Land Use Land Cover Change and the Integrated Economic-Environmental Modeling (IEEM) Framework

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SESSION OUTLINE

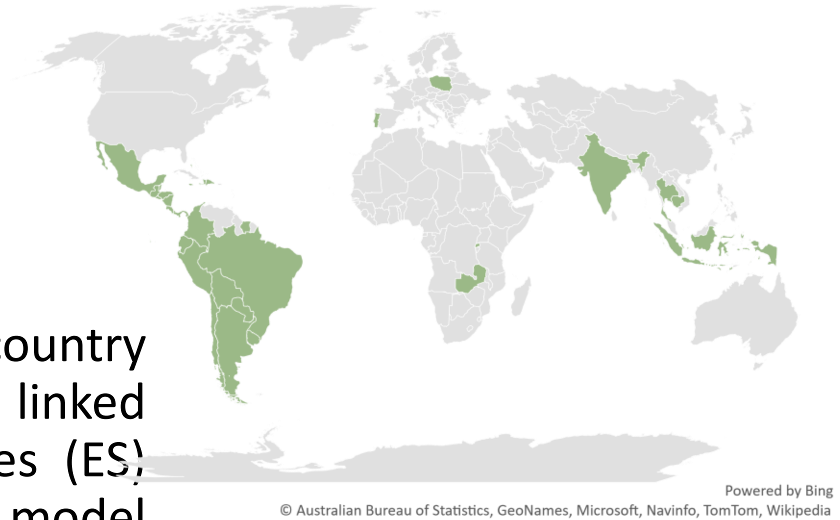
1. Overview of IEEM+ESM and Workflow.
2. Demonstrate the steps involved in implementing the dynamic IEEM+ESM approach- focus on land use and linkages between changes in ES and the economy.
3. Concluding remarks.

- Our goal is to demonstrate from a practical perspective how we link IEEM with LULC and ESM. This approach could be applied to MANAGE+ESM (India MANAGE+ESM Blueprint).

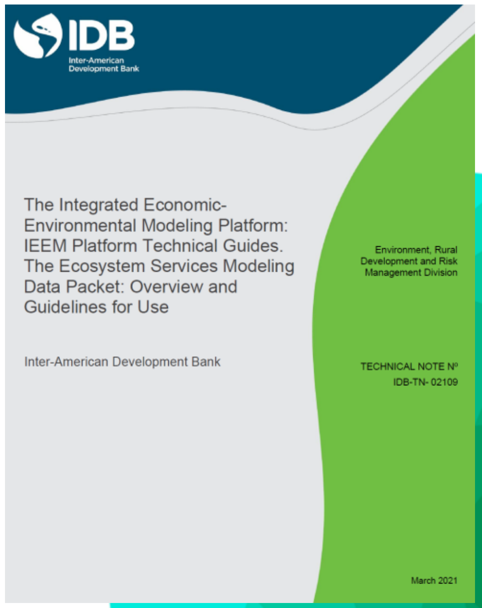
Note: Text highlighted/underlined in blue are responses to the key questions.

WHAT IS IEEM+ESM

- The Integrated Economic-Environmental Model (IEEM) is a single country recursive dynamic Computable General Equilibrium (CGE) model linked with spatial Land Use Land Cover (LULC) and Ecosystem Services (ES) models. Currently, we link IEEM with the Dyna-CLUE LULC change model and the InVEST suite of ES models.
- IEEM integrates the System of Environmental-Economic Accounting (SEEA) where data exists (provisioning ES in USD and quantities).
- Treatment of land in IEEM is flexible and can be endogenous or exogenous; decision depends on specific scenarios and country context.
- IEEM, Dyna-CLUE and InVEST models are open source, though a GAMS license is required to run IEEM. IEEM models and **ES datapackets** have been developed for over 30 countries; **Dyna-CLUE datapackets are in development. IEEM Excel interface- ISIM.**
- IEEM+ESM development has been driven by the aim of making the framework accessible and implementable by institutions of government, multilaterals (e.g. the IDB) and others. Capacity building has been integral.



IEEM+ESM countries identified in green.



WHY MODEL DEMAND FOR LAND (SPATIALLY)

1. Land is a factor of production like capital and labor. It is limited in supply and has a price. It can to a degree be substituted with increased capital, labor and other inputs (irrigation water, fertilizer, etc).

2. To understand policy impacts on regulating ES, we need to know future baseline and scenario demand for land and its spatial allocation (to enable ESM).

To link a CGE to LULC and ES modeling, treatment of land in a CGE must be able to model transition of land between alternative uses under 3 conditions:

(i) physical units of land are preserved; (ii) land is imperfectly mobile between sectors; and (iii) the extent to which land can move from use (or sector) A to use (or sector) B is not necessarily the same as the extent to which land can move from use B to use A.

WHEN DO(N'T) WE NEED SPATIAL LULC/ES MODELING?

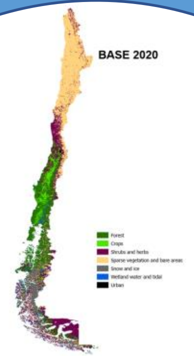
When change in ES is driven by LULC change or management practices. What are the feedbacks to the economy?

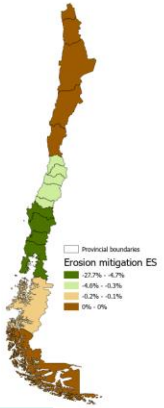
- Erosion mitigation and water purification ES: agricultural productivity; hydropower potential; water purification costs; human health; tourism; fisheries.
- Coastal protection ES: human settlement; lives/labor; infrastructure; land availability.
- Crop pollination ES: agricultural productivity; human nutrition; food security.
- Cultural and recreational ES: tourism demand.
- Climate change (CC) mitigation: where carbon taxes/markets exist, through incentives for maintaining forest cover/management.

When we may not need spatial LULC/ES modeling:

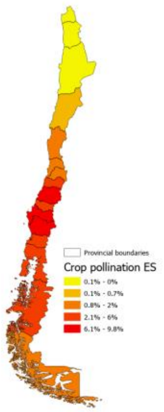
- Many CC impacts can be modeled without LULC change, with a damage function approach. Where individual country policy may not change outcomes (e.g. stopping deforestation in country x will reduce emissions, but not enough to individually affect sea-level rise), we may consider scenarios with/without global cooperation.
- For example, a damage function approach may be appropriate for modeling CC impacts on coastal zones via sea level rise, storm surge, coastal flooding; CC and temperature and precipitation; CC and other natural disasters (inland flooding, mass movement of land); Emissions and air quality.

THE DYNAMIC IEEM+ESM WORKFLOW





Policy question → Calibrate IEEM → Run BASE + scenarios in IEEM → Spatially allocate demand for land with LULC change model → Model ES with InVEST and IEEM+ESM data packets



- IEEM, the LULC change model and ES models are iterated to account for agent response to changes in future ES flows.
- All 3 models are iterated where demand for land is endogenous; LULC and ES models are iterated where demand is exogenous.
- In the process, an economic value estimate of regulating ES is generated consistent with a country's System of National Accounts.

