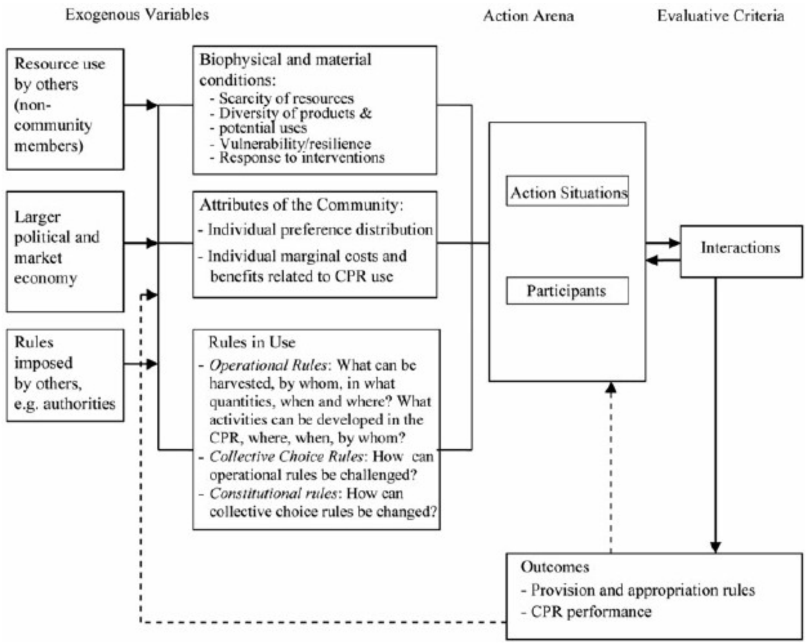


Source: Ostrom (1994).



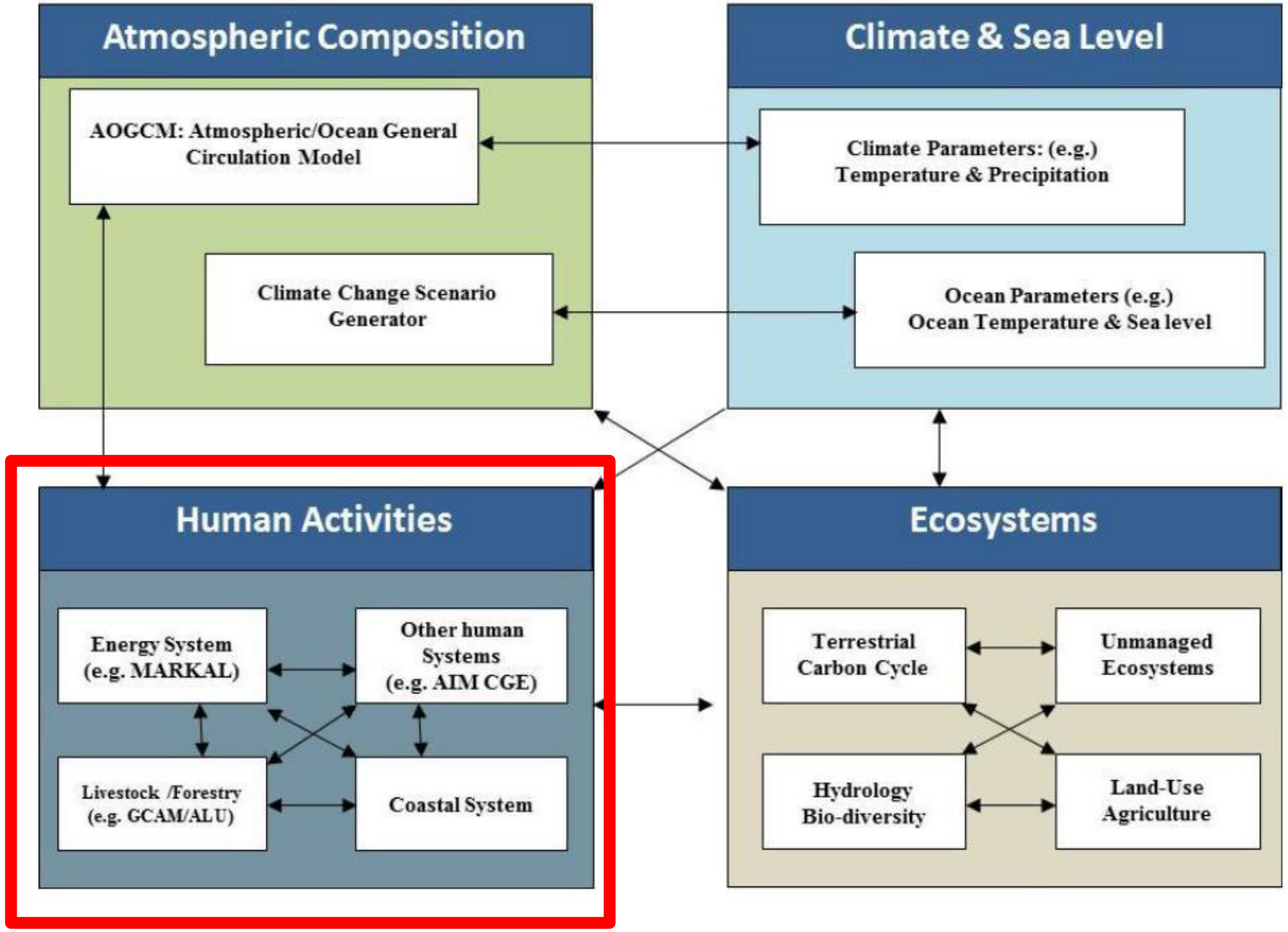
Politicized Institutional Analysis and Development (IAD) Framework

Source: Clement (2010).



Detailed Institutional Analysis and Development (IAD) Framework

Integrated Assessment Modelling Framework



Source: IPCC WGIII

Theories

- Economic theories: Supply and demand, classical, Keynesian, Neo-Malthusian, Marxism, Capitalism, Socialism, LCH, Rational Choice Theory, Prospect Theory, Tragedy of Commons

- Resilience Theory: IAD, Technology Diffusion, Innovation, Social Learning

Models

A model is a *simplified representation of an actual phenomenon*, such as an actual system or process.

Modeling, that is, the art of model building, is an integral part of most sciences, whether physical or social, because the real-world systems under consideration typically are enormously complex.

Models make '*precise assumptions about a limited set of variables*' and allow analysts to test specific part of theories and to simulate outcomes (Sabatier, 2007; Ostrom, 2005).

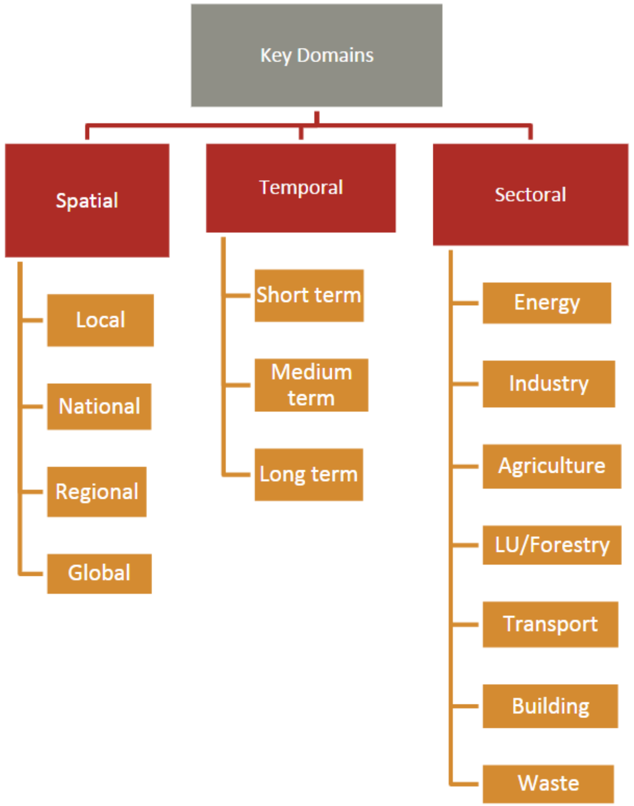


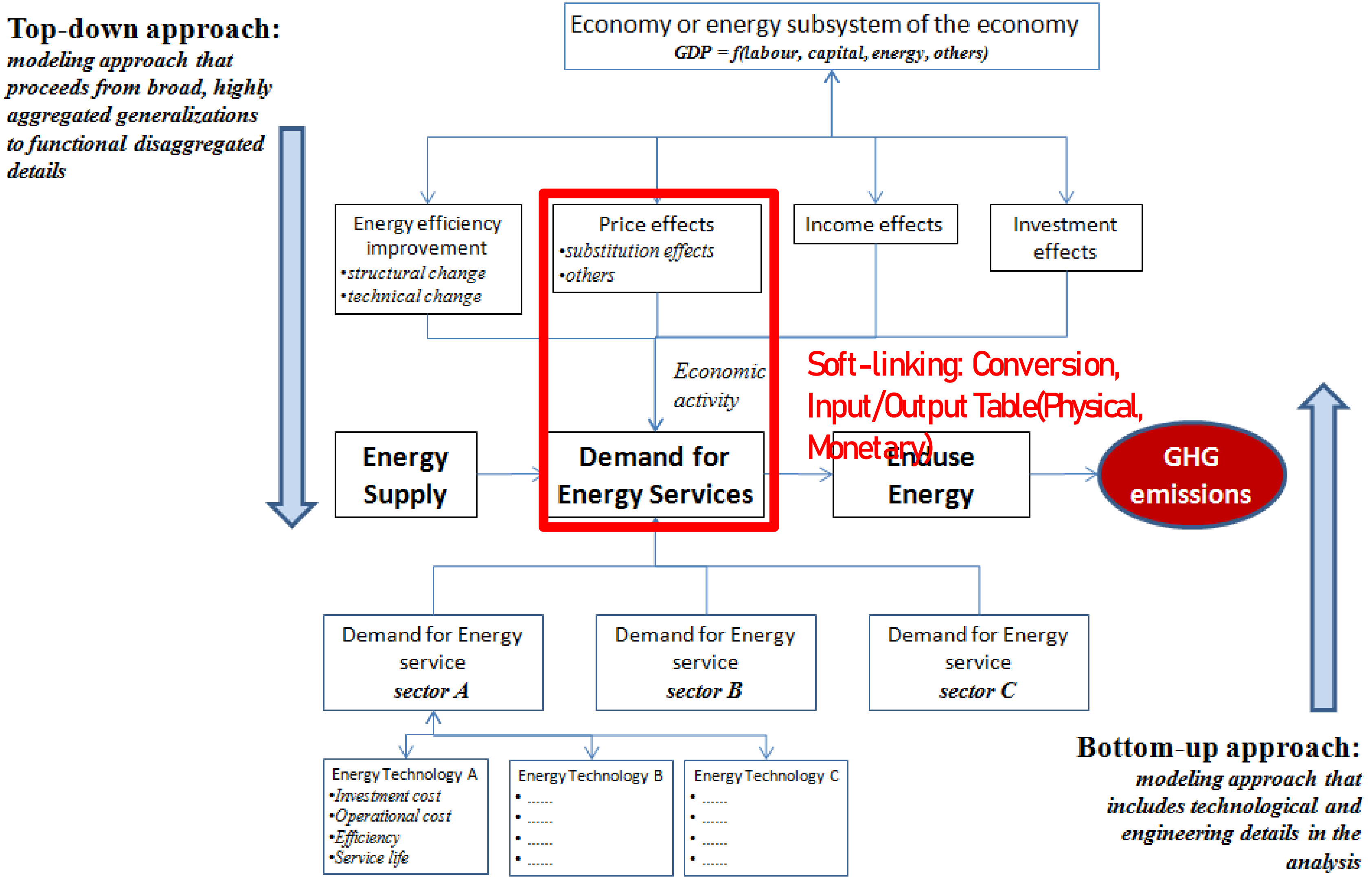
Figure 1: Key Modelling Domains – Spatial, Temporal and Sectoral

Source: Shukla, P. R. 2013. Review of linked modelling of low-carbon development, mitigation and its full costs and benefits. MAPS Research Paper. MAPS

Modelling Framework - Classification

	Bottom up	**Top Down**	**Simplified hybrid**	**IAMs**
Types	Optimization Accounting Partial equlibrium	CGE	Bottom up and Top down	Energy module Land Module Water Module Resource module Climate Module
Spatial	Local, National, Regional, Global	National, Regional, Global	National, Regional, Global	National, Regional, Global
Temporal	ST, MT, LT	ST, MT, LT	ST, MT, LT	ST, MT, LT
Sectoral	Single/Multi	Single/Multi	Single/Multi	Single/Multi
Technology data	Yes	No	Yes	Yes
Fuel/Energy data	Yes	Yes	Yes	Yes
Economic/Cost	Yes	Yes	Yes	Yes

Top-down & Bottom-up approach



Modified based on "Mapping the energy future", IEA, 1998

Summary

Criterion	Question
Name/acronym used	How is the framework referred to in the scientific literature?
Disciplinary origin	Which discipline does the framework depart from? In which discipline does it have its foundations?
Theoretical origin	On which theories does the framework base itself (implicitly/explicitly)?
Application fields	In which research fields can and has the framework been applied? What kind of research questions can be or have been addressed with the framework?
Analysis	
Purpose	For what purpose do the authors claim was the framework developed?
Temporal and spatial scale	What are the temporal and spatial scales at which the framework can be applied best?
Guidance/operationalization	Which type of guidance does the framework provide to operationalize its concepts and make it applicable to a real case study?

Source: Binder, C. R. et al. (2013)

Background of Global IAMs and scenarios

- Model based scenarios are essential piece of climate mitigation policies

- Global scenarios have been greatly contributing to international climate policy formulation, series of COPs, IPCC

- Well-coordinated model inter-comparison is the major sources of IPCC scenarios database
  - AR6 (EMF30, EMF33, ENGAGE, CDLINKS etc.)
  - AR5 (EMF23, EMF27, AMPERE, LIMITS etc.)

Source: Fujimori and Schaeffer 2022 [IAMC]

Question

Is national modelling and scenario development relevant?

Background of national IAM models and scenarios

- National scenarios play similar roles as global

- The importance and needs of national scenarios are increasing
  - Paris Agreement
    - NDC and updated NDCs
    - Long-term strategies
    - Periodic reviews and revisions of national strategies

- What is the situation of national scenarios?
  - Individual modeling teams have generated national scenarios individually.
  - Individual national MIPs (China, India, Japan, US)
  - Continental level MIPs (Asia, EU, Latin America)
  - Cross-national comparison (CDLINKS, COMMIT)
    - -> basically take global scenarios and use as boundary condition
    - Uniform carbon price
  - IPCC WG3 chapter 4 collects the existing national scenarios

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Contents lists available at ScienceDirect

Energy Economics

journal homepage: www.elsevier.com/locate/eneco

Climate Mitigation in Latin America: Implications for Energy and Land Use
Preface to the Special Section on the findings of the CLIMACAP-LAMP project

Available online at www.sciencedirect.com

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Advances in Climate Change Research 9 (2018) 1–15

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Multi-model comparison of CO_2 emissions peaking in China: Lessons from CEMF01 study

Oleg LUGOVOY[a,*], FENG Xiang-Zhao[b], GAO Ji[c], LI Ji-Feng[d], LIU Qiang[e], TENG Fei[f], ZOU Le-Le[g]

Sustainability Science (2021) 16:347–353
https://doi.org/10.1007/s11625-021-00931-0

SPECIAL FEATURE: EDITORIAL

Energy Scenarios for Long-Term Climate Change Mitigation in Japan

Introduction to the special feature on energy scenarios for long-term climate change mitigation in Japan

Masahiro Sugiyama[1] · Shinichiro Fujimori[2,3,4] · Kenichi Wada[5] · John Weyant[6]

Source: Fujimori and Schaeffer 2022 [IAMC]

Question

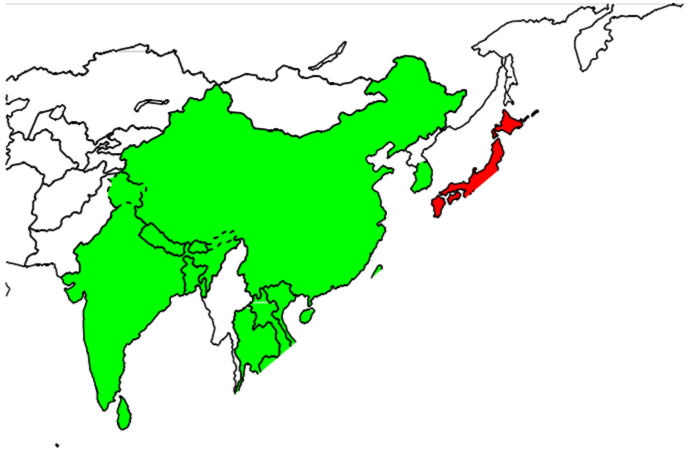
Is national modelling different from global IAMs?

Is national scenario development different from global IAMs?

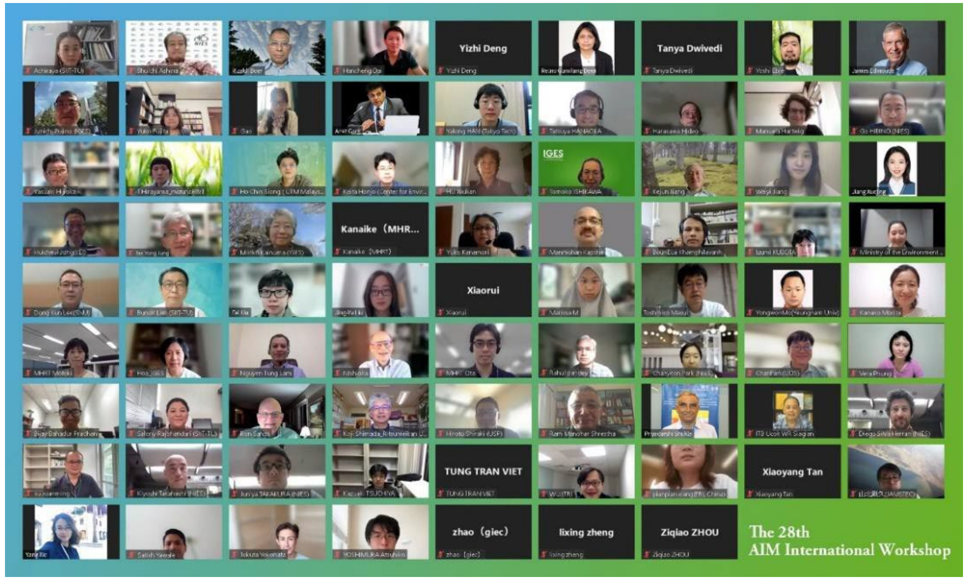
Asia-Pacific Integrated Assessment Model

AIM-FAMILY

International Network of AIM (Asia-Pacific Integrated Model) at NIES



https://www-iam.nies.go.jp/aim/index.html



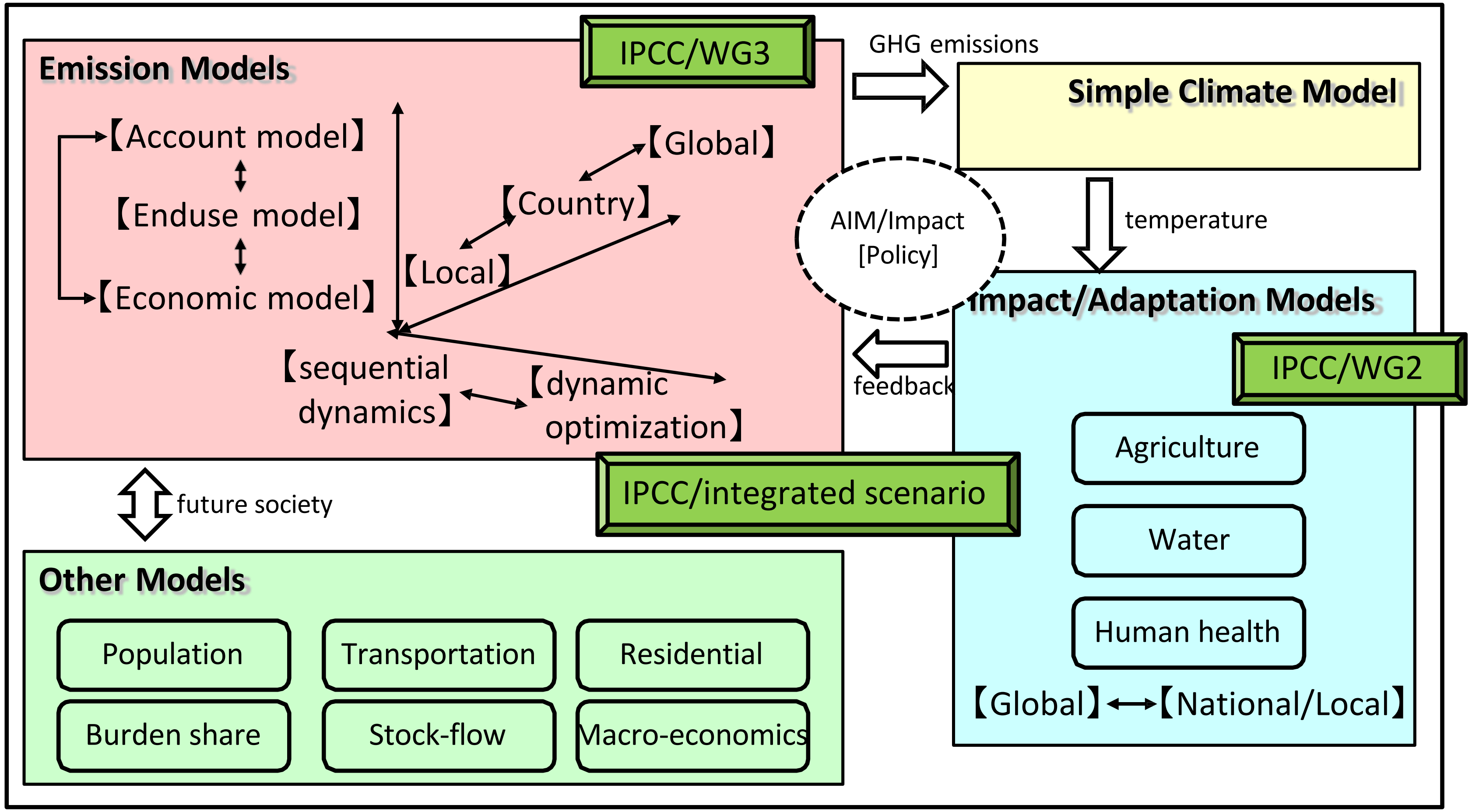
The 28th AIM International Workshop （Sept.13-14, 2022; Online）
http://www-iam.nies.go.jp/aim/index_j.html

- AIM (Asia-Pacific Integrated Model) project started in 1990.
- Asian countries/regions will update their mitigation target and roadmap to achieve the 1.5 & 2 degree target reflecting their issues to be solved and the resources to be endowed.
- Model can be a collaboration tool between science and decision making process. From the long-term viewpoint, each country/region will need the capacities to develop model and scenarios by itself.
- AIM has supported Asian countries/regions to develop the integrated assessment model (IAM) and their long-term low carbon/decarbonized scenarios.