LAND USE LAND COVER
IN
IEEM

IEEM AND ITS DATASET

- IEEM is a **single-country** recursive dynamic CGE model coded in GAMS
  - national as well as multi-regional (sub-national) variants
  - simplified multi-regional with national commodity markets
- The number of crop, livestock, and forestry sectors (activities/commodities) depends on the SAM that is used to calibrate the model.
- To calibrate IEEM, we build a national SAM using SUT and IEA (or gov budget and BoP) combined with
  - data on sub-national sectoral production (all/selected) to single out regions
  - data on production technologies to single out more than one activity producing the same product (e.g., cattle)
  - household surveys (to disaggregate labor and households)

IEEM AND ITS DATASET

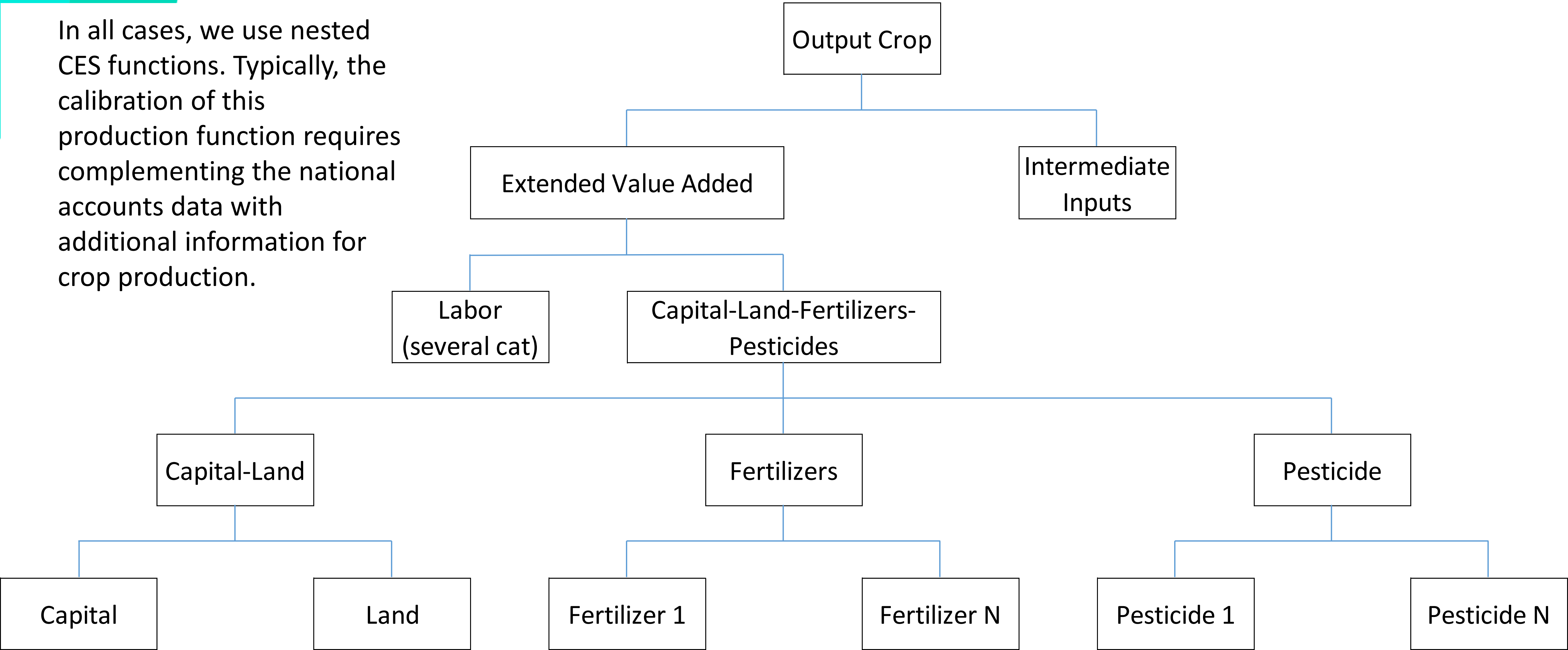
- The land use data (hectares) in IEEM consistent with land use data in spatially explicit LULC+ESM
  - if relevant, disaggregation by region
  - can consider AEZ if data is available
- Also, data on
  - sectoral employment by labor category
  - unemployment by labor category
  - population projections, by age groups (at least, total and labor force age)
  - emissions
  - elasticities
  - ….

LAND IN THE IEEM PRODUCTION FUNCTION

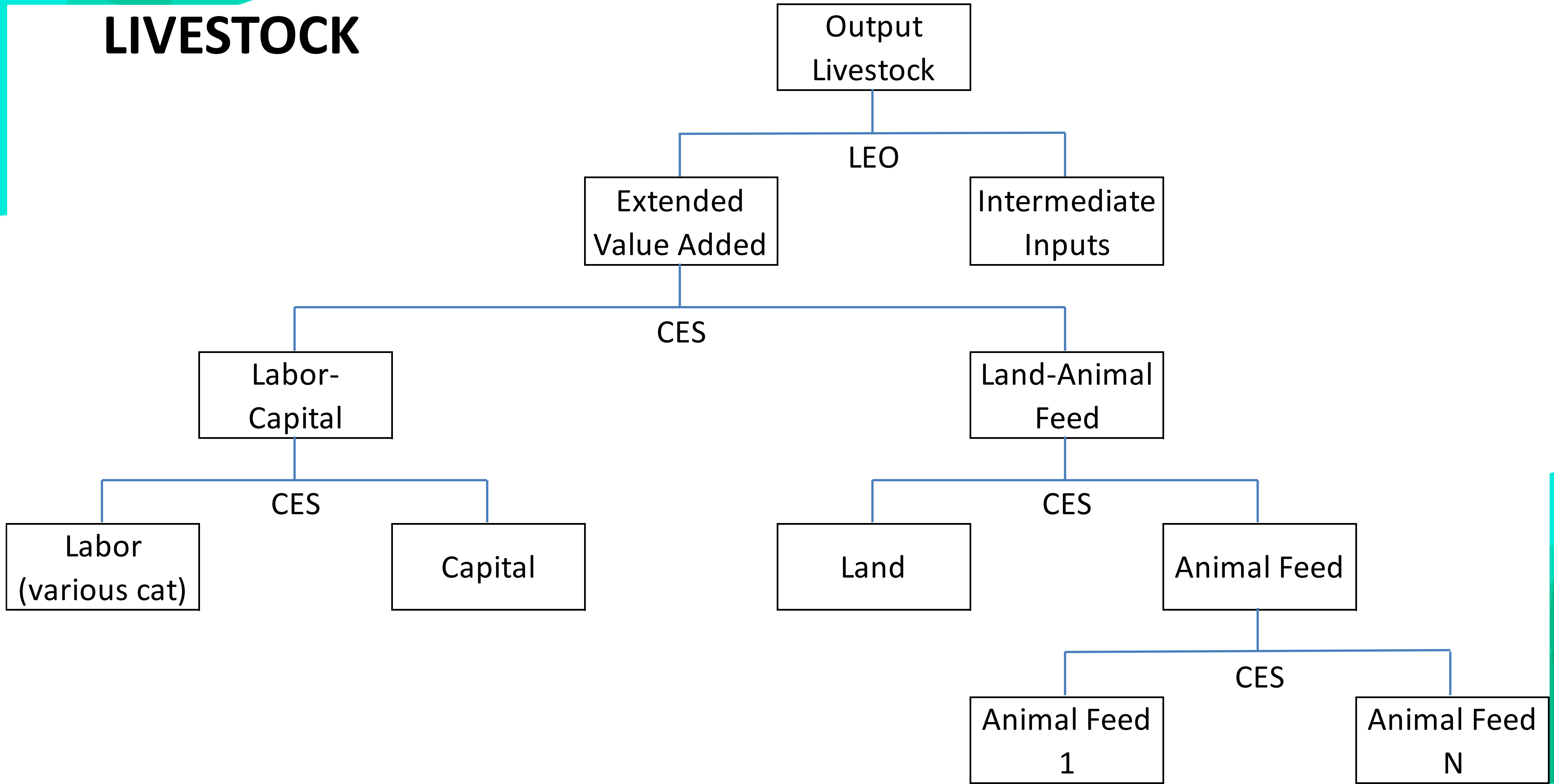
- Typically, land is an input (factor) into the production function of crops, livestock, and forestry → land demand function from sectoral production function.
  - land can be combined with selected intermediate inputs (e.g., fertilizers, animal feed, and/or water) -- nesting structure of production functions is fully flexible
  - nested CES production functions
  - in practice, sets and mappings defined in Excel allow defining nesting structure by activity

PRODUCTION FUNCTION: CROPS - FERTILIZERS AND PESTICIDES

In all cases, we use nested CES functions. Typically, the calibration of this production function requires complementing the national accounts data with additional information for crop production.

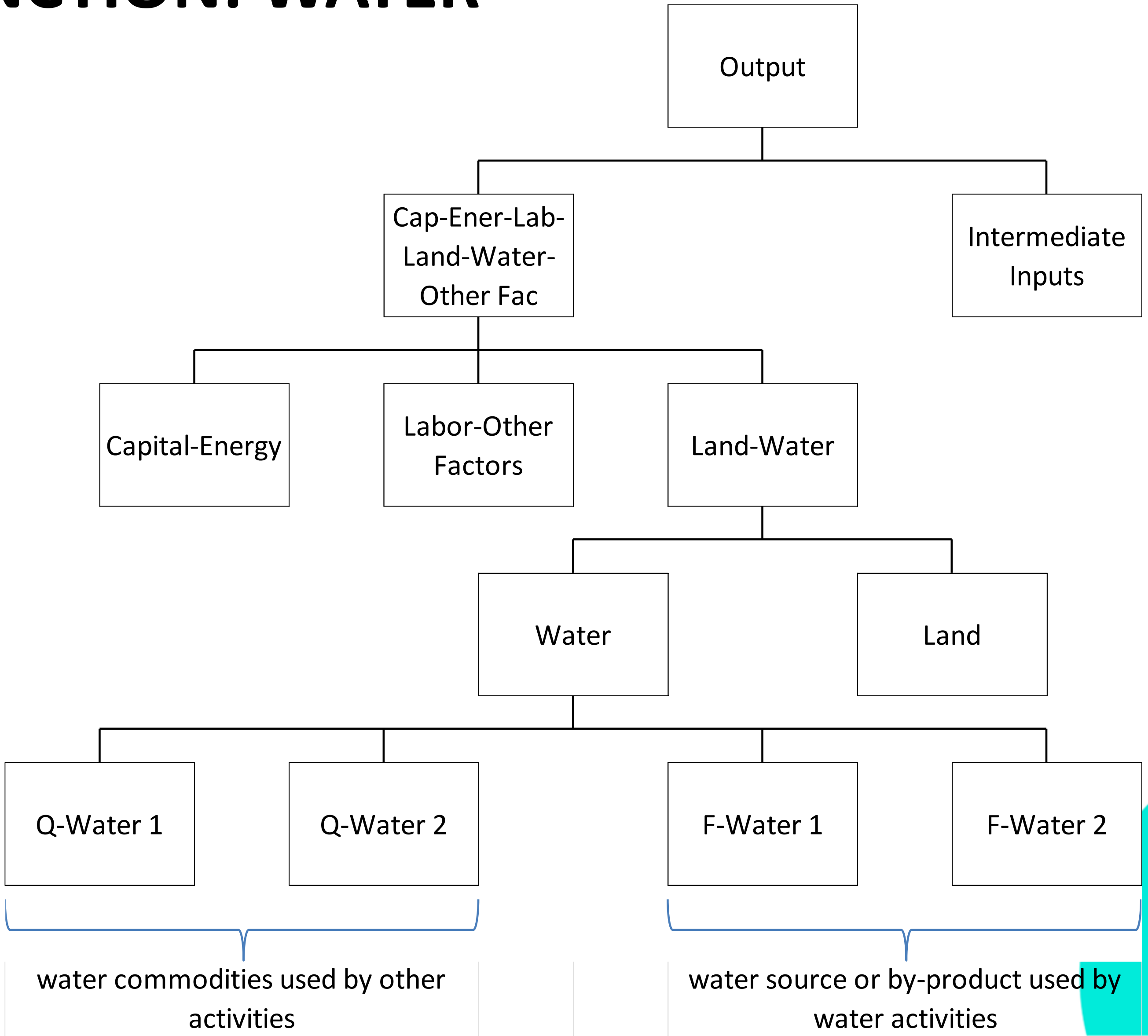


PRODUCTION FUNCTION: LIVESTOCK



PRODUCTION FUNCTION: WATER TREATMENT

In all cases, we use nested CES functions. It is necessary to single out the rent of the natural resource "water".



LAND MOVEMENT AND LAND SUPPLY

- IEEM allows for alternative treatments; in all cases, imperfect land mobility across activities
  - land (or factor) mobility functions
    - allow for an asymmetric response to incentives that promote land movements from activity A to activity B and from activity B to activity A
  - nested CET or additive-preserving ACET functions with flexible nesting
    - depends on data availability and assumptions
    - ACET = portfolio choice model
  - land conversion activities
    - an activity uses land type A as input into the production of land type B – 1 to 1 relation between land input and land output

LAND MOVEMENT AND LAND SUPPLY – CONT.