Source: AIM/Enduse Training Material 202317

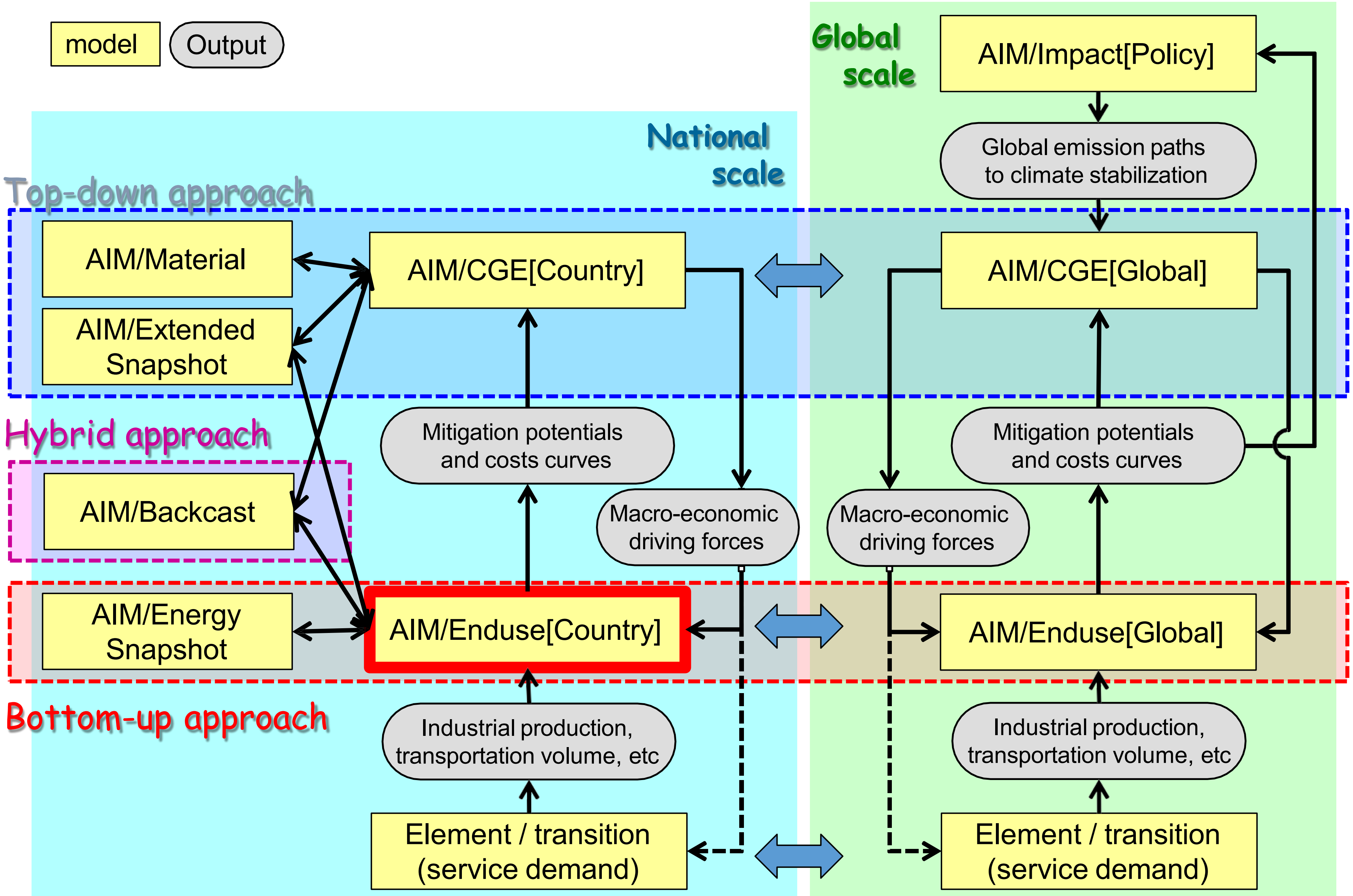
AIM (Asia-Pacific Integrated Model) family

AIM is an integrated assessment model
-to assess mitigation measures to reduce GHG emissions
-to assess impact/adaptation to avoid severe climate change damages



Source: AIM/Enduse Training Material 202318

AIM family for mitigation analysis



Models

Type of Model		AIM Family	Other Model
Bottom – up	Accounting Type	AIM/Snapshot	STAR LEAP (SEI)
	Sectoral Optimization	AIM/Enduse	MESSAGE (IIASA) MARKAL (ETSAP) TIMES (ETSAP) TIMER (PBL) PRIMES (NTUA)
Top - down	Input Output type	ExSS	TEESE
	Computable General Equilibrium	AIM/CGE AIM/CGE (SAM)	MERGE (IIASA) GTEM (Australia) EPPA (MIT, USA) PACE (ZEW GmbH)
	Macro-Economic		E3MG (UK)
Hybrid Bottom-up and Top-down models		AIM/CGE (basic)	IMACLIM-R MERGE-MESSAGE IIMA Soft-linked Integrated models
Abatement cost curve analysis		AIM/Enduse (ACC)	McKinsey's ACC
Integrated Assessment Models (IAMs)		AIM Family	MERGE-MESSAGE-GLOBIOM TIMER- ReMIND-MAGPIe XANTHOS-GCAM

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Top-down & approaches in the AIM mitigation models

Bottom-up : analysis on sector- or technology-wise impacts

Today's lecture

AIM/Enduse model

- This model can assess individual technologies under the detail technology selection framework and evaluate GHG emissions and mitigation costs.
- This model is a partial equilibrium model on energy (i.e. optimization model)

AIM/Energy Snapshot tool (AIM/ESS)

- This tool is an accounting type and can assess energy balance and CO_2 emissions among sectors simultaneously.
- This is a snapshot tool at a certain temporal point (i.e.non-optimization model).

Top-down : analysis on economic impacts

AIM/Extended Snapshot tool (AIM/ExSS)

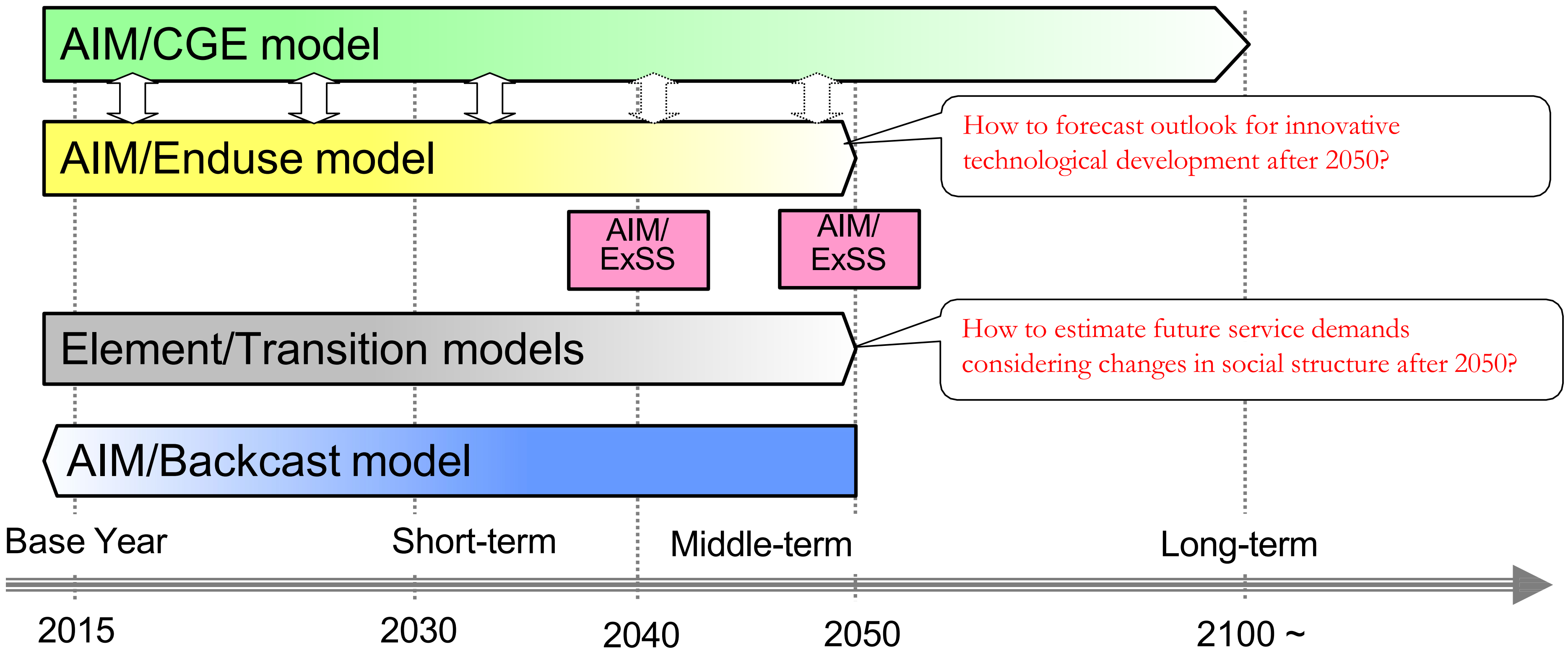
- This tool is an accounting type and can assess monetary balance, material balance, energy balance and GHG emission among sectors simultaneously.
- This is a snapshot tool at a certain temporal point (i.e.non-optimization model).

AIM/CGE model

- This model draws the balanced macro economy, based on social conditions such as population, technology and preference, countermeasures.
- This model is a Computable General Equilibrium model (i.e. optimization model)

Source: AIM/Enduse Training Material 2023

Temporal scale of mitigation analysis



- Due to data constraints of future technology information and service demands, Enduse model analyzes scenarios with horizons of 2030, and up to around 2060 at most.
- To utilize Enduse model for Low Carbon Society scenario study toward 2050, it is essential to discuss outlook for innovative technological development and future service demands considering changes in social structure.

Cost: definitions and determinants

1) The direct engineering and financial costs of specific technical measures

Cost of switching from coal to gas in electric production, of improving energy efficiency of appliances, of planting trees in reforestation program. Technical costs can show negative net costs because a given technology may yield enough energy cost saving to more than offset the costs of adopting and using the technology. These costs depend on both technical-economic data and a given interest rate.

Enduse models

2) Economic costs for a given sector

Cost by "partial equilibrium" analysis in sectroral models that do not capture the feedback effects between the behaviour of a sector and that of the overall economy.

CGE models

3) Macroeconomic costs

The impact of a given strategy on the level of the GDP and its components (household consumption, investment, etc). This aggregated index measures the monetary value added of goods and services and provides an index of the scale of human activities including the feedback effects between the behaviour and economy.

4) Welfare costs

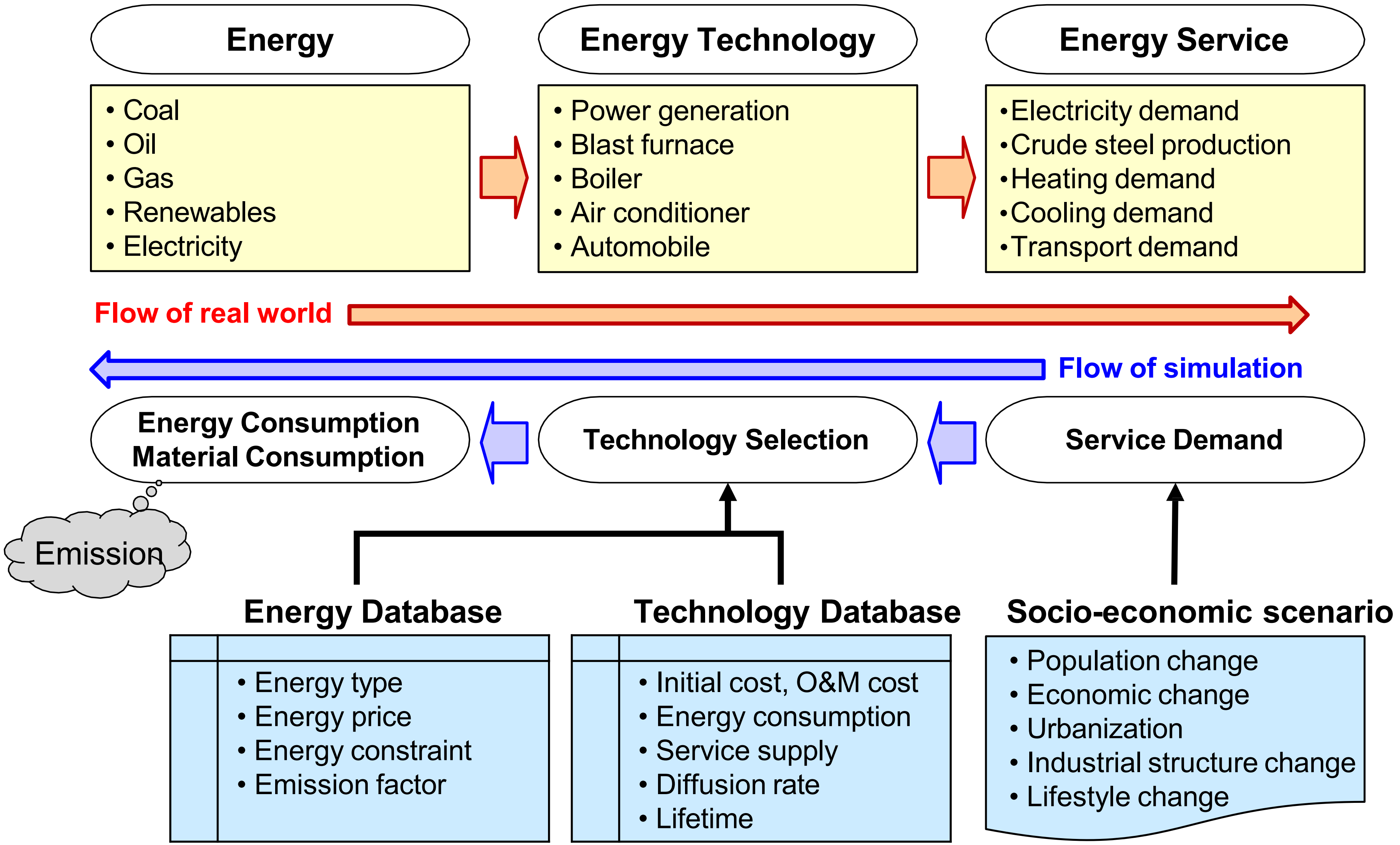
Source: IPCC Second Assessment Report, WGIII, Chapter 8, pp 269-270

AIM/Enduse : Characteristics

- Bottom-up type model with detailed technology selection framework with optimization
- Recursive dynamic model
- Assessing technological transition over time
- Analyzing effect of policies such as carbon/energy tax, subsidy, regulation and so on.
- Target Gas : Multiple gases
  - CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, SO_2, NOx, CFCs, HCFCs, etc
- Target Sectors : multiple sectors
  - power generation sector, industry sector, residential sector, commercial sector, transport sector, agriculture sector, municipal solid waste sector, fugitive emissions sector, F-gas emissions sector
- (each of these can be further disaggregated into sub-sectors)

Source:: AIM/Enduse Training Wksp

Overview Structure of the AIM/Enduse model



Source: AIM/Enduse Training Material 2023

Differences between AIM/Enduse and MARKAL

AIM/Enduse model

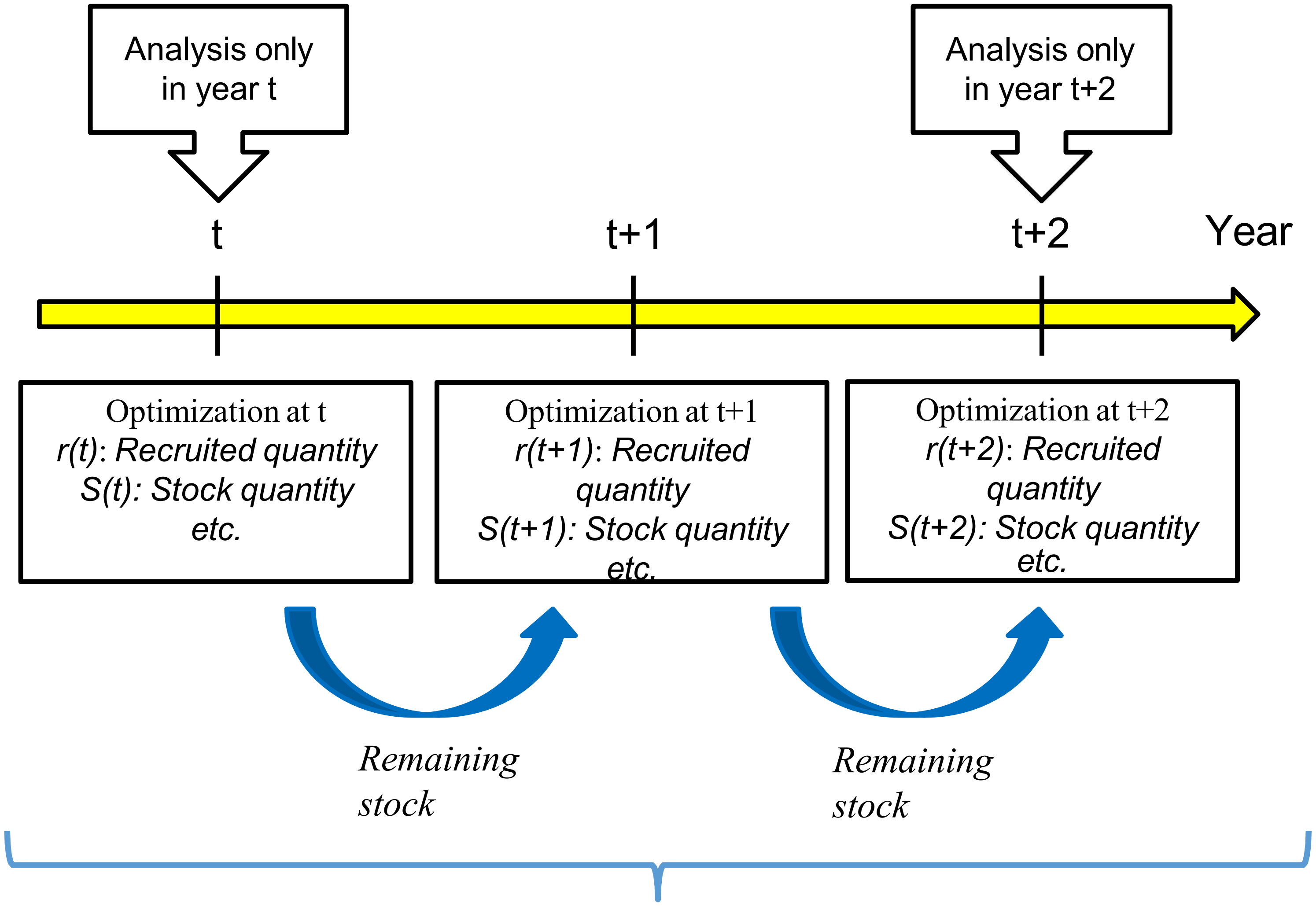
- **Recursive dynamic simulation: optimizing the total system cost year by year.**
- It focuses on evaluating people's preferences on technology selections under given conditions, year by year up to the target year. It is more effective to analyze decision makings on technologies that have a short duration of technology development.
- Strong point: analysis from the viewpoint of energy demand side.