- The land supply to agriculture (crops and livestock) and forestry can depend on deforestation
  - deforestation as function of returns to land used in agriculture
  - deforested land can be used in crop and/or livestock production; depends on assumptions made
  - in any case, upper bound to agricultural land availability
    - e.g., $QLAND_{lnd,t} = qlandmax_{lnd} / \left(1 + \chi_f \cdot e^{-\gamma_f \cdot WLANDAVG_{lnd,t}}\right)$
- IEEM has a module for land use land cover accounting to keep track of
  - forest land not used as an input to production
  - cropland, grassland, and forest land used as an input to forestry production
  - other land categories (e.g., shrubland) also not used as an input into production
  - facilitates “handshake” with LULC+ES modeling

LAND MOVEMENT AND LAND SUPPLY – CONT.

- To link IEEM to LULC and ES modeling, we model transitions of land between alternative uses under three conditions:
  - (i) physical units of land (e.g., hectares) are preserved;
  - (ii) land is imperfectly mobile between sectors; and
  - (iii) the extent to which land can move from use (or sector) A to use (or sector) B is not necessarily the same as the extent to which land can move from use B to use A.
    - For instance, from a biophysical perspective, it is easier and more likely for forest to be converted to pasture than for pasture to be converted to forest; at least, this is what observation of historical LULC change shows.

LAND MOBILITY FUNCTIONS

$$WLANDRAT_{lnd,lnd\prime,t} = \frac{WLANDAVG_{lnd\prime,t}}{WLANDAVG_{lnd,t}}$$

$$QLANDMIGR_{lnd,lnd\prime,t} = QLANDINIT_{lnd,t}\left(\frac{WLANDRAT_{lnd,lnd\prime,t}}{WLANDRAT^{0}_{lnd,lnd',t}}\right)^{\eta^{migr}_{lnd,lnd\prime}} - QLANDINIT_{lnd,t}$$

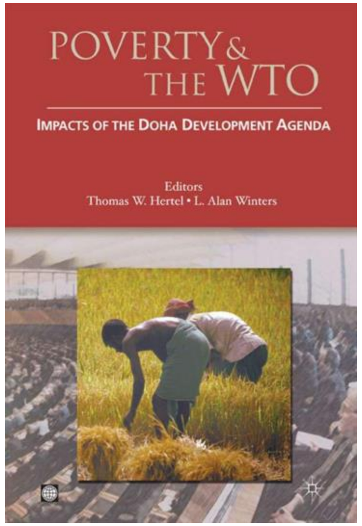
$$QLANDMIGR_{lnd,lnd\prime,t} \geq 0$$

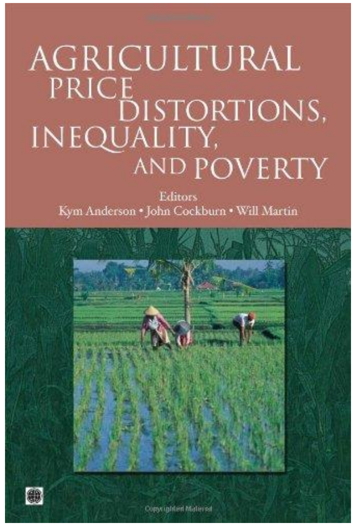
$$QLANDMIGR_{lnd,lnd,t} = QFINSINIT_{lnd,t} - \sum_{lnd\prime \in MFFP(LND,LND)} QLANDMIGR_{lnd,lnd\prime,t}$$

$$QLAND_{lnd,t} = \sum_{lnd\prime \in MFFP(LND,LND)} QLANDMIGR_{lnd\prime,lnd,t}$$

LINKING GLOBAL MODEL WITH NATIONAL MODEL

- The reason for a two-step approach is that a (single-country) national model is more complete and accurate in its representation of the focus economy.
- It's been done for assessing the impact of global trade liberalization → world prices linking variables between global model (GTAP/Linkage) and national models.
- In practice, single-country model better suited for **country-level** analysis of medium- and long-run development policies.

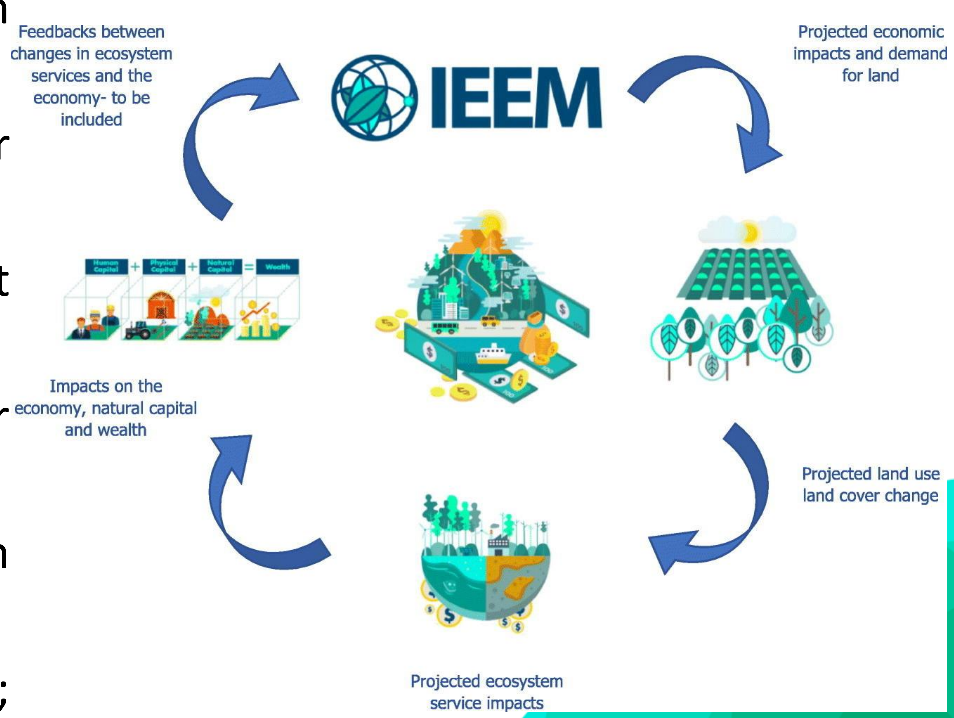




STEPS IN DYNAMIC IEEM+ESM IMPLEMENTATION; FOCUS ON LULC+ESM

STEPS IN DYNAMIC IEEM+ESM IMPLEMENTATION

1. Design and implement scenarios in IEEM. Run IEEM and validate results with stakeholders and client. There are few surprises with LULC+ESM results. Spatial modeling only once.
2. Once validated, run IEEM to generate a projection of demand for land for first period (5-years).
3. Spatially attribute demand for land with LULC model for first period.
4. Run InVEST ES model, for example, erosion mitigation ES model for baseline and scenario for years 1 and 5.
5. In Geographic Information System (GIS), calculate change in erosion between scenario and base in year 5.
6. Calculate erosion shock and implement in IEEM for next period; generate projection of demand for land for next period (years 6 to 10).
7. Return to step 2 and repeat for next period until reaching end of study time horizon.



LULC MODEL REQUIREMENTS FOR IEEM/MANAGE INTEGRATION

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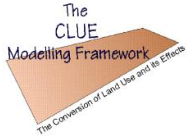
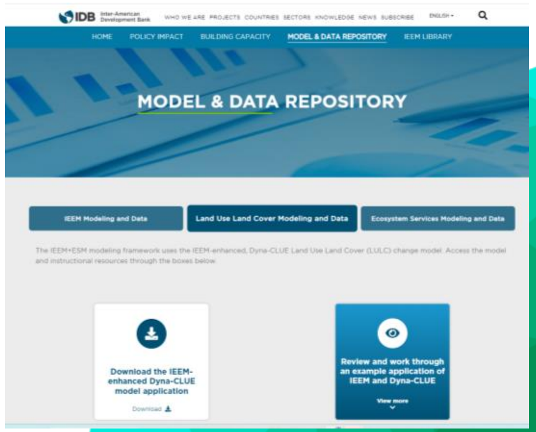
1. Can use IEEM projected demand for land as an input and handle multiple regions (spatially targeted policies).
2. Outputs as LULC rasters at adequate resolution for ES modeling.
3. Straightforward to format data and run, good error detection.

- We use the Dynamic Conversion of Land Use and its Effects (Dyna-CLUE) model.
- We have invested considerably in improving LULC change modeling for IEEM+ESM integration.
- **<u>IEEM-LULC Model beta version</u>**, funded by the IDB Inter-American Development Bank developed with C# using Windows Forms .Net 6 Microsoft technology. At least 20% faster, larger dimensional limit. RMGEO Consultants Inc. is currently testing and improving IEEM-LULC. Underlying theory follows Dyna-CLUE exactly.



The CLUE model
Article
More info and model.

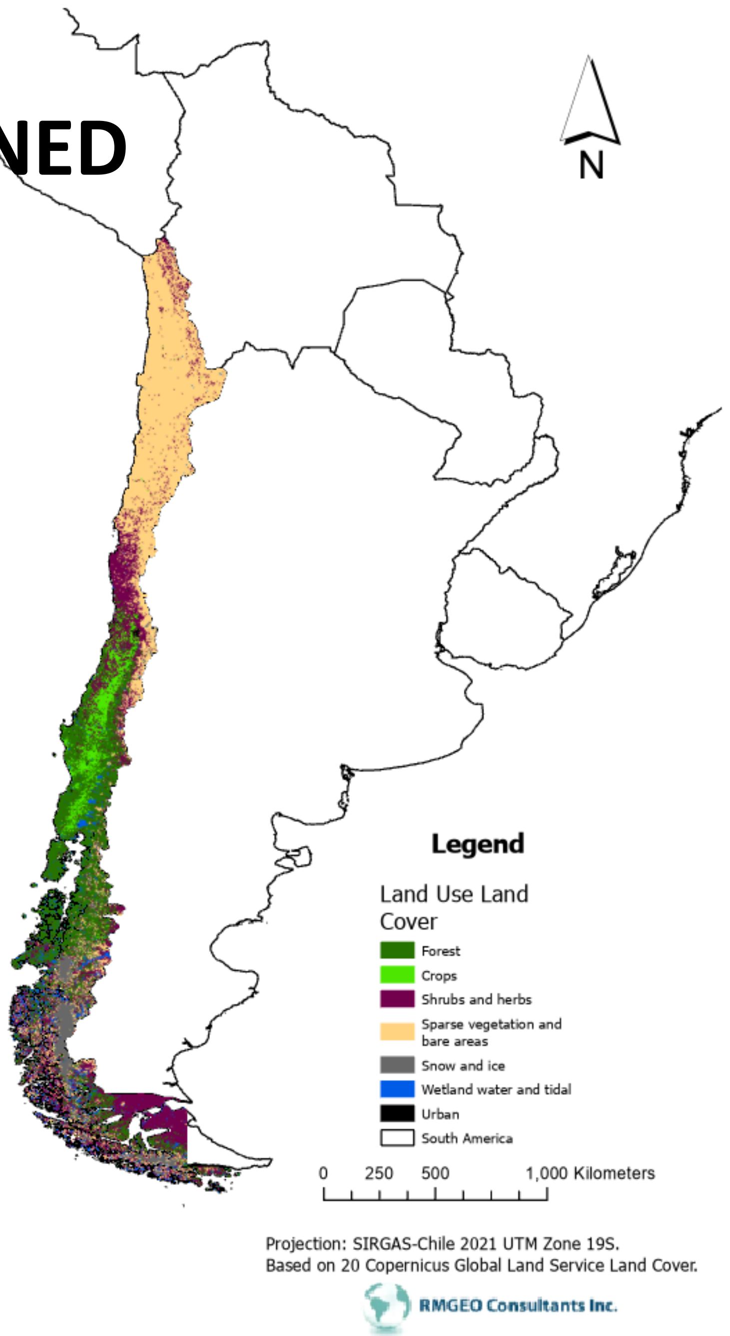
The CLUMondo land systems model
Article
More info and model.



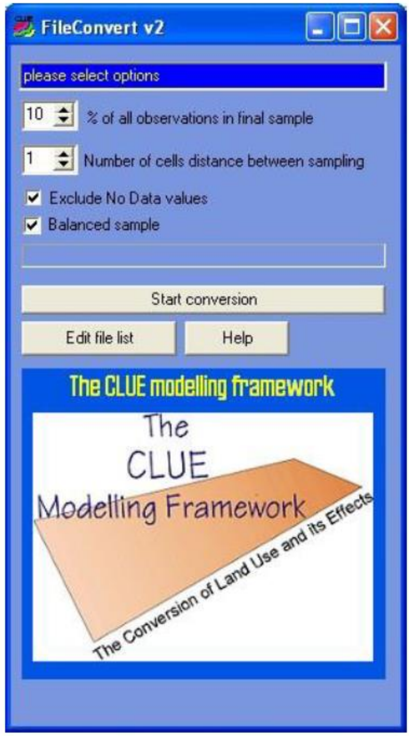
IEEM

EXAMPLE OF CHILE'S NATIONALLY DETERMINED CONTRIBUTIONS

- IEEM+ESM application to Chile's Nationally Determined Contributions; developed for Central Bank of Chile IEEM+ESM workshop, May 2023. Scenarios for reducing deforestation, afforestation and forest restoration; aligned with Government NDC Strategy.
- The base map is the starting point: Copernicus 2019 Global Land Service, 100m; 23 classes reclassified to 7.
- Level of LULC and regional aggregation depends on policy question.
- IEEM baseline uses LULC map initial areas (cross checked with census data); includes forest, crops and grassland.