MARKAL model

- **Dynamic simulation: optimizing the total system cost simultaneously over the entire period (i.e. minimize combined cost of all the years of modeling horizon)**
- It focuses on evaluating the best timing of investments over the modeling period. It is more effective to analyze the optimal investment of large facilities with long lifetime such as power plants.
- Strong point: analysis from the viewpoint of energy supply side.

Approaches for emission modeling

What is a dynamic approach? What is a static approach ?



<u>Static model</u>

Calculating at a specific year

<u>Recursive dynamic model</u>

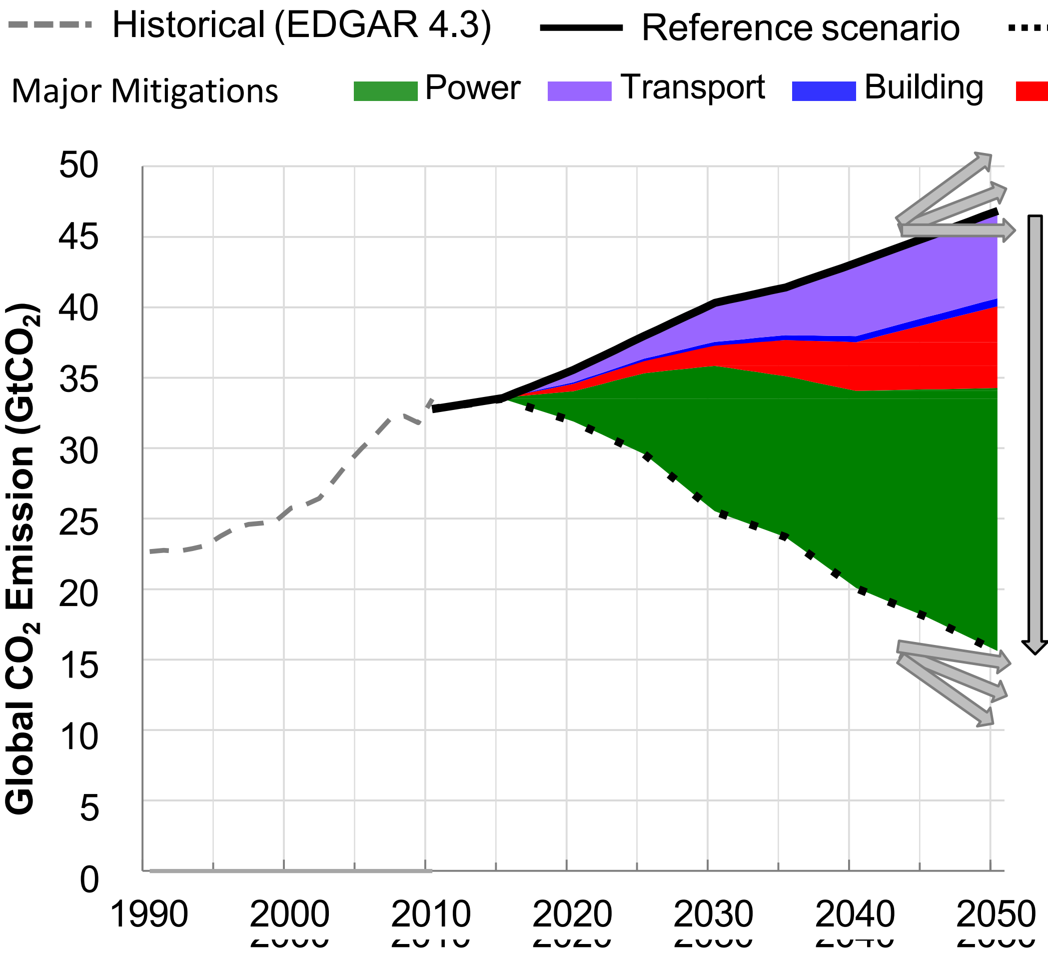
Calculating year by year

<u>Dynamic model</u>

Calculating the entire period

Source: AIM/Enduse Training Material 202327

What are mitigation costs ?
What are mitigation potentials ?



How to set the future projections of the reference scenario?

Mitigation potentials (tCO_2)
= Emissions in the reference scenario – Emissions in the mitigation scenario

Total mitigation costs (US $)
= Costs in the reference scenario – Costs in the mitigation scenario

Unit mitigation cost (US $ / tCO_2)
= (Costs in the reference scenario – Costs in the mitigation scenario)
/ (Emissions in the reference scenario – Emissions in the mitigation scenario)

How to set the future projections of the mitigation scenario?

The results of mitigation potentials and costs will depend
not only **what types of mitigation measures you consider**
but also **how you set the reference scenario**

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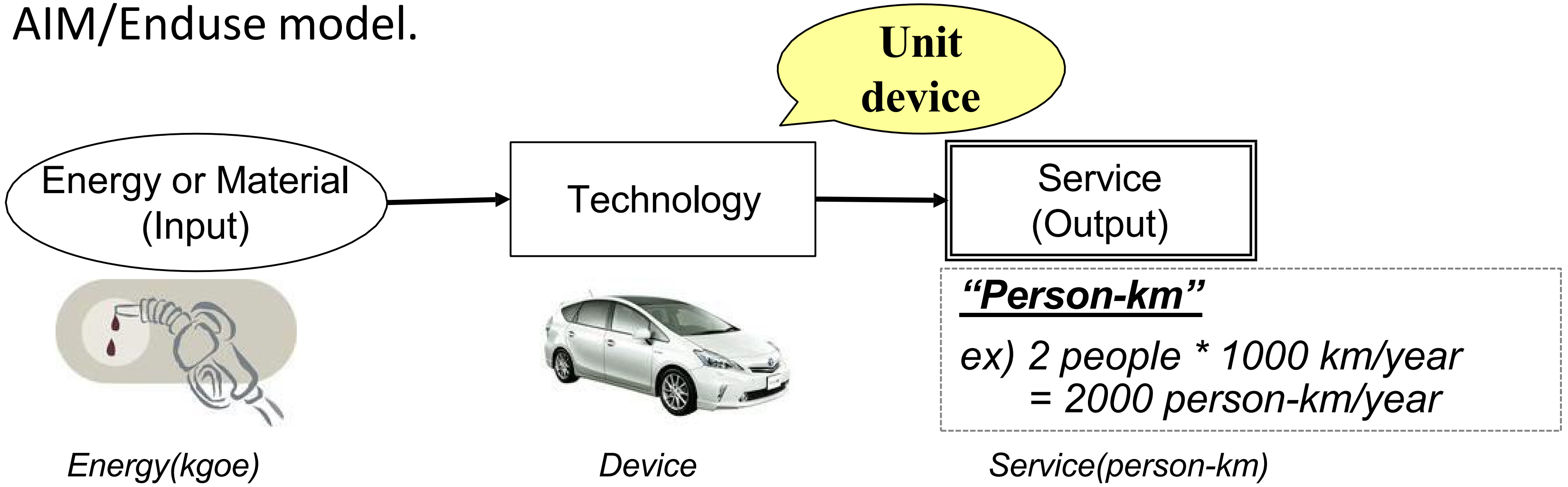
Source: AIM/Enduse Training Material 202328

Key concept ①: Technology system

- Calculation flow of "Energy-Technology- Service" is the key, when developing database for the AIM/Enduse model.



- "Energy technology" refers to a device that provides a useful "energy service" by consuming "energy".
- By using this concept, the model user defines technology system in each sector and analyzes relations among all sectors.
- An important point is, how to define "unit device" of the technology option. It will depend on data availability and characteristics in each sector, and the unit of energy service varies with the type of service.

Key concept ②: Energy service demand

Definition of "energy service" in AIM/Enduse:
"Energy service" refers to a measurable need within a sector that must be satisfied by supplying an output from a device.

- It can be defined in either tangible or abstract terms
  - In residential sector, a device of air conditioner is an energy technology and space cooling is an energy service (abstract term).
  - In transportation sector, a vehicle is an energy technology and transportation volume of people (person-km) is an energy service (abstract term)
  - In steel sector, various types of furnace are energy technologies and crude steel products are energy service (tangible term).

- Thus "service demand" refers to the quantified demand created by a service;

  i.e. service outputs from devices satisfy service demands.

- Energy-service demands used in this model are determined based on scenarios or simulation results obtained from other models/sources

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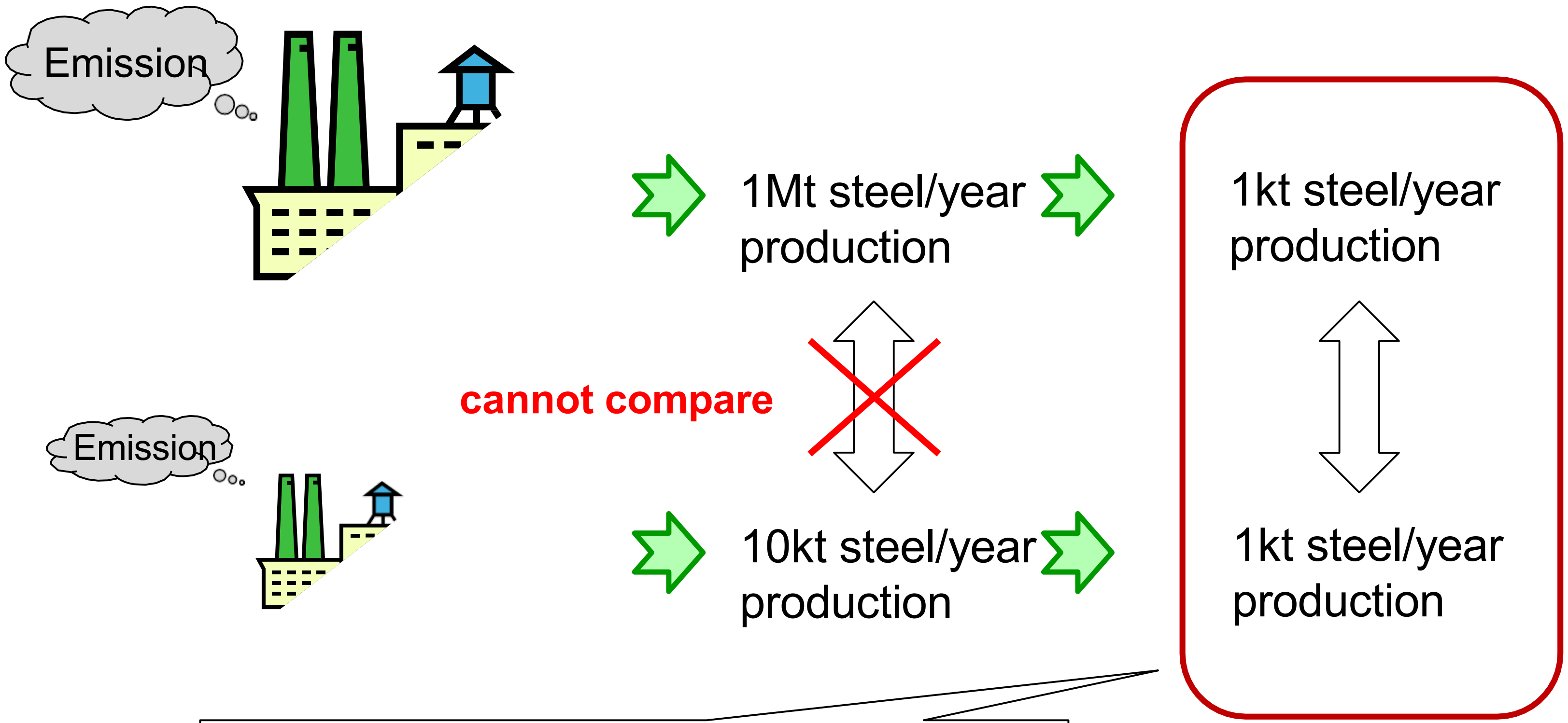
Source: AIM/Enduse Training Material 202330

Key concept ③: Unit device

How do you compare a large scale plant and a small scale plant?

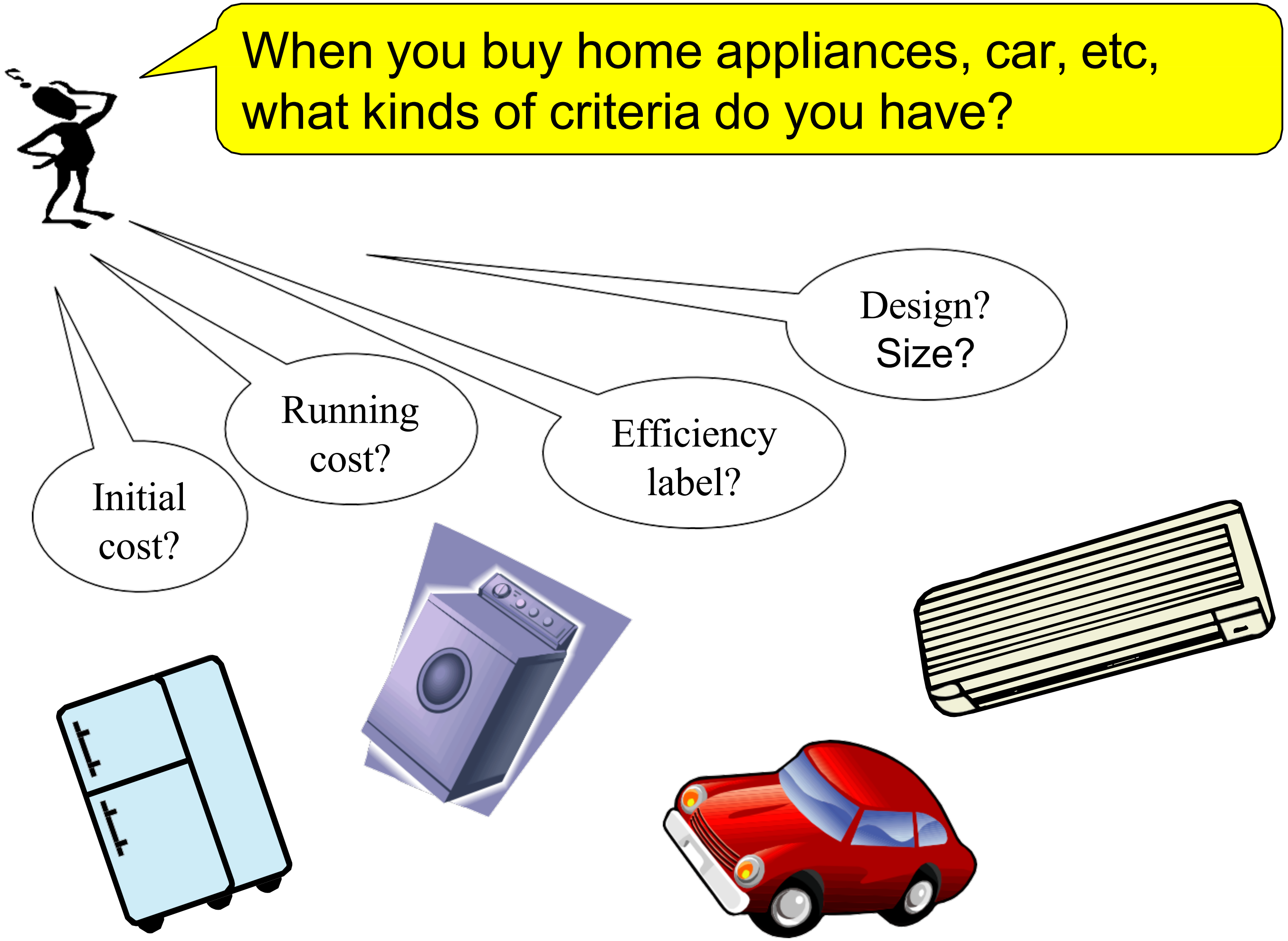


You prepare input data (energy and material) to each plant based on this unit service definition, then can compare different size of plants.

Unit service per unit operation of device(plan)

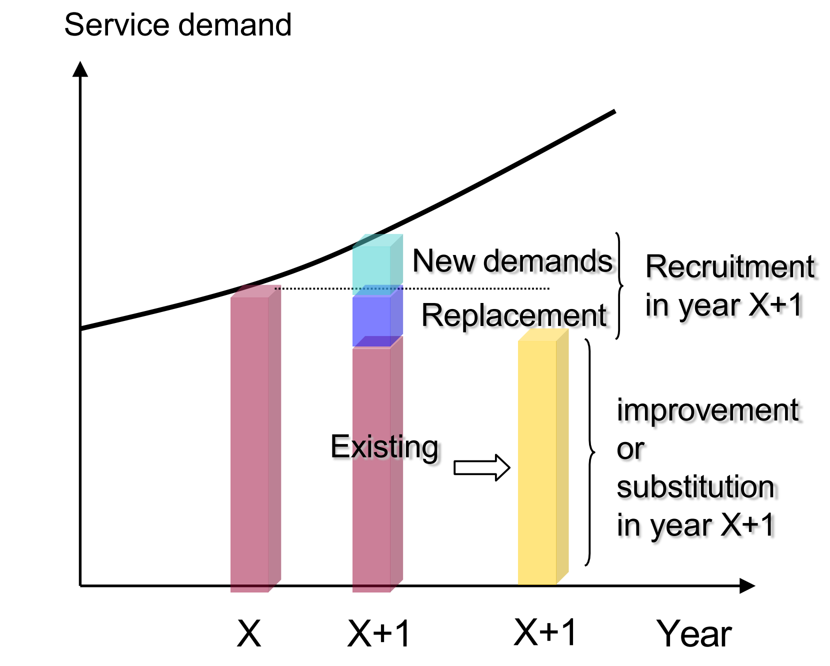
Source: AIM/Enduse Training Material 202331

Key concept ④: Technology selection



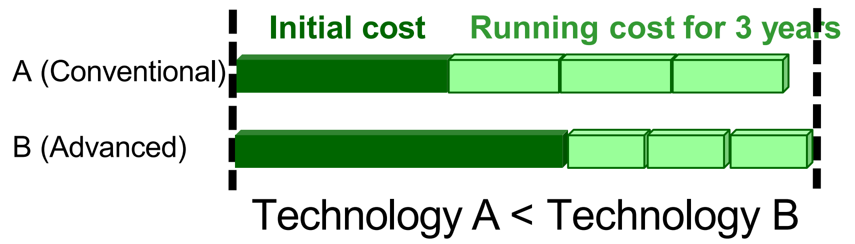
Source: AIM/Enduse Training Material 202332

Key concept ④: Technology selection

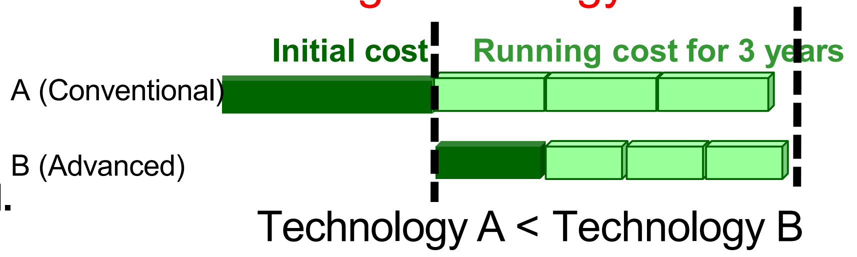


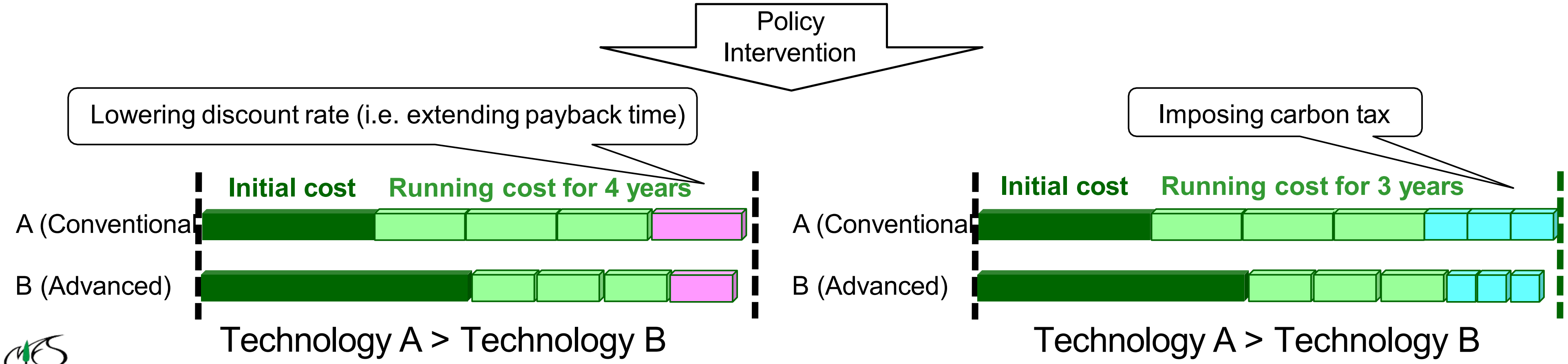
The least costly technology option is selected.
If Tech A ＜ Tech B ⇒ <u>Tech A</u> is selected

(1) Recruitment of new technology to satisfy new demand and demand for replacement



(2) Substitution or improvement of existing technology





Source: AIM/Enduse Training Material 2023

Key formulation ①: Total system cost

1) Objective function of the AIM/Enduse model

Minimize *Total Cost (TC) at year t*

TC= Initial investment cost ($) ← it should be annualized !