STEPS IN PREPARING DYNA-CLUE MODEL INPUTS

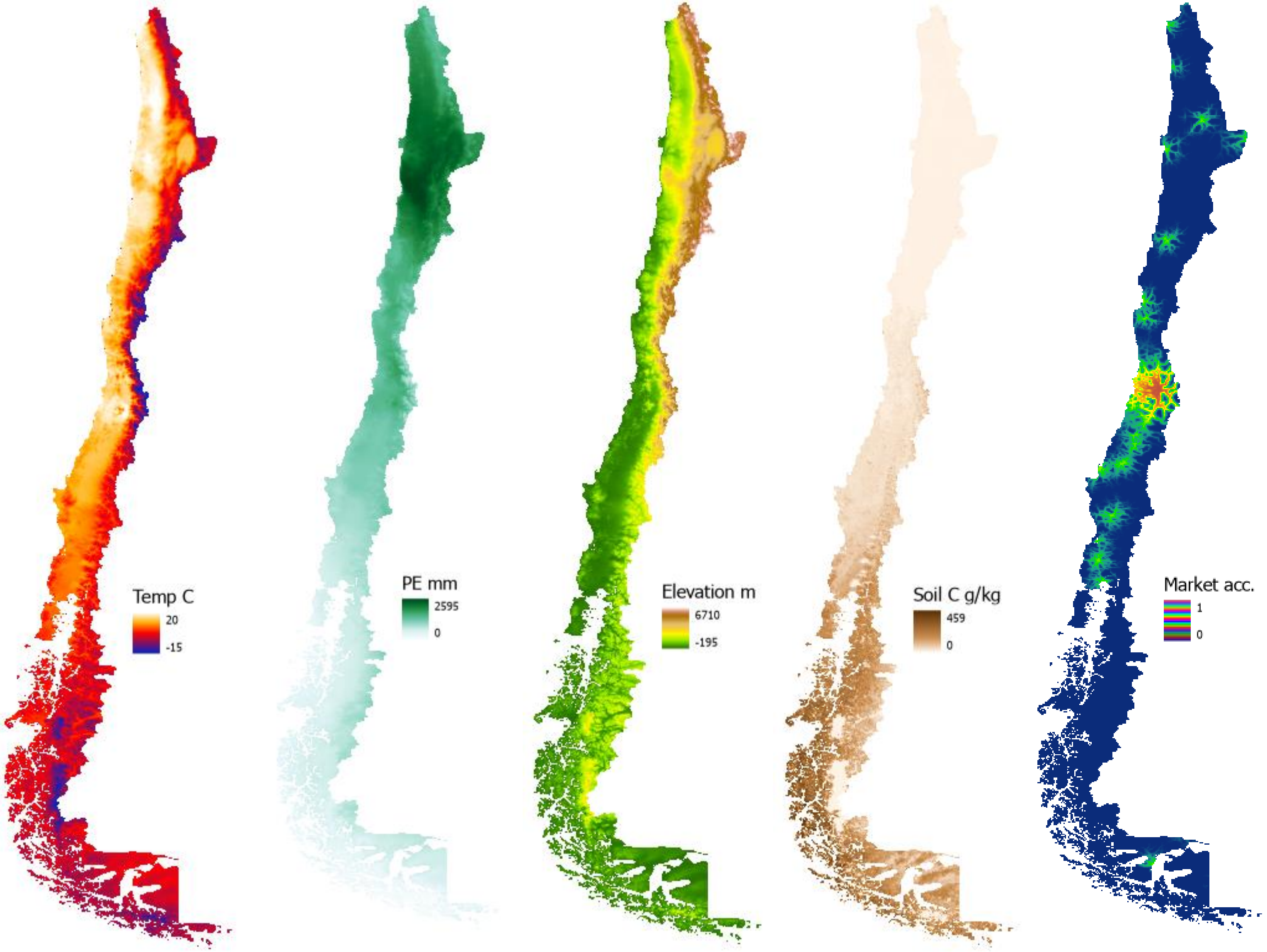


1. Create mask of area of interest: region file with exclusion (e.g. protected, sensitive) areas. Apply regional mask to all ascii spatial inputs to ensure same dimensions.
2. Create binary presence/absence LULC class maps.
3. Process driving factors spatial data (LULC Datapackets).
4. Use conversion tool to translate spatial data into a tabular format for import in statistical packages. One table for each binary LULC map and all drivers.
5. Run stepwise regression in statistical package (Stata, R, SPSS, etc.).
6. Prepare main file, allow, allocation and demand files.

Input preparation is highly demanding in terms of data and time. There are LARGE efficiency gains to be had by pre-assembling global datasets and developing GIS tools to assist in data processing. Can substitute global for local where available.

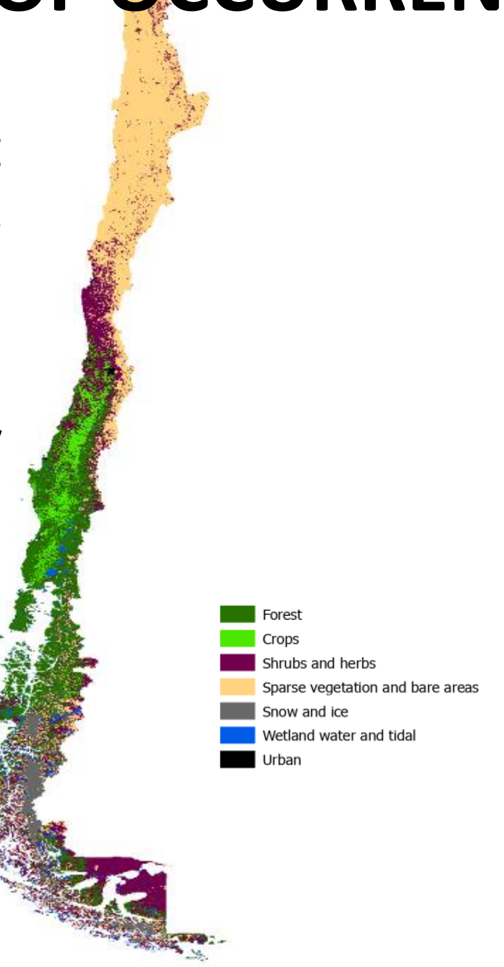
LULC DRIVING FACTORS

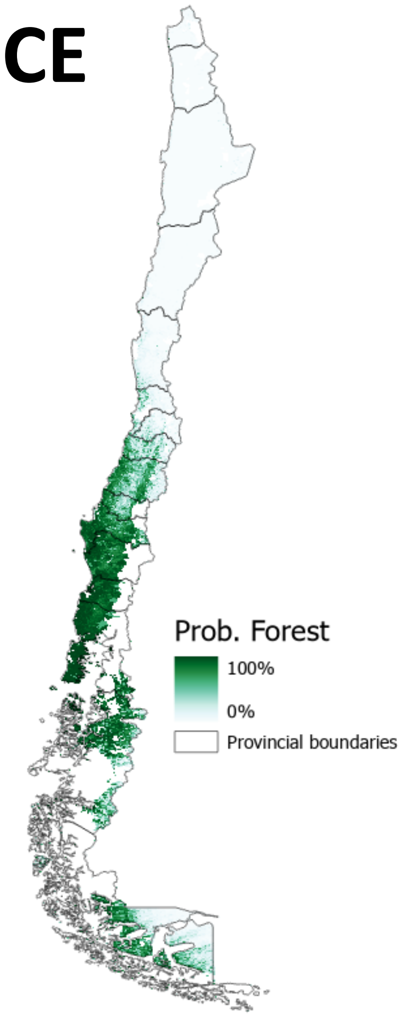
- 15 driving factors (climate, topography, soils, socioeconomic factors).
- LULC Datapacket; contains all spatial layers and an example application for rapid reuse.