+ Operating and maintenance cost ($/year)

+ Energy cost ($/year)

+ Payment for energy tax ($/year)

+ Payment for emission tax ($/year)

} Annual cost

Discount rate is used for annualizing investment cost,
but what does "discount rate" mean in the AIM/Enduse model?

Source: AIM/Enduse Training Material 202334

Key formulation ②: Cost of technology - how to annualize initial cost-

Initial cost is annualized | **Annual cost**

Annual total cost = annualized initial cost - subsidy + O&M cost + energy cost + tax

A capital recovery factor

α: Discount rate for investments

$T_{l,i}$: Lifetime of energy device L in region/sector *i*.

An inverse value of this capital recovery factor represents the payback period

(i.e. this study takes the payback period into account indirectly by setting a discount rate for investments)

e.g.) As private industries and actors take into account high investment risk for energy conserving technologies, a payback period of 3-years is usually assumed.
(the discount rate corresponding to 3-years payback is about 33% based on the assumption of 30 years lifetime for a large-size plant.)

How to calculate payback time

$$C = B \cdot \frac{\alpha(1+\alpha}{\quad}$$

C: Annualized initial cost
B: Initial cost
T: Device lifetime
α: Discount rate for investments

An inverse value of the capital recovery factor represents the payback period

		Discount rate for investment						
		1%	2%	3%	5%	10%	20%	30%
Device lifetime	1 year	0.99	0.98	0.97	0.95	0.91	0.83	0.77
	2 year	1.97	1.94	1.91	1.86	1.74	1.53	1.36
	3 year	2.94	2.88	2.83	2.72	2.49	2.11	1.82
	4 year	3.90	3.81	3.72	3.55	3.17	2.59	2.17
	5 year	4.85	4.71	4.58	4.33	3.79	2.99	2.44
	6 year	5.80	5.60	5.42	5.08	4.36	3.33	2.64
	7 year	6.73	6.47	6.23	5.79	4.87	3.60	2.80
	8 year	7.65	7.33	7.02	6.46	5.33	3.84	2.92
	9 year	8.57	8.16	7.79	7.11	5.76	4.03	3.02
	10 year	9.47	8.98	8.53	7.72	6.14	4.19	3.09
	20 year	18.05	16.35	14.88	12.46	8.51	4.87	3.32
	30 year	25.81	22.40	19.60	15.37	9.43	4.98	3.33
	40 year	32.83	27.36	23.11	17.16	9.78	5.00	3.33

Table of payback time (Year)

Source: AIM/Enduse Training Material 2023

Key formulation ④: Various constraints

- *Service demand*

$$D(j) \leq \sum A(j,l$$

$D(j)$: *Service demand quantity of service type j*
$A(j,l)$: *Output of service j per unit operation of device l*
$X(l)$: *Operating quantity of device l*

- *Stock dynamics*

Remaining stock quantity from the previous year

$$S(l) = \bar{S}(l) \cdot \left(1 - \frac{1}{T(l)}\right) + r(l) - w(l)$$

$S(l)$: *Stock of device l*
$\bar{S}(l)$: *Stock of device l in the previous year*
$T(l)$: *Life time of device l*
$r(l)$: *Recruited quantity of device l*
$w(l)$: *Retired quantity of device l*

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Source: AIM/Enduse Training Material 202337

Key formulation ⑤: Emission constraints

- *Emission quantity*

$$Q(m)=\sum_{l} X(l)\cdot e(l,m)$$

$Q(m)$: *Emission of gas m*

$X(l)$: *Operating quantity of device l*

$e(l,m)$: *Emission of gas m per unit operation of device l*

- *Maximum limit of gas emission*

$$Q^m(m)\leq$$

$Q^m(m)$: *Emission of gas m*

$\hat{Q}(m)$: *Maximum limit on emission of gas m*

Source: AIM/Enduse Training Material 202338

Key formulation ⑥: Energy supply constraints

- *Maximum energy supply constraints*

$$E(k,l)\cdot X(l) \leq \hat{E}^{\max}(k)$$

$E(k,l)$: *Energy use of energy kind k per operating unit of device l*

$\hat{E}^{\max}(k)$: *Maximum supply quantity of energy kind k*

- *Minimum energy supply constraints*

$$E(k,l)\cdot X(l) \geq \hat{E}^{\min}(k)$$

$E(k,l)$: *Energy use of energy kind k per operating unit of device l*

$\hat{E}^{\min}(k)$: *Minimum supply quantity of energy kind k*

Key formulation ⑦: Device share constraints

- *Maximum device share constraints*

$$\theta^{max}(j,l)\cdot\sum_{l'}A(j,l')\cdot X(l')\geq A(j,l)\cdot X(l)$$

$\theta^{max}(j,l)$:*Maximum share of device l in service j*

$A(j$: *Service output of service j per operating unit of device l*

$X(l)$: *Operating quantity of device l*

- *Minimum device share constraints*

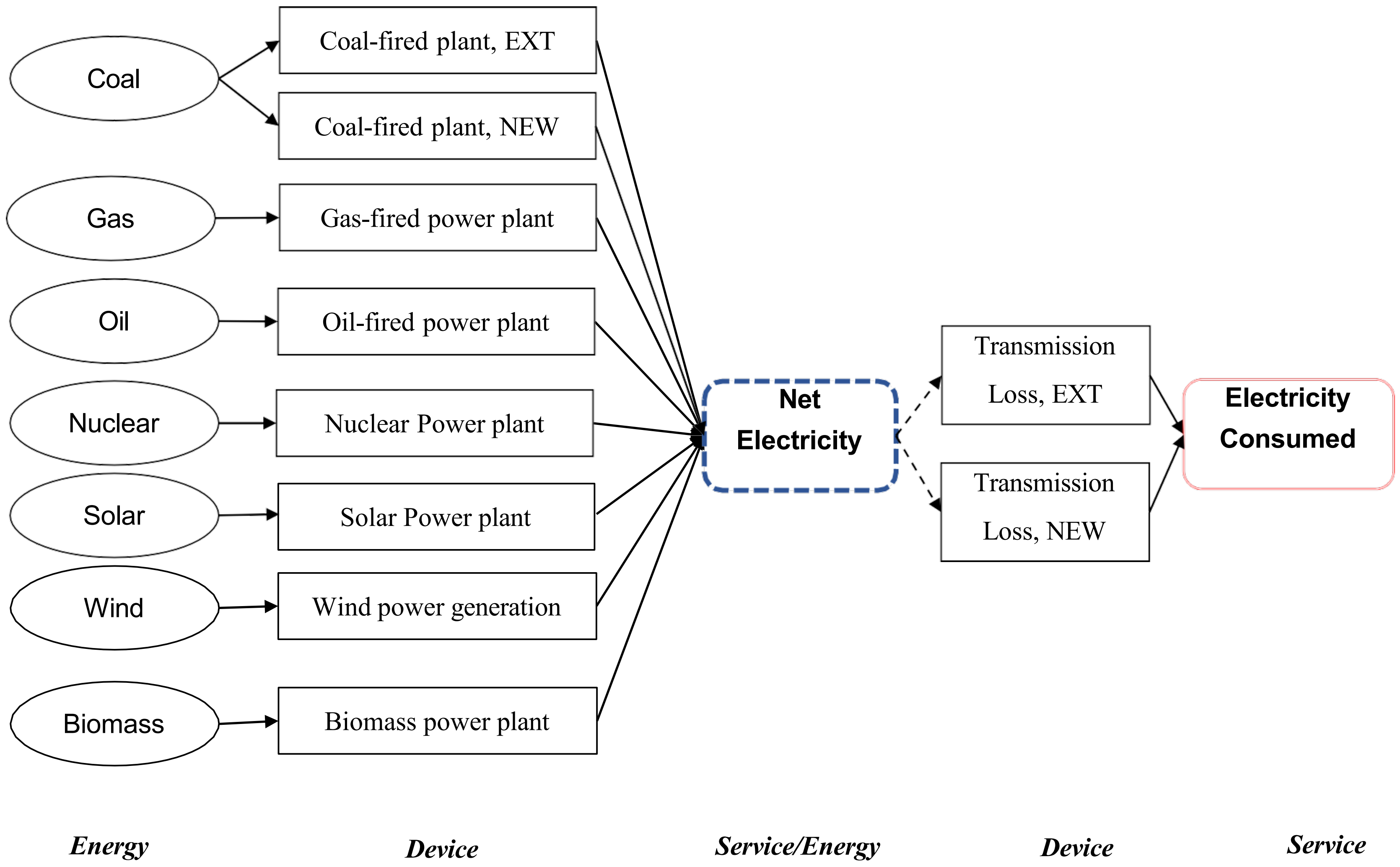
$$\theta^{min}(l,j)\cdot\sum_{l'}A(l',j)\cdot X(l')\leq A(l,j)\cdot X(l)$$

$\theta^{min}($:*Minimum share of device l in service j*

$A(j,l)$: *Service output of service j per operating unit of device l*

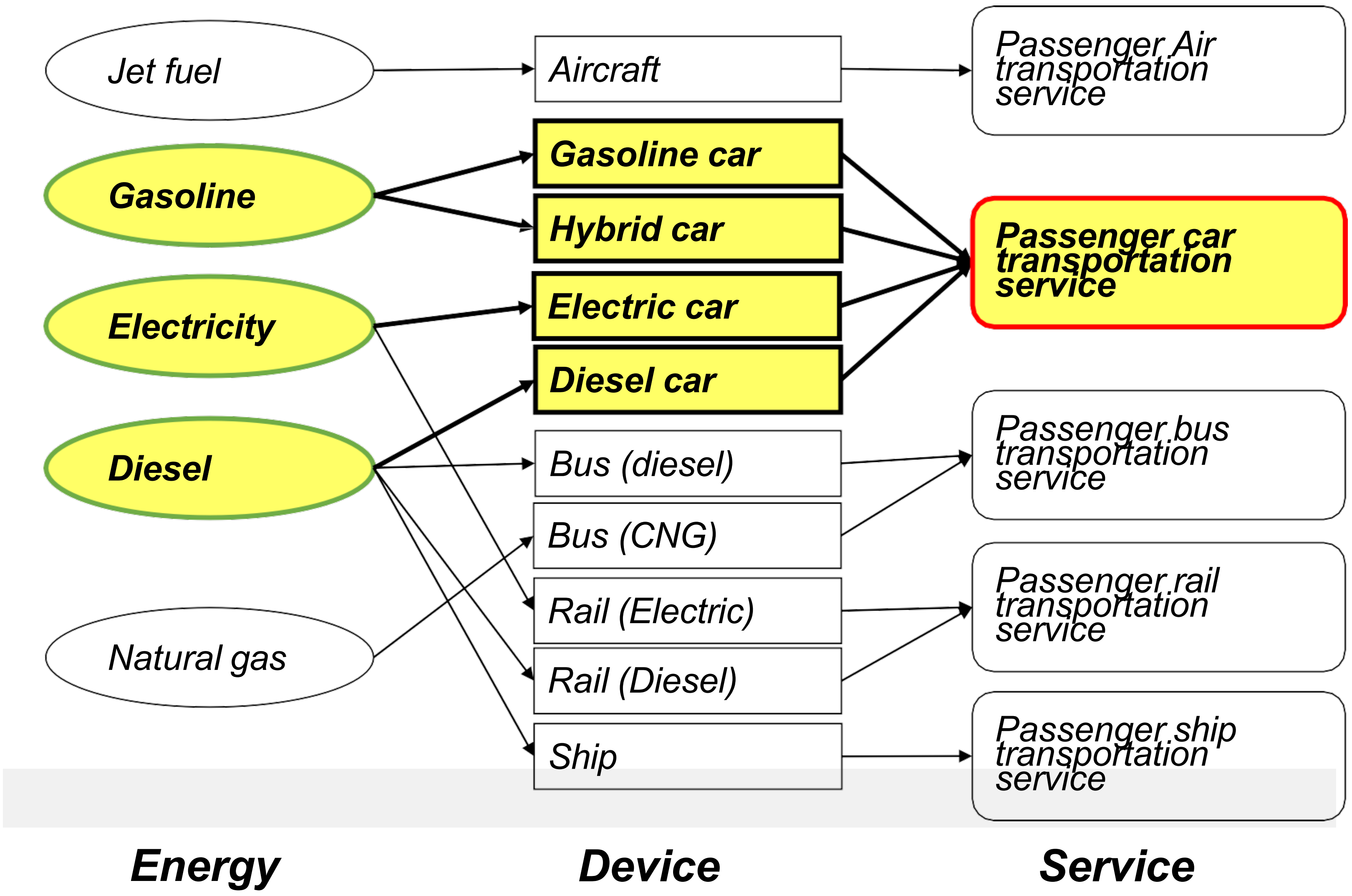
$X(l)$: *Operating quantity of device l*

Example of Power system



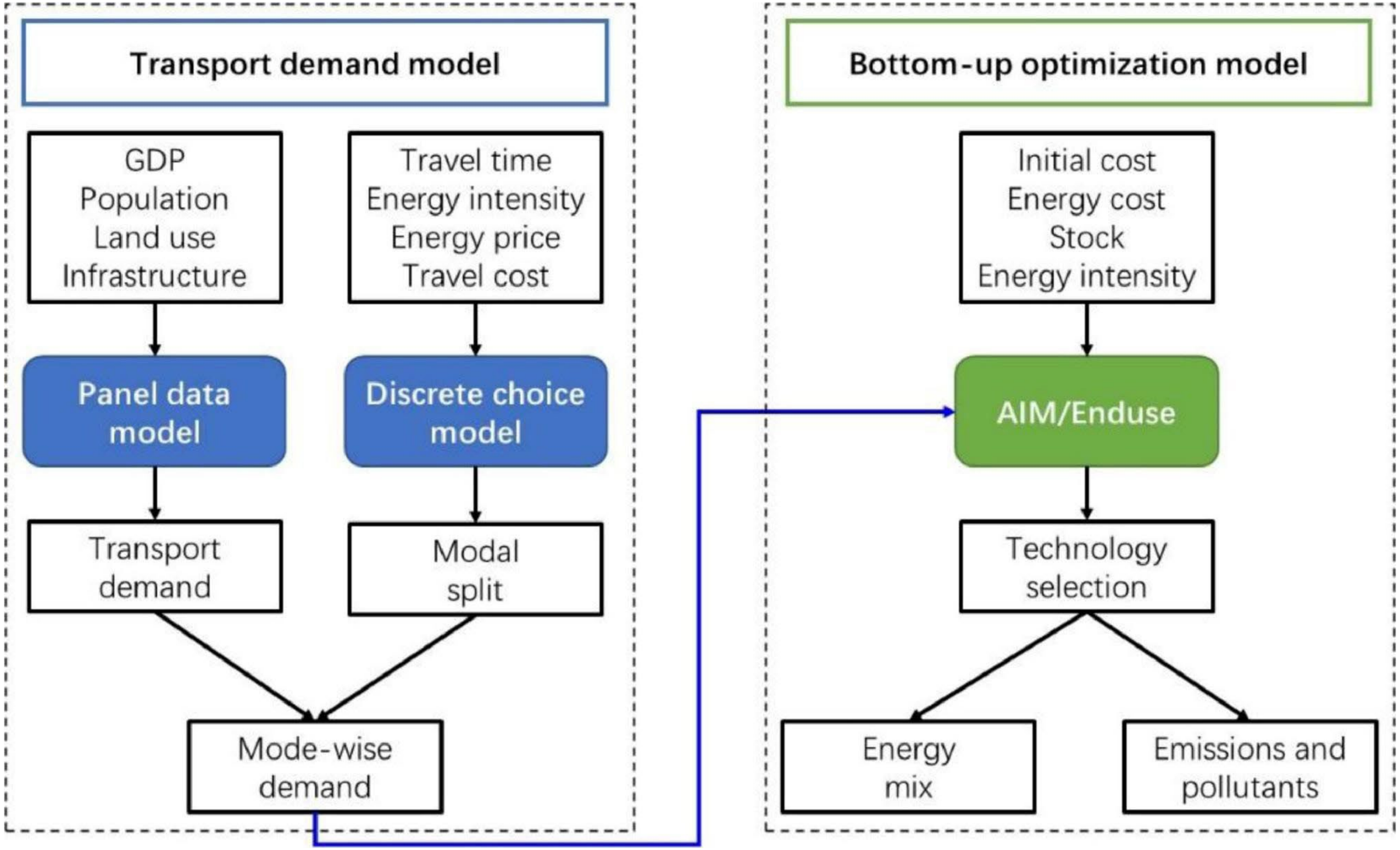
Source: AIM/Enduse Training Material 202341

Example of Transport system



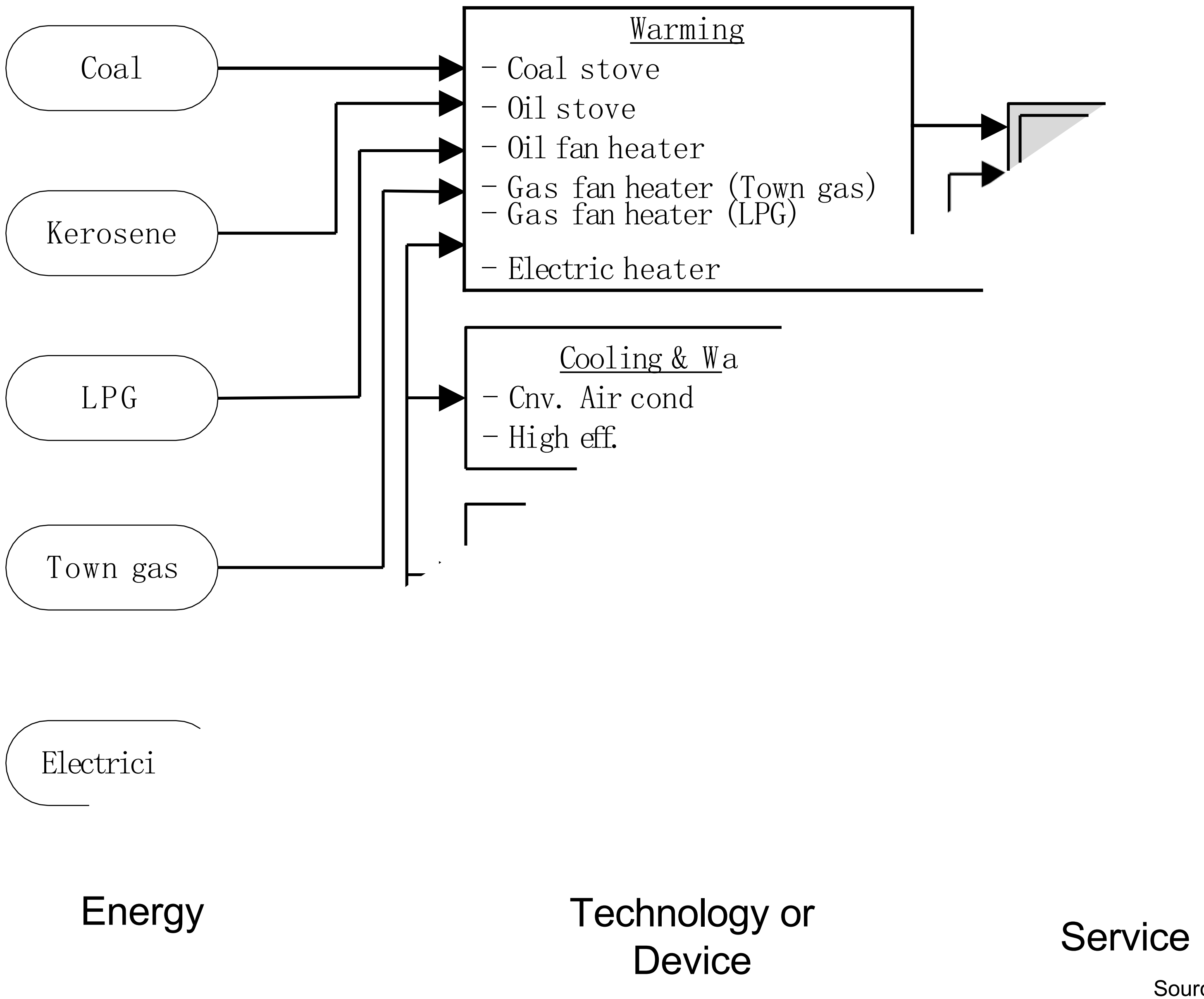
Source: AIM/Enduse Training Material 202342

Transport: Demand and Energy Model

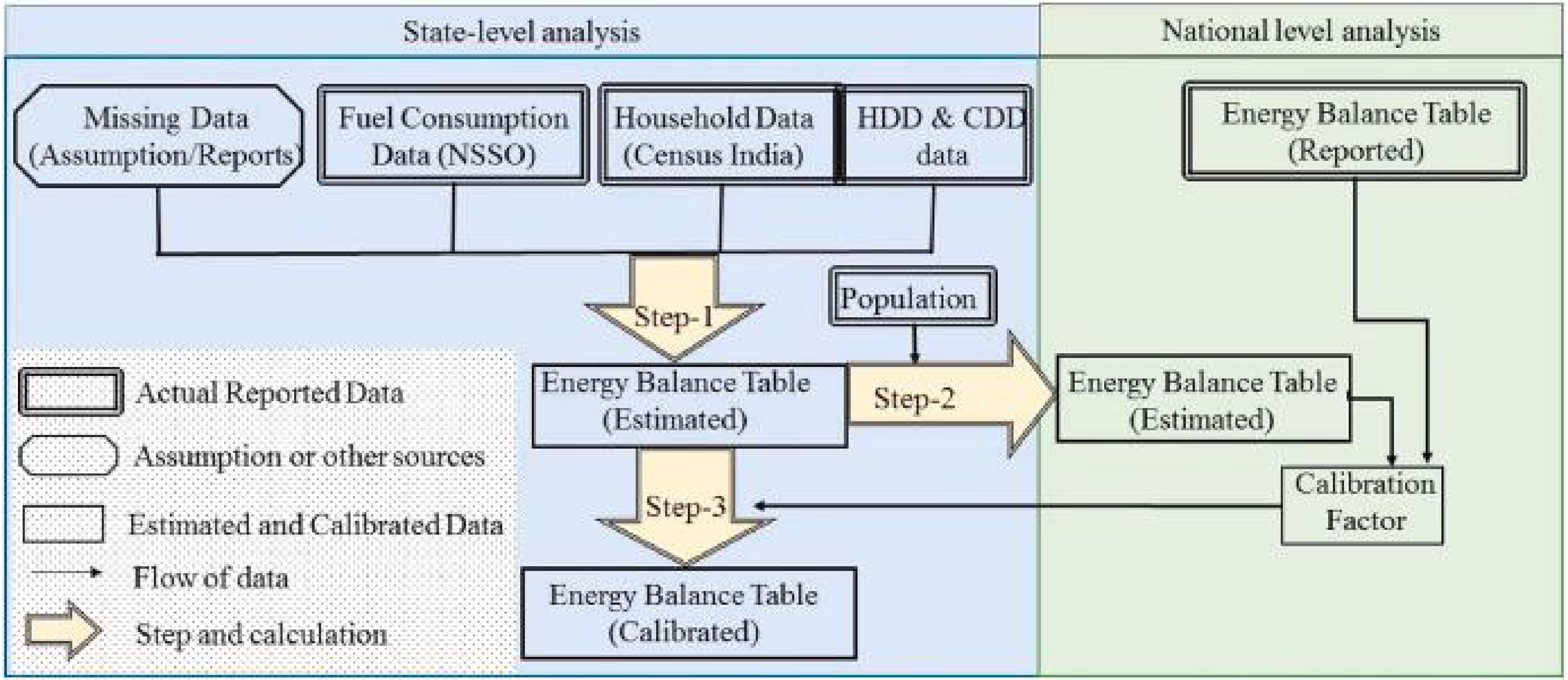


Source: Zhang et al 2021

Example of residential system



Building: State to National Model



Source: Yawale et al 2021

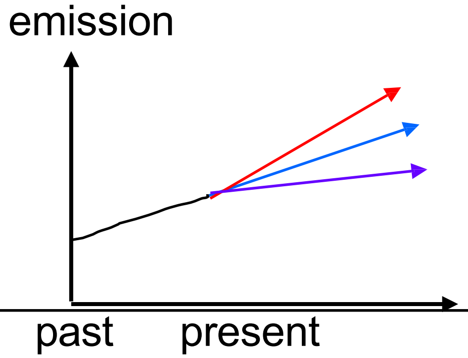
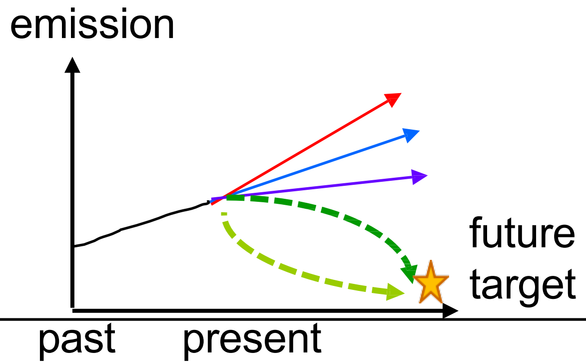
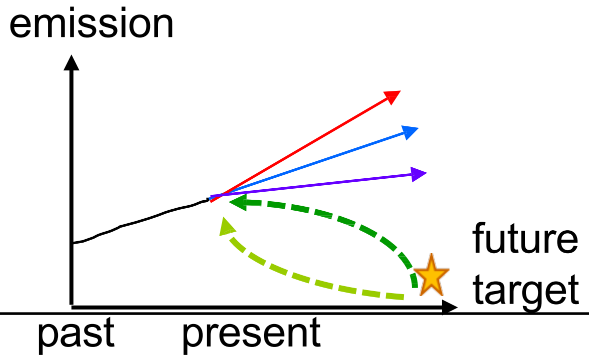
Example of sectors and services

Sector	Service
Industry	
Iron and steel	Steel
Cement	Cement
Petrochemicals	Ethylene
Paper and pulp	Kraft pulp, Mechanical pulp, Wastepaper pulp, Paper products
Food	Furnace, Motor, Other Heat, Other Electricity, Steam
Textile	Furnace, Motor, Other Heat, Other Electricity, Steam
Other chemicals	Furnace, Motor, Other Heat, Other Electricity, Steam, Non energy use
Glass products	Furnace, Motor, Other Heat, Other Electricity, Steam
Other non-metallic minerals	Furnace, Motor, Other Heat, Other Electricity, Steam
Non-ferrous metals	Furnace, Motor, Other Heat, Other Electricity, Steam
Machinery	Furnace, Motor, Other Heat, Other Electricity, Steam
Construction	Furnace, Motor, Other Heat, Other Electricity, Steam
Other manufacturing	Furnace, Motor, Other Heat, Other Electricity, Steam, Non energy use
Agriculture, Forestry and Fishing	Agriculture Drying, Agriculture Machinery, Agriculture Greenhouse, Agriculture Electricity, Forestry, Fishing
Residential	Hot Water, Cooking, Lighting, Electric Appliances, Cooling, Warming
Commercial	Cooking, Hot Water, Cooling, Warming, General Lighting, Electric Appliances, High-Intensity Lighting
Transportation	Passenger Vehicle, Passenger Train, Passenger Ship, Passenger Air, Freight Vehicle, Freight Train, Freight Ship, Freight Air
Electricity generation	Electricity
Oil refineries	Oil
Gas works	Gas
District heat system	District Heat

Source: AIM/Enduse Training Material 2023

Scenario Development

Types of scenarios in emission modeling

	Exploratory scenario **Forecasting Method.** **A method of exploring the future vision by considering a wide range of driving-forces and story branches**	**Normative scenario** **Backcasting Method.** **A deductive method to find a pathway from the desired image back to the current situation**
BaU scenario **(Reference scenario)** **A future scenario considering various paradigms, social structure changes, technological changes, policies etc as an extension of the status quo**		
Mitigation scenario **A plausible future scenario that explores the choices of mitigation actions and policies toward the future target in a desirable directoin**		

Source: AIM/Enduse Training Material 2023

National Modelling

INDIA

India: Context

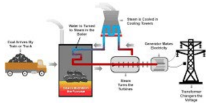
China: 3.9 Bt
India 0.77 Bt
Indonesia: ~0.55 Bt
USA: ~0.54 Bt
Australia:~ 0.54 Bt

2nd largest producer of coal, **2nd largest consumer** of coal
Employs ~15 million people directly and in connected businesses,
4 states' revenues depend on coal royalties

Thermal coal (91%), Metallurgical coal (9%)
Surface mining (>94%), *Underground mining (<6%)*
>220 million ton imported each year

3rd largest consumer of energy
Total **1400 Bn** Unit of electricity/year
But only ~1000 kWh/capita/year
Energy mix *: Coal (56%) followed by oil (25%)*

kWh/cap
Canada: 16000 USA: 12000
Australia:9800
Germany: 6700
China: 5300
Southa Africa: 3760
Brazil: 2800



Coal projected to remain major source of electricity generation in India for some years (until when?)
54% generation capacity, ~ 72% generation share
39 GW under construction (68% supercritical, 20% ultra-supercritical), ~20 GW de-commissioned in 5 years
Simultaneous ***<u>500 GW renewable target</u>*** *by 2030 (~5 times 2021 capacity)*

Around **750 million people** have gained access since 2000
100% Village (600 thousand total) completely electrified by 2019
Access and Affordability of electricity to all are major issues

Agriculture sector is the **main source of non-CO_2 emission (CH_4 and N_2O)**
(14% of total national GHG emissions)
Difficult to mitigate these gases from agriculture, sub sustenance, poor and marginal farmers

15% of CO2 emissions in 2016 were removed by the LULUCF sector (forestland, cropland, settlements)

विद्याविनियोगाद्विकासः
IIM AHMEDABAD

Source: Vishwanathan et al. 202

India’s NDCs (2005-2030)

1. To put forward and further propagate a healthy and sustainable way of living based on traditions and values of conservation and moderation.
2. To adopt a climate friendly and a cleaner path than the one followed hitherto by others at corresponding level of economic development.
3. **To reduce the emissions intensity of its GDP by <u>33 to 35 per cent</u> by 2030 from 2005 level.**
4. **To achieve about <u>40 per cent cumulative electric power installed capacity</u> from non-fossil fuel-based energy resources by 2030 with the help of transfer of technology and low cost international finance including from Green Climate Fund (GCF).**
5. **To create an <u>additional carbon sink of 2.5 to 3 billion tonnes of CO_2 equivalent</u> through additional forest and tree cover by 2030.**
6. To better adapt to climate change by enhancing investments in development programmes in sectors vulnerable to climate change, particularly agriculture, water resources, Himalayan region, coastal regions, health and disaster management.
7. To mobilize domestic and new & additional funds from developed countries to implement the above mitigation and adaptation actions in view of the resource required and the resource gap.
8. To build capacities, create domestic framework and international architecture for quick diffusion of cutting edge climate technology in India and for joint collaborative R&D for such future technologies.

Development priority, India still raising its ambitions

Mapped more than 150 climate related policies – more 60% were announced post Paris

	Measures	Pre-Paris	Post-Paris
Power	National Solar Mission Renewable Energy Retirement of Coal Plants T&D Losses reduction	20 GW of solar by 2020 100 GW of renewables by 2020 No initiative No scheme was present	100 GW of solar by 2030. 175 GW by 2022 (2015), 450 GW by 2030 (2019), **500 GW by 2030 (2021).** 170 thermal generation units retired by 2018. Ujwal Discom Assurance Yojana (UDAY) scheme, reduce losses to 15%.
Industry	Perform, Achieve and Trade (PAT)	PAT Cycle I (2012-13 to 2014-15) with 478 designated consumers (DCs) across 8 sectors	PAT Cycle II (2016-17 to 2018-19) with **621** designated consumers (DCs), **across 11 sectors** (petroleum refinery, railways and DISCOM).
Transport	Electric Vehicle Ethanol Blended Program Metro Rail Freight Rail Road Construction Speed	No scheme was launched 5% Ethanol Blending Metro rail coverage is limited to 4-5 major cities of India. No scheme. ~11 km/per day	The number of electrified two-and three-wheelers has grown by more than 60% each year on average since 2015. **30:30 target** **10% Ethanol Blending by 2022 and 20% by 2030** In 2020, over 650 km of metro rail was operational in 18 cities of India. Dedicated freight corridor: Increase freight rail share to 45%
Buildings	Standards and Labeling programme LPG Connection Green Buildings Buildings Energy Efficiency Programme	It covered sectors such as air conditioners, ceiling fans, refrigerators, TVs No scheme was launched No scheme was launched No scheme was launched	Currently, the programme covers 26 appliances of which 10 appliances are under the mandatory regime. As on December 2020, a total of 287.4 million households have LPG connections (including PMUY beneficiaries). Green building footprint was 7.61 billion sq.ft. with total number of 5918 green buildings as on October, 2020. Building energy efficiency projects completed in 10,344 buildings
Agriculture	Neem Coated urea application Energy Efficient Pump Programme	No production of neem coated urea Only 2209 pump sets have been replaced in pilot project at Solapur district.	Both imported and indigenously produced urea available in the country is neem coated since 2016. N2O emissions reduce by ~20% 74,136 pumps have been installed by EESL
Waste	Sanitation (Swachh Bharat Abhiyan)	No scheme was launched.	More than 6.2 million individual toilets and 0.59 million community and public toilets have been constructed.
Water	Micro-irrigation	Area covered under micro-irrigation was 7.73 million hectare till 2015.	Area covered under micro-irrigation was 8.7 million hectare till November 2019.

India's COP26 Declarations

1. To put forward and further propagate a healthy and sustainable way of living based on traditions and values of conservation and moderation.
2. To adopt a climate friendly and a cleaner path than the one followed hitherto by others at corresponding level of economic development.
3. **To reduce the emissions intensity of its GDP by 45 per cent by 2030 from 2005 level.**
4. **To have 500 GW of renewable power generation capacity by 2030.**
5. **To create an additional carbon sink of 2.5 to 3 billion tonnes of CO2 equivalent through additional forest and tree cover by 2030.**
6. **To achieve about 50 per cent cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030 with the help of transfer of technology and low-cost international finance including from Green Climate Fund (GCF).**
7. **To mitigate 1 billion tonnes of CO_2 equivalent by 2030.**
8. **Indian Railways to become Net Zero by 2030.**
9. **India to become Net Zero by 2070.**

Initiatives already launched by India – International Solar Alliance (with France),
Coalition for Disaster resilient Infrastructure,
Most recent being One Sun-One World-One Grid (with UK) at COP26 last year.

Development and Climate Change: SDG and NDC

India has been setting ambitious targets to achieved its development and Paris Agreement commitment by 2030

Development

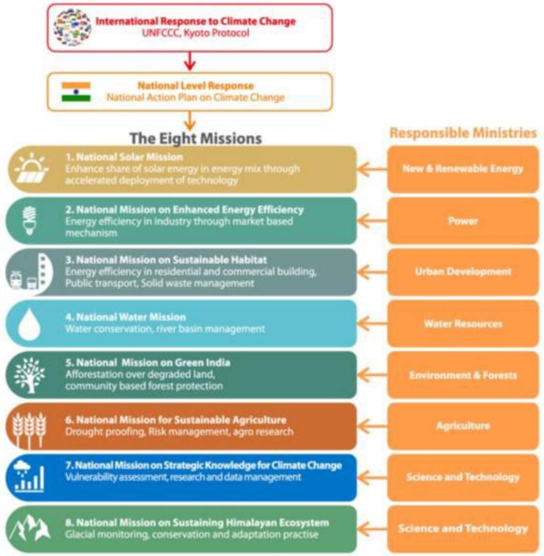
MDG (2000 – 2015)

Source: UN MDG 2000

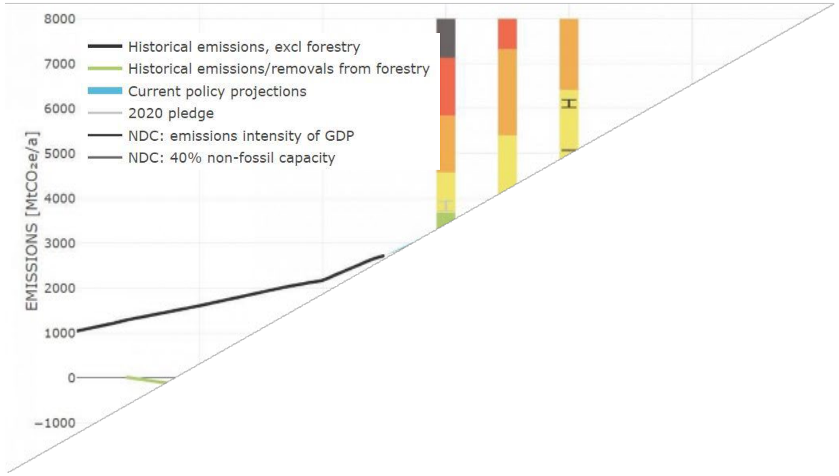
SDG (2015 -2030)