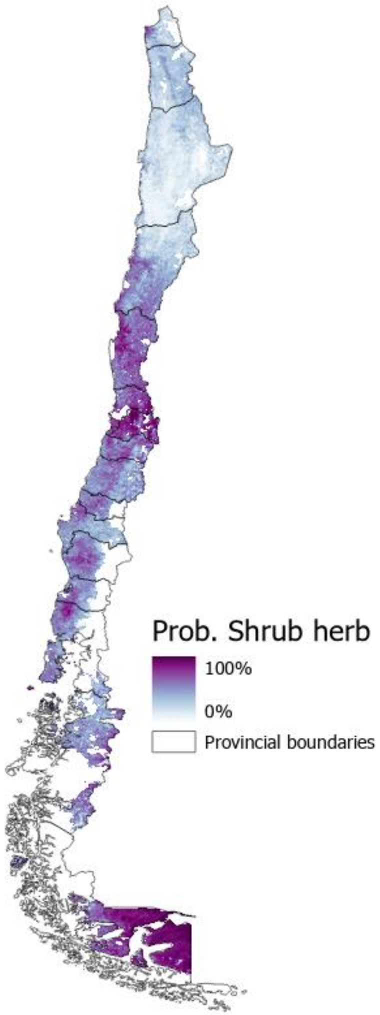


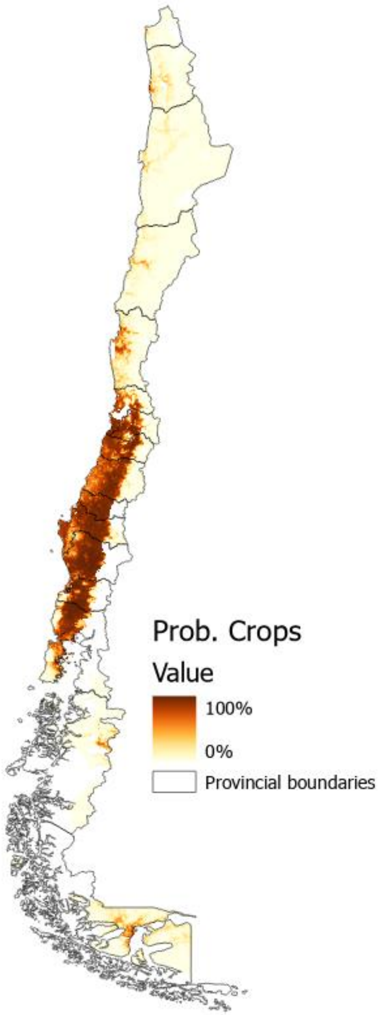
PROBABILITY OF OCCURRENCE

- Verify that probability maps are reasonable.
- Probability usually mostly aligned with current LULC.









DYNA-CLUE FILE PREPARATION

- Allow matrix.
- Allocation file (regression results).
- Main parameters file includes:

-dimensions of project, number of LULC classes, driving factors; conversion resistance; error terms, etc.

	FUTURE							
		Forest	Crops	Shrubs herb	Sparse veg	Snow and ice	Wetland, wate	Urban
PRESENT		0	1	2	3	4	5	6
Forest	0	1	1	0	0	0	0	0
Crops	1	0	1	0	0	0	0	0
Shrubs herb	2	1	0	1	0	0	0	0
Sparse veg	3	0	0	0	1	0	0	0
Snow and ice	4	0	0	0	0	1	0	0
Wetland, water	5	0	0	0	0	0	1	0
Urban	6	0	0	0	0	0	0	1