Source: UN SDG 2015

Climate Change



Source: NAPCC 2008



Source: https://climateactiontracker.org/countries/india/, 2020

Drivers

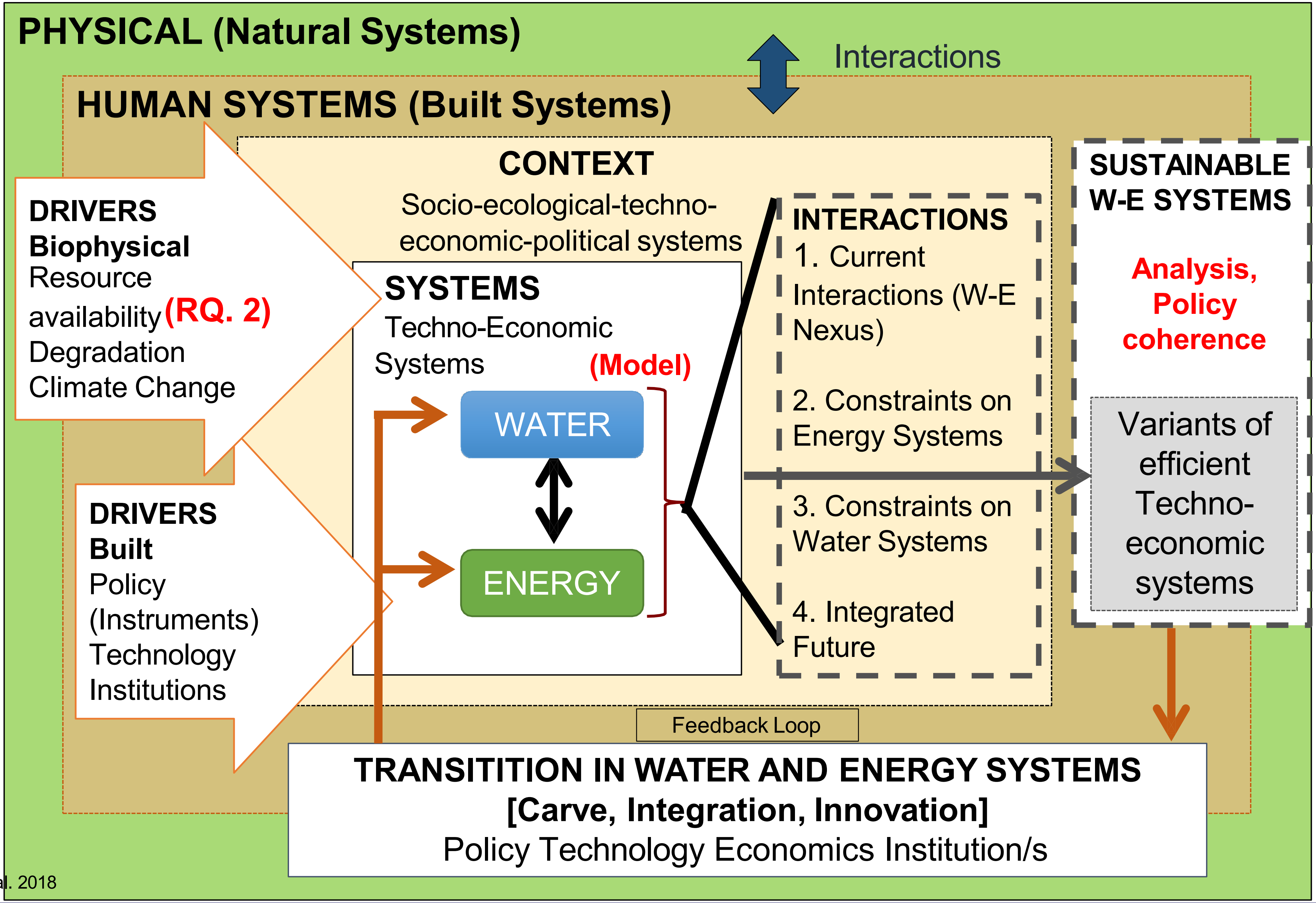
- **Demand Drivers**
  - Population
  - Economic growth
  - Structural changes
  - Consumption patterns
  - Global production and trade pattern
  - Technology development (transfer, adoption, adaptation, indigenous)

- **Sectoral Drivers**
  - Technical Efficiencies
  - Resource Consumption

- **Resource Balance Drivers**
  - Service Demand
  - Resource Transfer

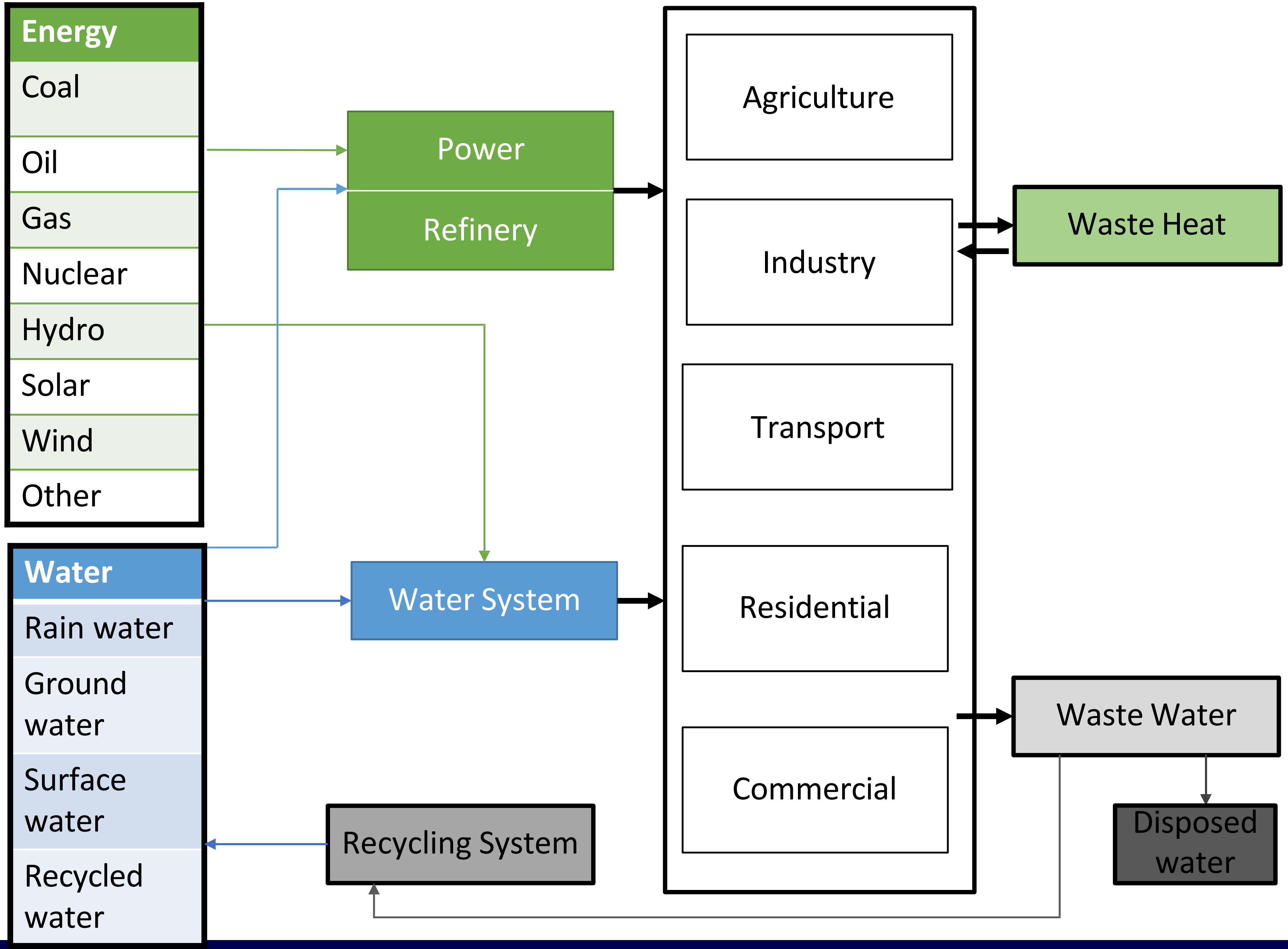
- **Constraints**
  - Emissions
  - Resources (energy, water)

Research Framework



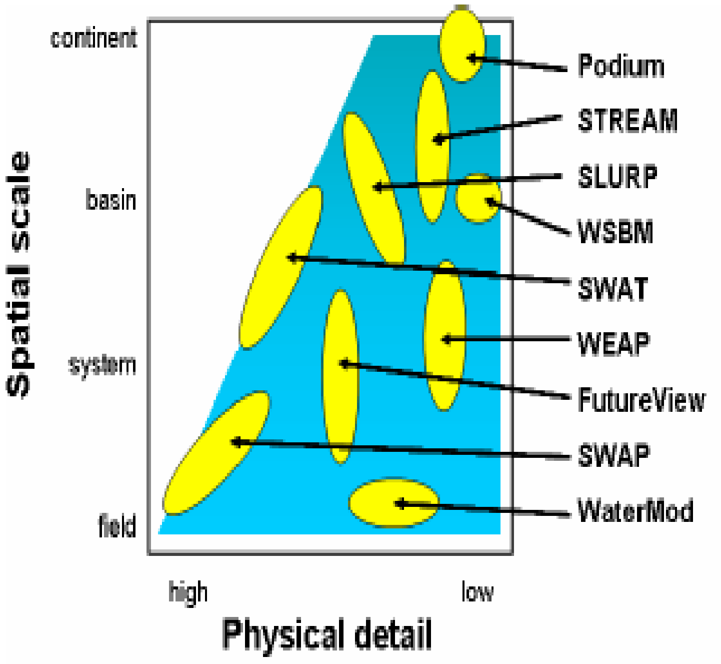
Source: Vishwanathan et al. 2018

Energy and Water Flow



Source: Vishwanathan et al. 2018

Water Models

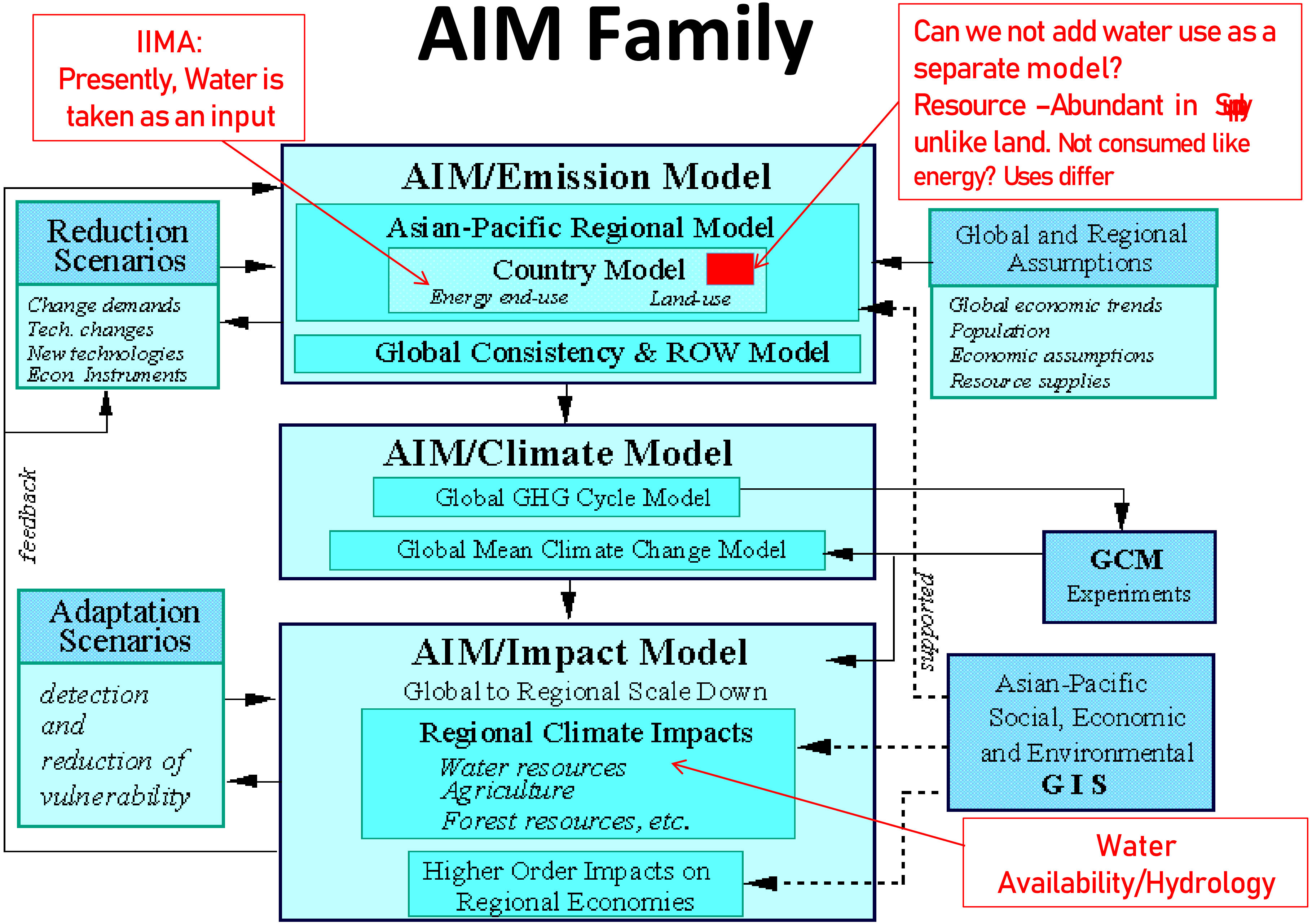


Source: Droogers, [illegible]

Type of Model	Name of Model
Bottom – up (Global, National) Last decade	WEAP MESSAGE-WATER TIMES-WATER MARKAL-WATER
Top - down	GCAM-WATER
Hydrological Models	Catchment Water Allocation Tool (CaWAT) [IWMI] Global Environmental Flow Calculator (GEFC) [IWMI] Options Analysis in Irrigation System (OASIS) [IWMI] PODIUMSim (Water and Food Supply Scenarios) [IWMI] WaterGAP (Global Assessment and Prognosis) WATCH (Integrated Water and Global Change) [IIASA] SCENES (Scenarios for Europe and Neighboring States) [IIASA] Water Footprint Network for Manufacturing Processes

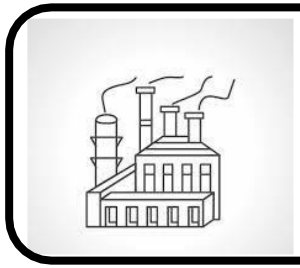
Source: Vishwanathan et al. 2018

AIM Family


IIMA:
Presently, Water is taken as an input
Can we not add water use as a separate model?
Resource –Abundant in Supply unlike land. Not consumed like energy? Uses differ
AIM/Emission Model
Asian-Pacific Regional Model
Country Model
Energy end-use
Land-use
Global Consistency & ROW Model
Reduction Scenarios
Change demands
Tech. changes
New technologies
Econ. Instruments
Global and Regional Assumptions
Global economic trends
Population
Economic assumptions
Resource supplies
AIM/Climate Model
Global GHG Cycle Model
Global Mean Climate Change Model
feedback
GCM
Experiments
supported
Adaptation Scenarios
detection
and
reduction of
vulnerability
AIM/Impact Model
Global to Regional Scale Down
Regional Climate Impacts
Water resources
Agriculture
Forest resources, etc.
Higher Order Impacts on Regional Economies
Asian-Pacific Social, Economic and Environmental
GIS
Water Availability/Hydrology

Example – Agriculture, Industry

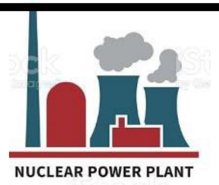
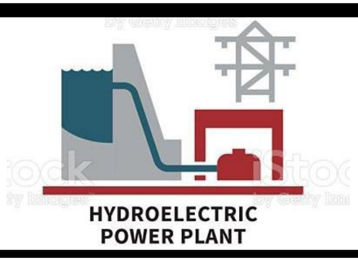
Resource Type → Technology → Service

	Resource Type	Technology		Service
	Water Energy	Irrigation Pumps		Crop Production
	Water Energy	Irrigation Pumps		Crop Production
	Water Energy	Sugar Ethanol	Wastewater Technology	Sugar, Ethanol Production
	Water Energy Raw Materials	Production Technology	Wastewater Technology	Industrial Production

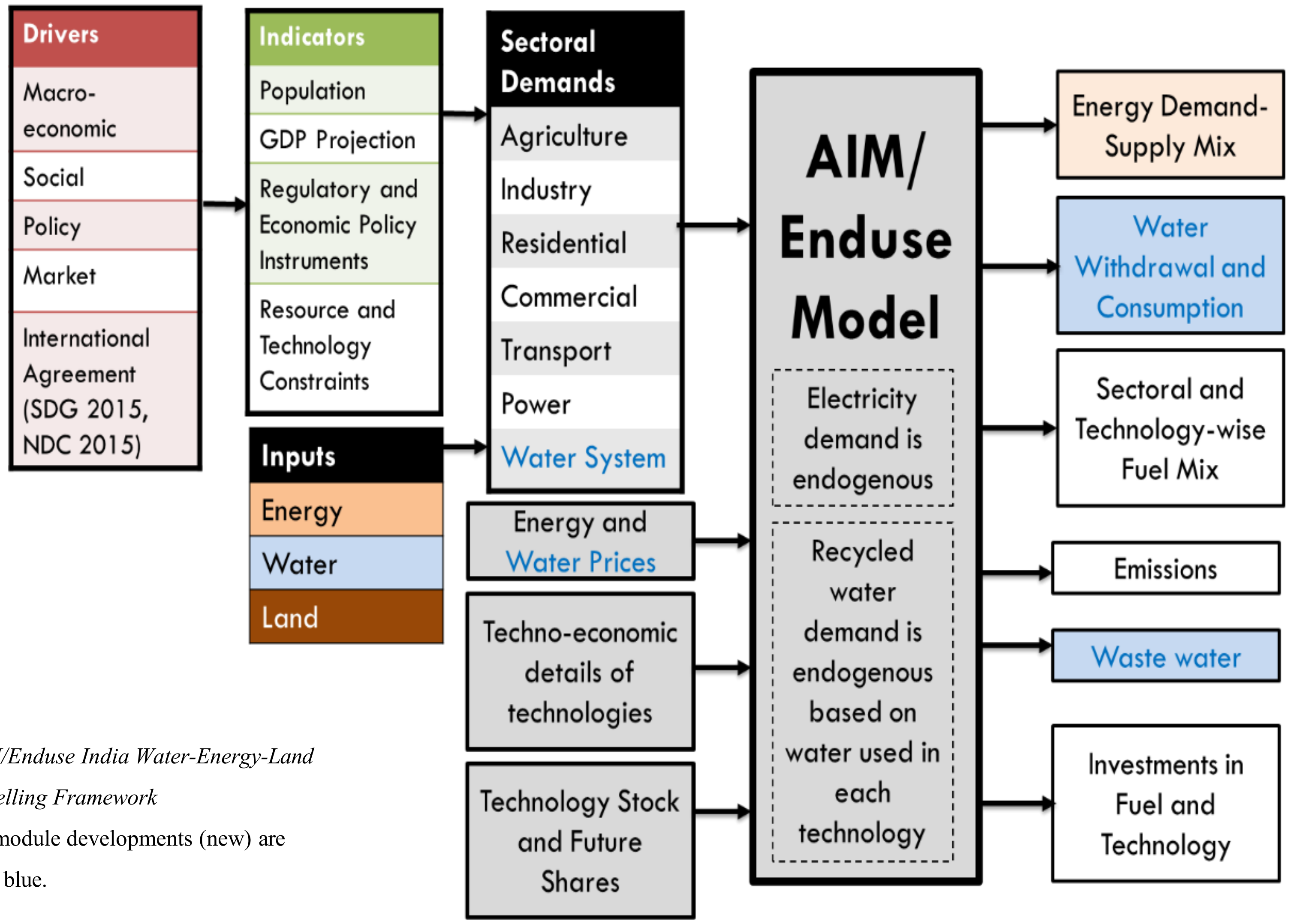
Source: Vishwanathan et al. 2018

Example – Power generation

Resource Type → Technology → Service

	Resource Type	Technology	Service
	Water Coal	Boiler Retrofit Cooling system ESP, FGD	Electricity
	Water Nuclear fuel	Boiler Cooling system	Electricity
	Water	Turbine Pump Storage	Electricity
 	Water Critical mineral	PV, CSP	Electricity

AIM/Enduse India



Modified AIM/Enduse India Water-Energy-Land (W-E-L) Modelling Framework

Note: Water module developments (new) are highlighted in blue.

Source: Vishwanathan et al. 2018

Difference between WEAP and AIM/Enduse

WEAP

1. **Objective Function**
   1. Optimize Demand Site
   2. Optimize Instream Flow requirements

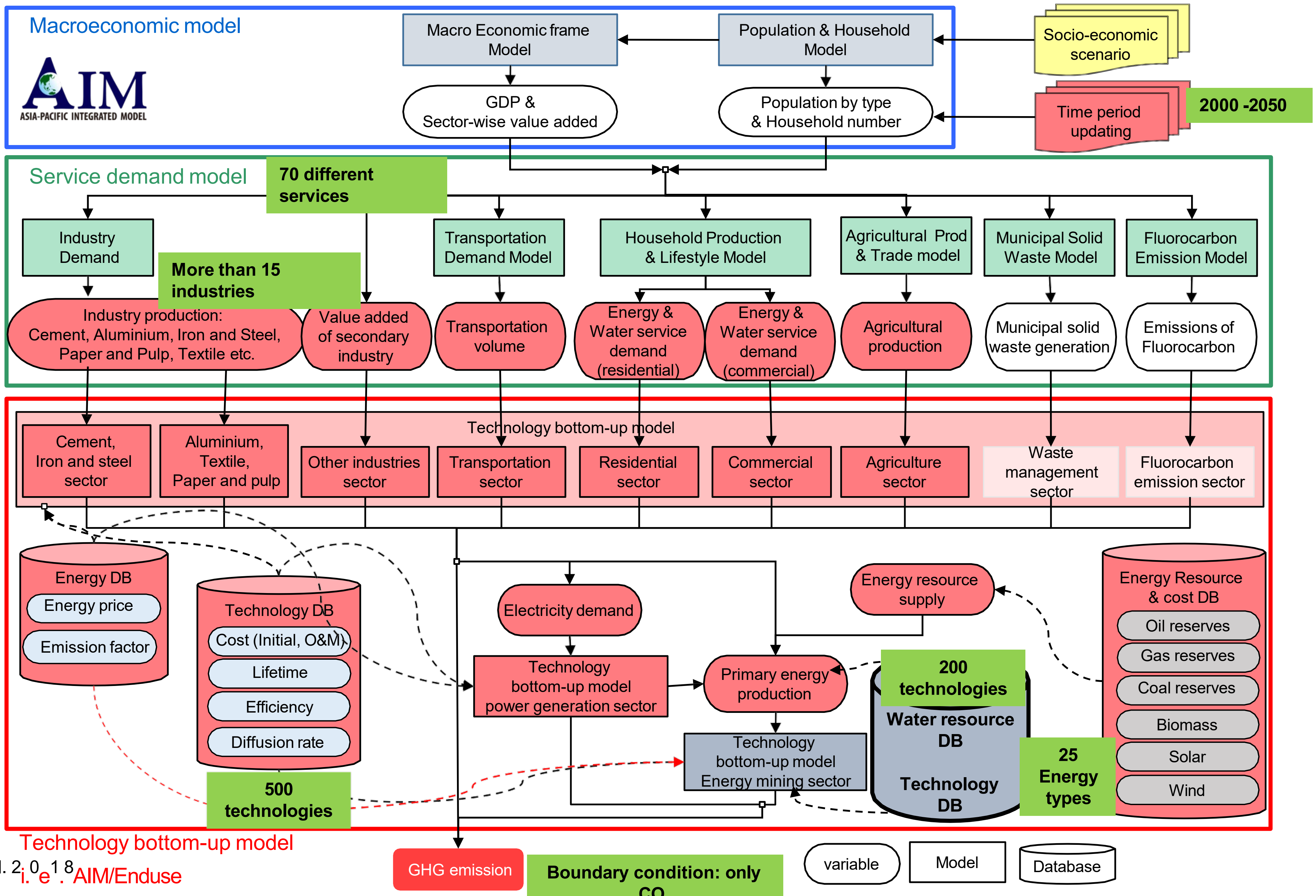
2. **Constraints**
   1. Demand Priorities
   2. Supply Preferences
   3. Mass Balance
   4. Other (like quality?)

AIM-End Use

1. **Objective Function**
   1. Minimize Total Cost

2. **Constraints**
   1. Service Demand
   2. Stock Dynamics
   3. Pollution quantity
   4. Max. limit of pollution
   5. Resource supply (max./min.)
   6. Device share (Max./min.)

AIM/Enduse model and element models



Source: Vishwanathan et al. 2018 i.e. AIM/Enduse

Water Supply and Demand

Temporal and Spatial

Global Circulation Models
CC5M4, GFDL-ESM2M, MRCC5, NoESMI (2)

Hydrological Models
Variable Infiltration Capacity (VIC)
NOAH (Land Surface Model)
Community Land Model (CLM)

Water Inflow (m3/s)

II. Plant level
Water Constraint
(region wise/state wise)

I. AIM-End Use
(Global, National, Sub-national)
Statistical Extrapolation -> Re

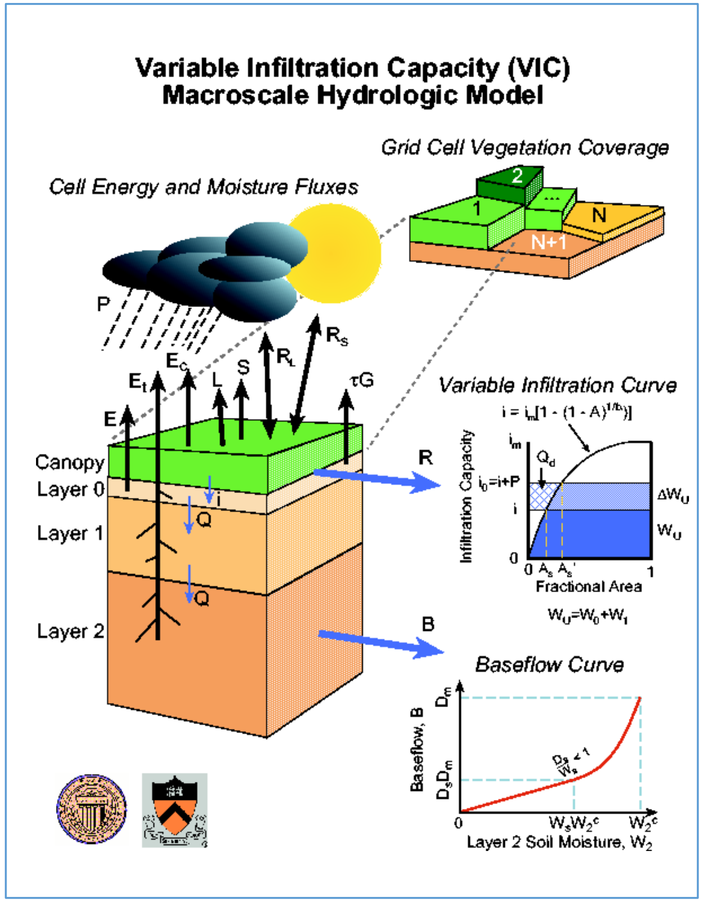
Ouput:
1. Water demand for thermal power plants
2. Energy Demand

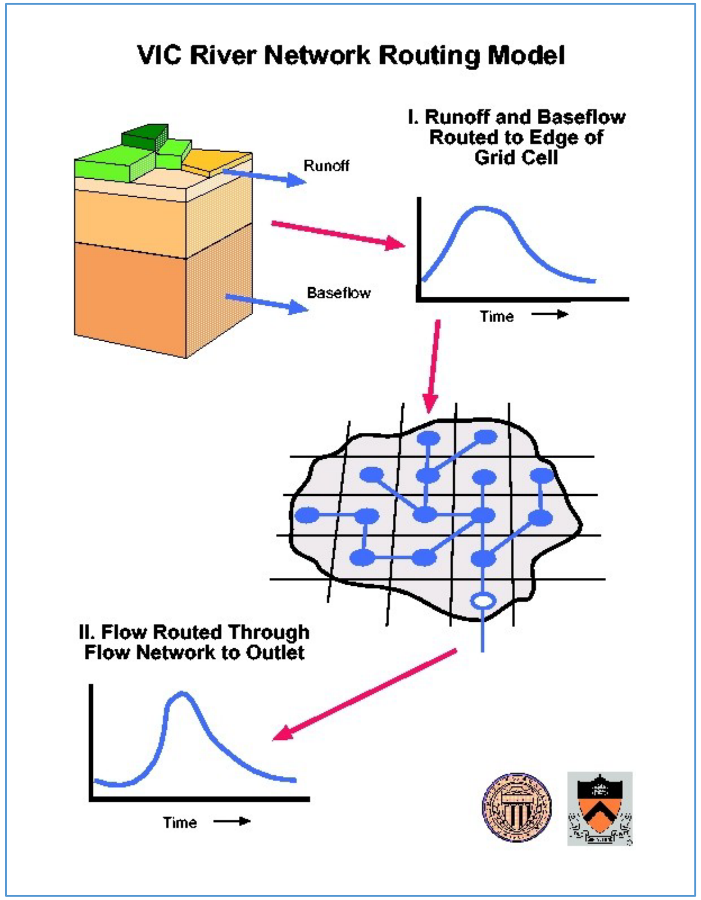
Under various scenarios
1. W/O Autonomous efficiency
2. Technology eff.
3. Cooling system
4. Water constrained

Power Plant Secondary Literature and Database
Output:
1. Water use intensity M3/MWh
2. Generation (MWh) -> PJ
3. Capacity (GW)

Source: Vishwanathan et al. 2018

Climatic – Hydrological Models





Institute	Nation	Modeling Center	Model Name
BCC	China	Beijing Climate Center, China Meteorological Administration	BCC-CSm1.1
INM	Russia	Institute for Numerical Mathematics	INM-CM4
MPI-M	Germany	Max Planck Institute for Meteorology	MPI-ESM-LR
MRI	Japan	Meteorological Research Institute	MRI-CGCM3
NCC	Norway	Norwegian Climate Centre	NorESM1-M

Source: Vishwanathan et al. 2018

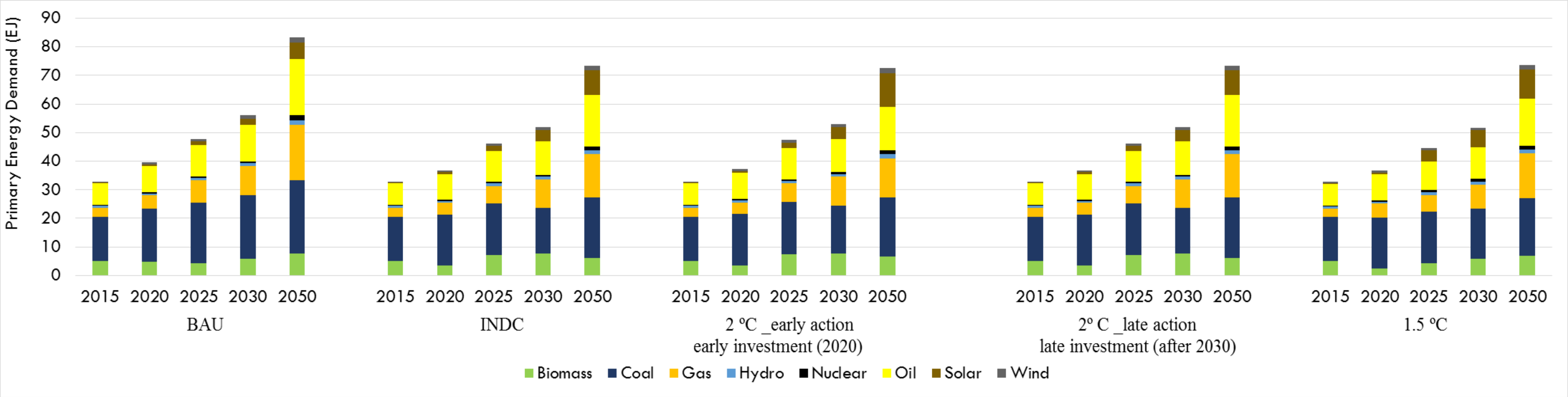
Scenario Development

	Scenarios	Comments
	I. Business as usual (BAU)	**20-25%** emission intensity of GDP during 2005-2020
A Energy Futures	**II. National determined contributions (INDC) (3- 3.5 °C)**	**33-35%** emission intensity of GDP during 2005-2030, 40% non fossil-fuels, renewables limit
	III. 2 °C scenario	**Carbon budget : 115-130 Bt** CO_2 during 2011-2050
	IV. 1.5 °C scenario	**Carbon budget : Around 90-115** Bt CO_2
B. Water Futures	**II. National determined contributions (INDC) (3- 3.5 °C)**	**WUE: 20%,** 33-35% emission of GDP during 2005-2030, 40% non fossil-fuels
	III. 2 °C scenario	**WUE: 25%,** Carbon budget : 115-130 Bt CO_2 during 2011-2050
	IV. 1.5 °C scenario	**WUE: 30%,** Carbon budget : Around 90-115 Bt CO_2
C. Integrated Futures		**Water supply limit, coal and renewable limits, carbon budget**

Source: Vishwanathan et al. 2018

RESULTS

Primary Energy (Alternate futures)

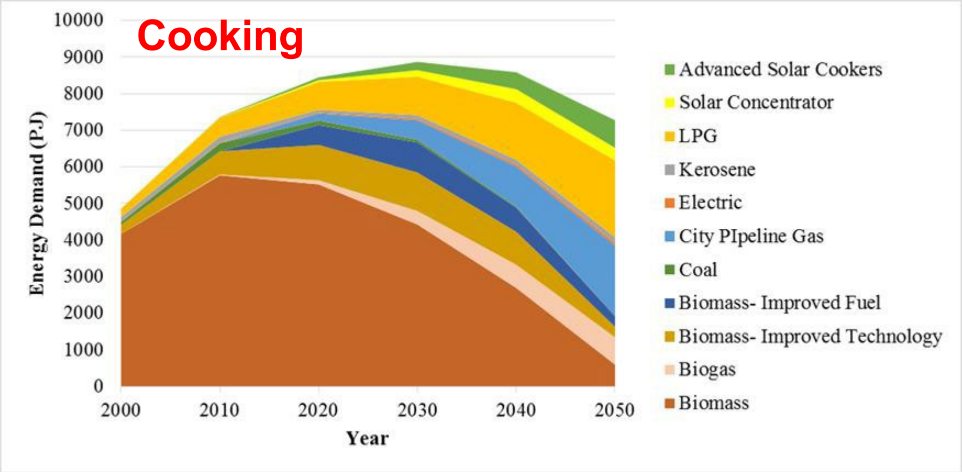


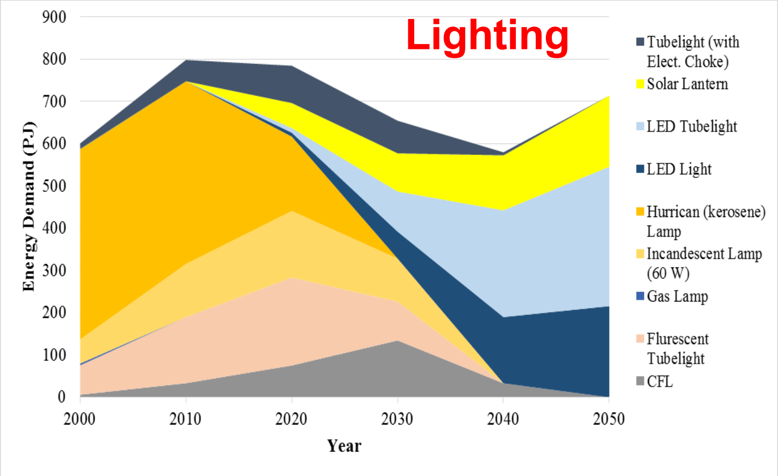
%	BAU			INDC		2 °C_early		2 °C_late		1.5 °C	
Year	**2015**	**30**	**50**	**30**	**50**	**30**	**50**	**30**	**50**	**30**	**50**
Biomass	15	15	10	15	9	15	9	15	9	12	9
Coal	48	41	31	31	29	32	29	31	29	34	28
Natural gas	10	19	24	20	21	20	19	20	21	16	22
Renewables	2	6	9	10	14	10	20	10	14	14	16

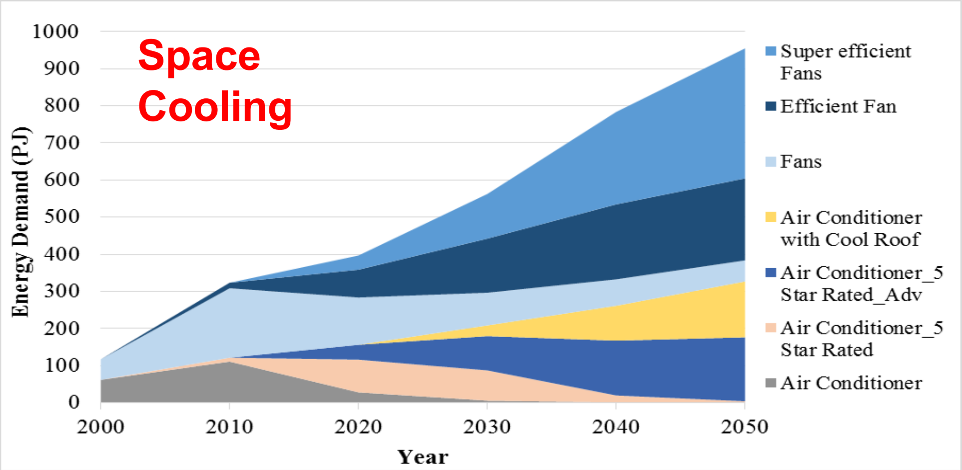
Coal dominates the energy-mix, including in low carbon scenarios
Share of **natural gas** increases in low carbon scenarios by 2050 – industry, transportation
Share of renewables increases in low carbon scenarios by 2050– power, buildings

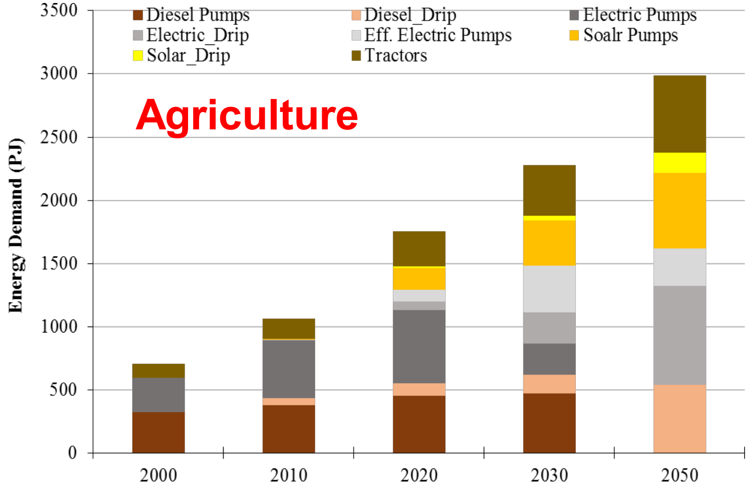
Source: Vishwanathan et al. 2018

Technology Transitions (Buildings, Agriculture)









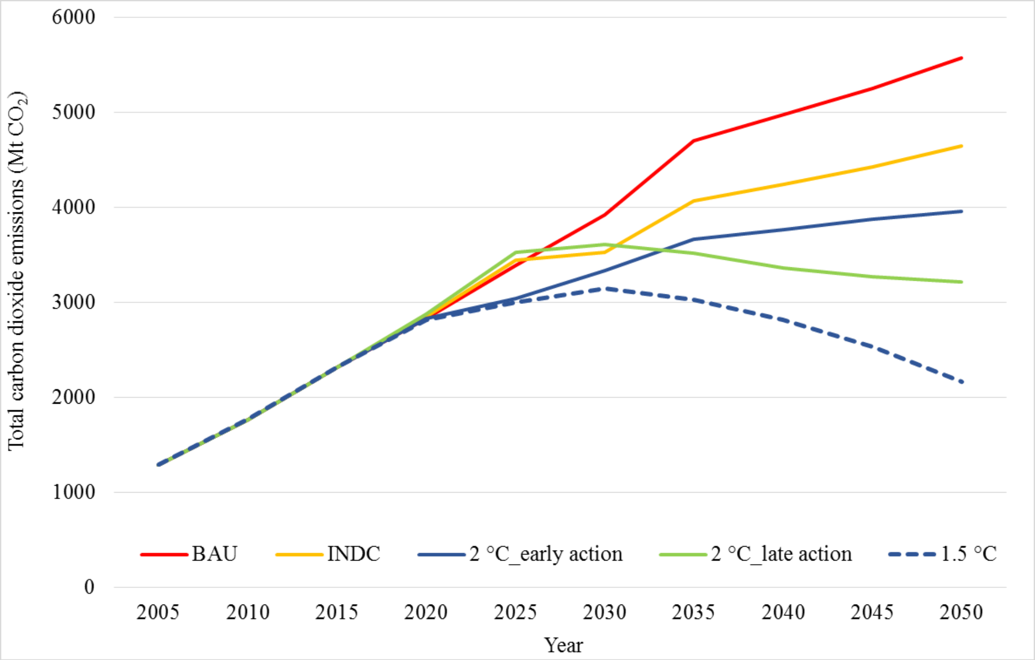
- **Continuous and Dynamic processes, High Impact Opportunities change over time**
- **Buildings**

Cooking: Technology substitution (Biomass to more eff. fuel and technology), Fuel switch (biomass to LPG, PNG, electricity; **Lighting:** Shift to LED; **Space cooling**: Transition to EE ACs, ACs with cooled roof

Agriculture : Shift to EE diesel and electric pumps, solar pumps

Source: Vishwanathan et al. 2018

CO_2 Emissions



Scenario	Budget	CO2/capita (2050)
BAU	165	3.2
INDC	147	2.7
2 °C_early (early action)	136	2.3
2 °C_late (late action)	128	1.9
1.5 °C (well below 2 °C)	108	1.2

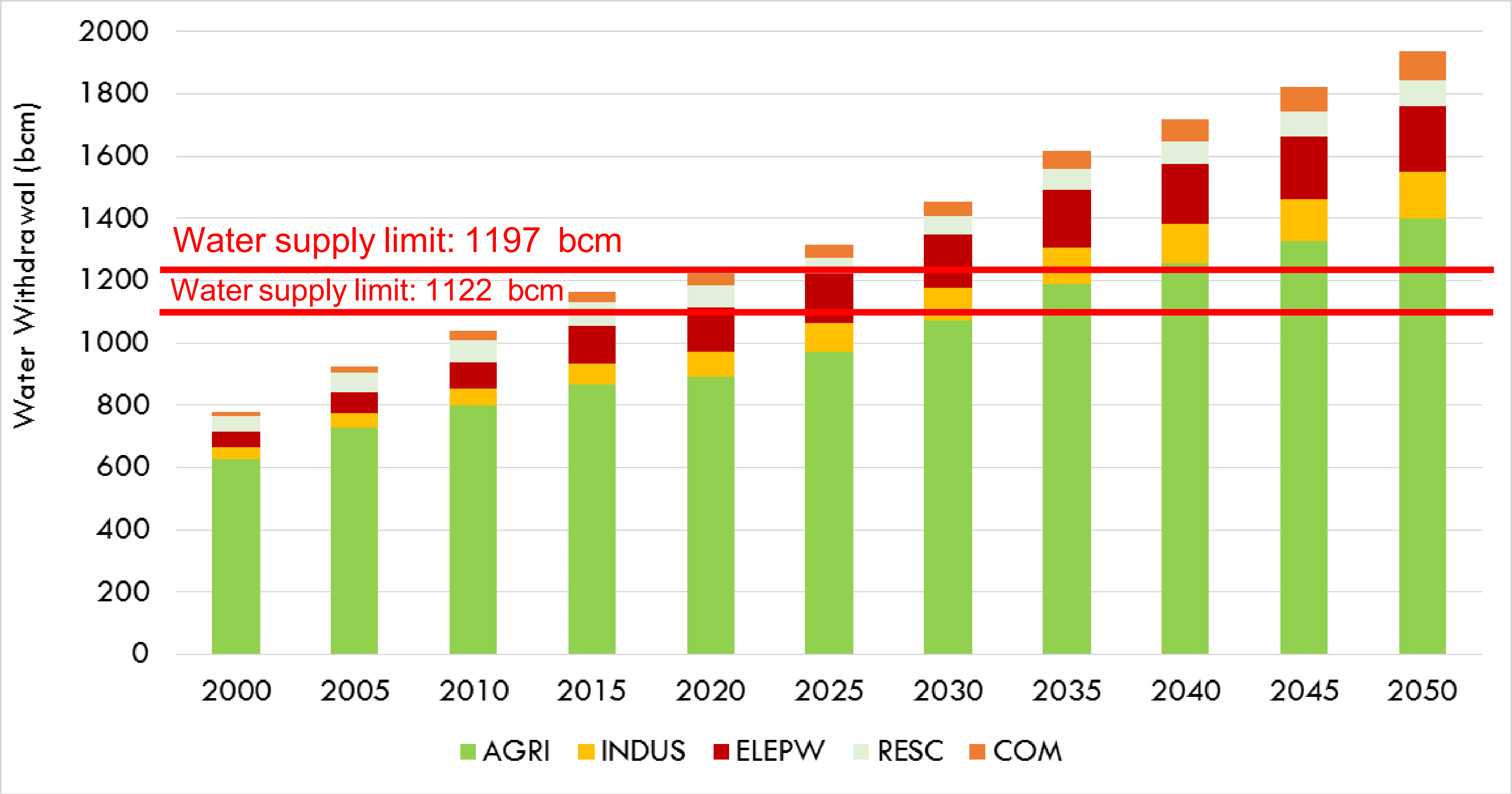
Note:
Carbon budget 2011-2050 in billion ton-CO_2

Scenarios	Bt-CO_2 (% reduction)	Energy Efficiency (bt-CO_2)	Renewables (bt-CO_2)	Demand Reduction (bt-CO_2)	CCS (bt-CO_2)
BAU to INDC	**18 (11%)**	10	7	1	0
INDC to 2 °C	**11-19 (8-13%)**	1-2	3-5	3-4	4-8
INDC to 1.5 °C	**39 (27%)**	4	6	6	23

Cumulative CO_2 budget: India needs room for development, results within higher range of global models.

Source: Vishwanathan et al. 2018

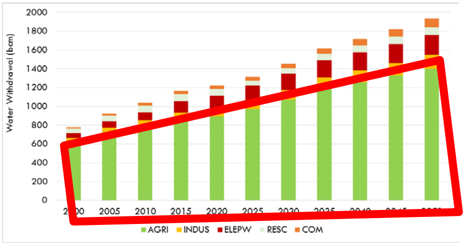
Water Demand – BAU

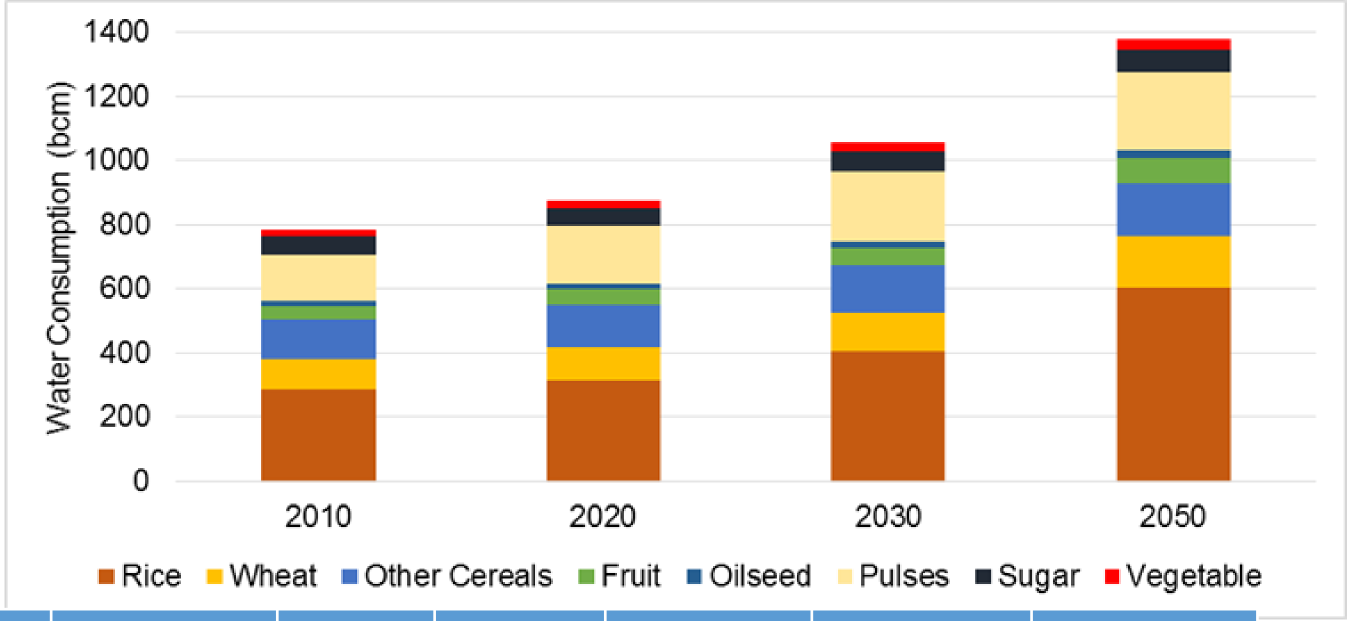


Water Supply Limit: 1122-1197 bcm (based on secondary literature).
Agriculture share is currently more than 70%.
Water demand exceeds supply by 2025, almost doubles during 2010-2050.

Source: Vishwanathan et al. 2018

Water in Agriculture - BAU





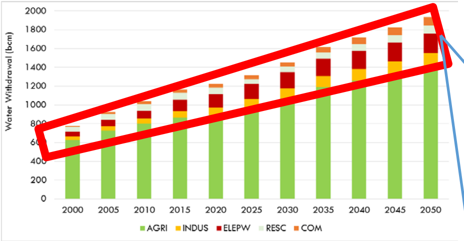
Year	Rice	Wheat	Other Cereals	Fruit	Oilseed	Pulses	Sugarcane	Vegetable
2010	2.99	1.07	2.90	0.78	0.33	4.48	0.16	0.18
2020	2.88	1.02	2.76	0.75	0.31	4.24	0.15	0.17
2030	2.95	1.05	2.84	0.73	0.31	4.39	0.16	0.18
2050	2.77	0.99	2.64	0.78	0.31	4.07	0.14	0.16

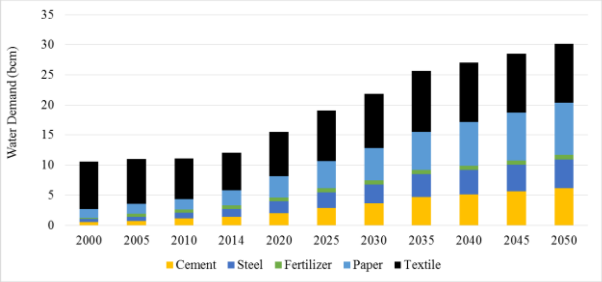
Unit: bcm/million tonne

Agriculture (major crop wise) and livestock water demand incorporated in energy model.
Largest share is occupied by rice followed by wheat and other cereals.
Some water scarce regions are also growing water intensive crops.

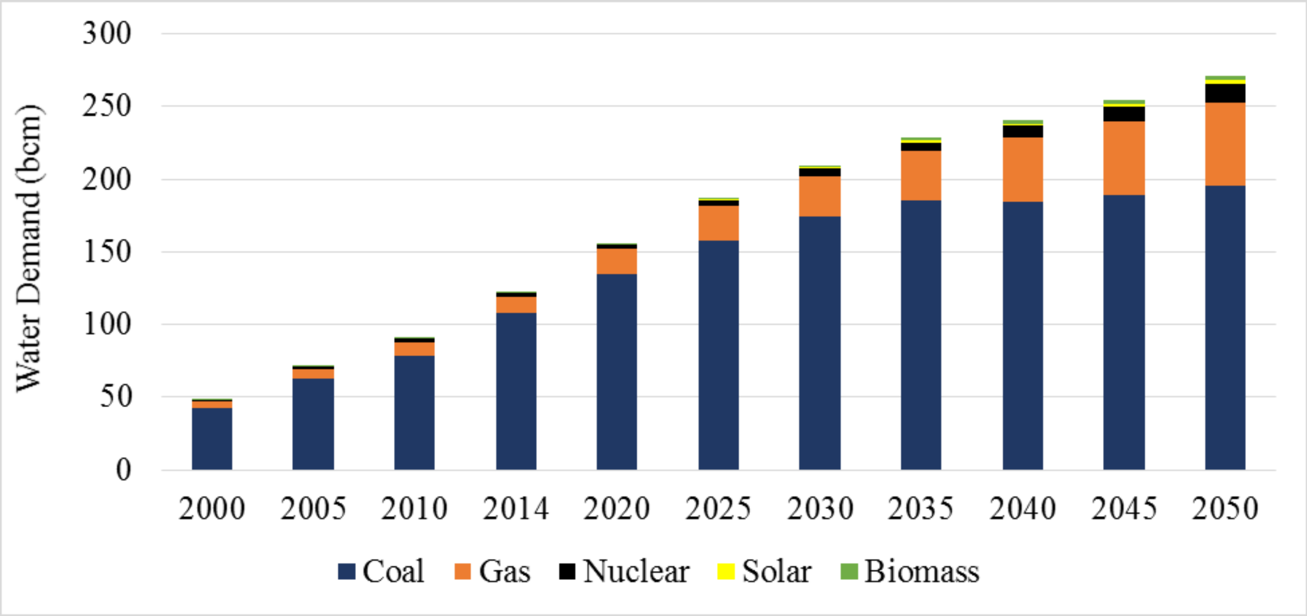
Source: Vishwanathan et al. 2018

Water in Industry - BAU





Industry



Power Sector

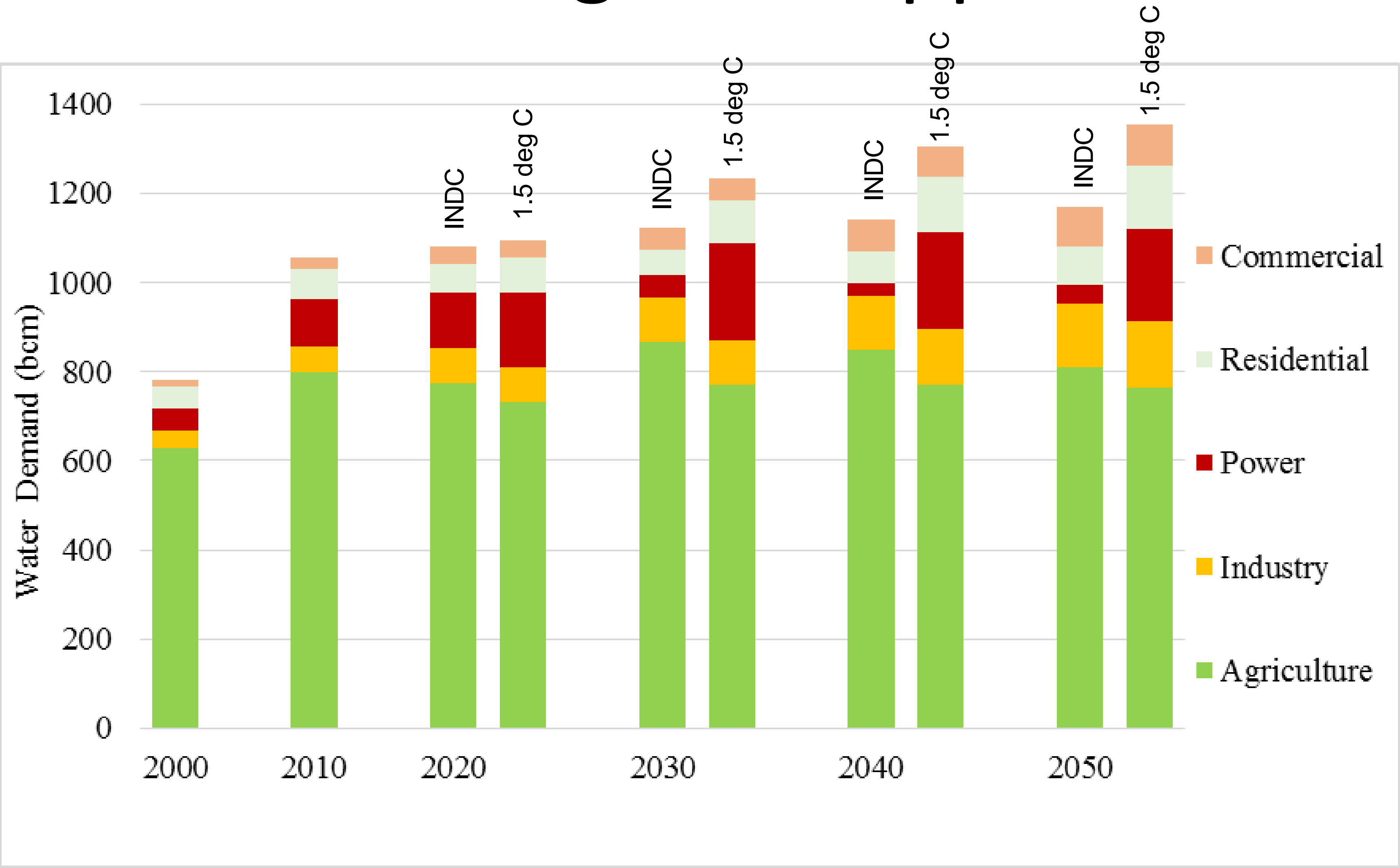
Decrease in share of water use per unit of product compared to 2010.

Year	Power	Steel	Fertilizer	Pulp Paper	Textile
2010	100	100	100	100	100
2020	98	100	100	96	83
2030	96	94	93	89	77
2050	91	88	87	83	58

Largest share is occupied by power followed by water intensive industries – textile, paper pulp

Source: Vishwanathan et al. 2018

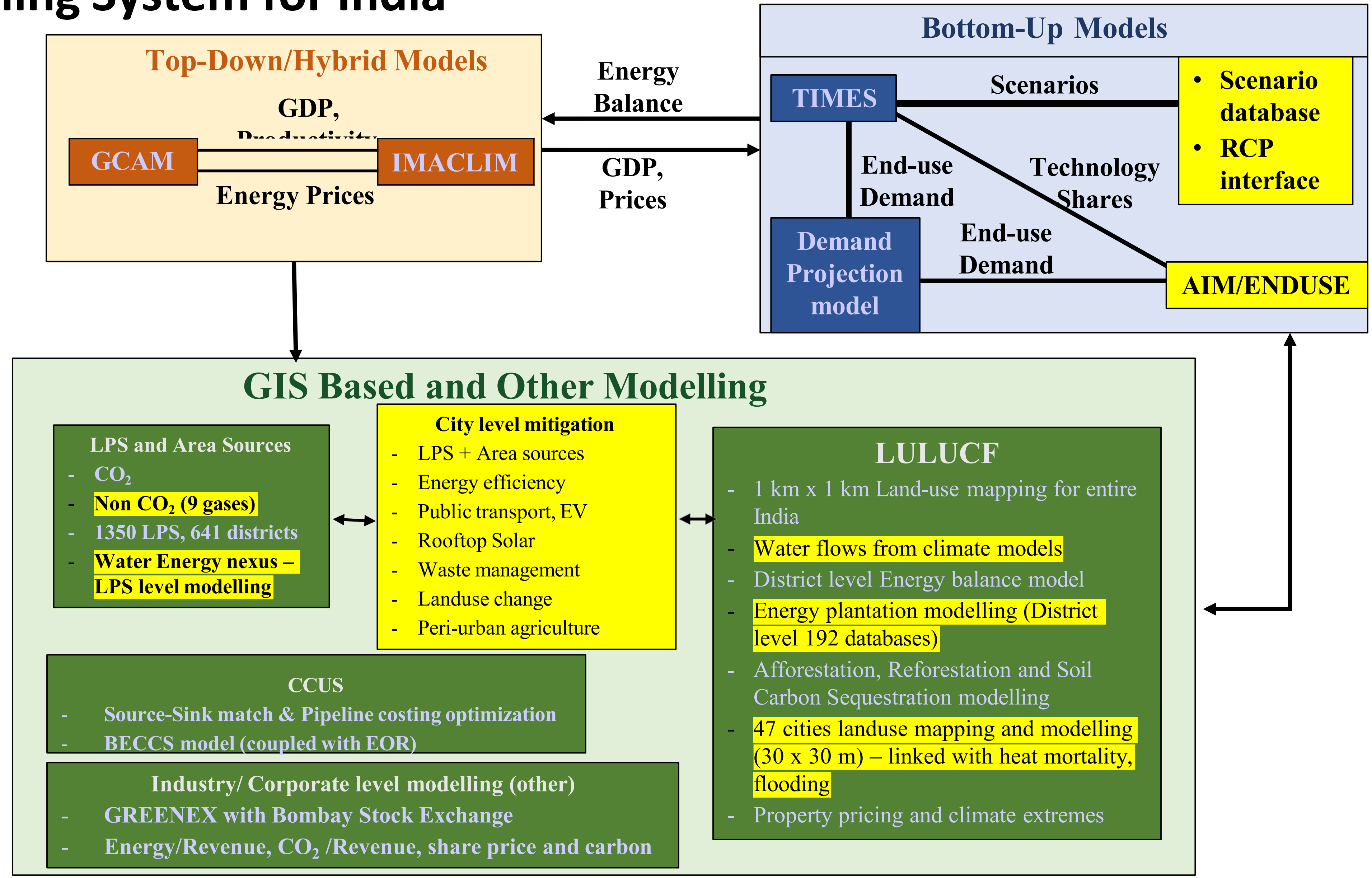
Demand: Integrated Approach



Agriculture sector takes a hit due to water constraint, which is followed by power sector
Shift to drip irrigation in agriculture sector
Dry cooling technologies in power sector due to water constraints in INDC
Water consumption increase in 1.5 deg C due to CCS

Source: Vishwanathan et al. 20

Soft Linked Top-down, Bottom-up, Hybrid and GIS modeling System for India



Source: Vishwanathan et al. 2018

What is required?

More national, subnational and local modelling

Stakeholder engagement to inform policy making

Looking into adaptation and impact assessments

Co-creation of scenarios for decision-making

Challenges

- Data Collection
  - National, Sub-national, Local
- Data Preparation
  - Activity data
  - Energy data
  - Water data
  - Cost data
- Soft-linking Bottom-up and Top-down
  - Data preparation

Thank You