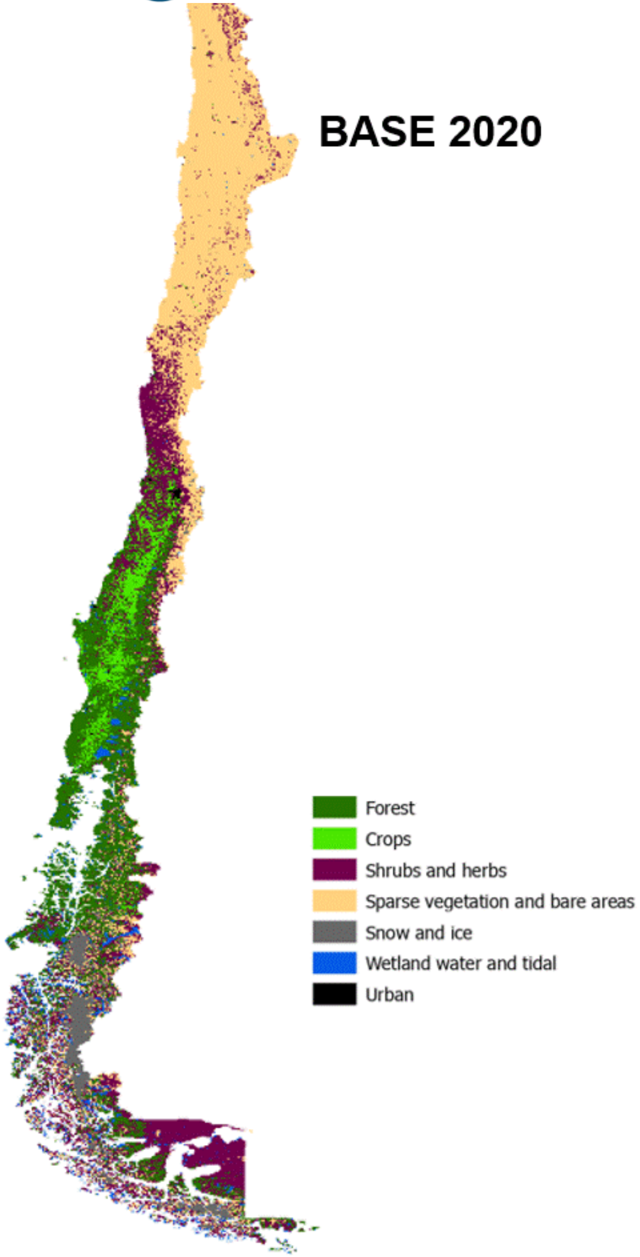
DEMAND FILE

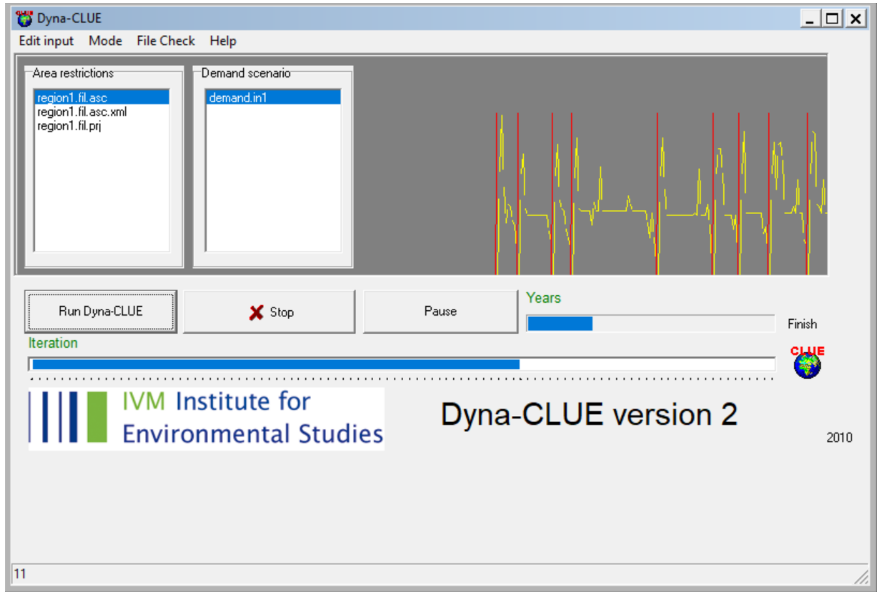
- Based on IEEM demand for land in the baseline and each scenario, prepare demand file.

BASE	Forest	Crops	Shrubs	Sparse veg	Snow/ice	Wet/water	Urban
	0	1	2	3	4	5	6
Years of simulation	31						
2020 Year 0	17,728,281	4,213,750	16,201,563	31,173,906	2,937,031	2,923,750	251,875
2021 Year 1	17,609,241	4,332,791	16,201,563	31,173,906	2,937,031	2,923,750	251,875
2022 Year 2	17,490,999	4,451,032	16,201,563	31,173,906	2,937,031	2,923,750	251,875
2023 Year 3	17,373,552	4,568,479	16,201,563	31,173,906	2,937,031	2,923,750	251,875
2024 Year 4	17,256,894	4,685,138	16,201,563	31,173,906	2,937,031	2,923,750	251,875
2025 Year 5	17,141,018	4,801,013	16,201,563	31,173,906	2,937,031	2,923,750	251,875
2026 Year 6	17,025,921	4,916,110	16,201,563	31,173,906	2,937,031	2,923,750	251,875
2027 Year 7	16,911,597	5,030,435	16,201,563	31,173,906	2,937,031	2,923,750	251,875
2028 Year 8	16,798,040	5,143,991	16,201,563	31,173,906	2,937,031	2,923,750	251,875
2029 Year 9	16,685,246	5,256,786	16,201,563	31,173,906	2,937,031	2,923,750	251,875
2030 Year 10	16,573,209	5,368,822	16,201,563	31,173,906	2,937,031	2,923,750	251,875
2031 Year 11	16,461,924	5,480,107	16,201,563	31,173,906	2,937,031	2,923,750	251,875
2032 Year 12	16,351,387	5,590,644	16,201,563	31,173,906	2,937,031	2,923,750	251,875
2033 Year 13	16,241,592	5,700,439	16,201,563	31,173,906	2,937,031	2,923,750	251,875
2034 Year 14	16,132,534	5,809,497	16,201,563	31,173,906	2,937,031	2,923,750	251,875
2035 Year 15	16,024,209	5,917,823	16,201,563	31,173,906	2,937,031	2,923,750	251,875
2036 Year 16	15,916,610	6,025,421	16,201,563	31,173,906	2,937,031	2,923,750	251,875
2037 Year 17	15,809,735	6,132,296	16,201,563	31,173,906	2,937,031	2,923,750	251,875
2038 Year 18	15,703,577	6,238,454	16,201,563	31,173,906	2,937,031	2,923,750	251,875
2039 Year 19	15,598,132	6,343,900	16,201,563	31,173,906	2,937,031	2,923,750	251,875
2040 Year 20	15,493,394	6,448,637	16,201,563	31,173,906	2,937,031	2,923,750	251,875
2041 Year 21	15,389,361	6,552,671	16,201,563	31,173,906	2,937,031	2,923,750	251,875
2042 Year 22	15,286,025	6,656,006	16,201,563	31,173,906	2,937,031	2,923,750	251,875
2043 Year 23	15,183,384	6,758,648	16,201,563	31,173,906	2,937,031	2,923,750	251,875
2044 Year 24	15,081,431	6,860,600	16,201,563	31,173,906	2,937,031	2,923,750	251,875
2045 Year 25	14,980,164	6,961,867	16,201,563	31,173,906	2,937,031	2,923,750	251,875
2046 Year 26	14,879,576	7,062,455	16,201,563	31,173,906	2,937,031	2,923,750	251,875
2047 Year 27	14,779,664	7,162,367	16,201,563	31,173,906	2,937,031	2,923,750	251,875
2048 Year 28	14,680,422	7,261,609	16,201,563	31,173,906	2,937,031	2,923,750	251,875
2049 Year 29	14,581,847	7,360,184	16,201,563	31,173,906	2,937,031	2,923,750	251,875
2050 Year 30	14,483,934	7,458,097	16,201,563	31,173,906	2,937,031	2,923,750	251,875
MODEL RUI	14490781.2	7454375	16198437.5	31173906.2	2937031.2	2923750	251875
DEVIATION BETWEEN DEMAND AND RESULT							
	0.05%	-0.05%	-0.02%	0.00%	0.00%	0.00%	0.00%

RUN DYNA-CLUE

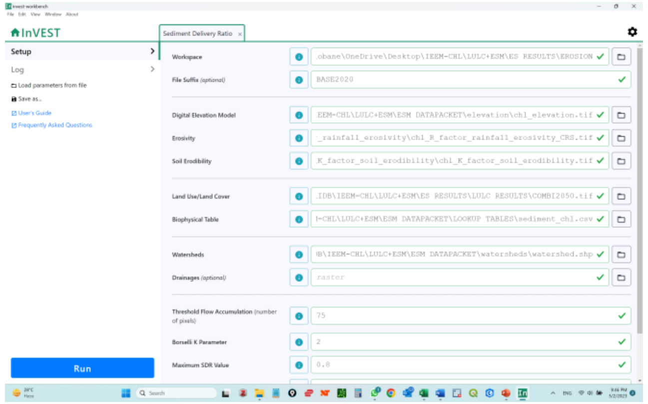
- Run baseline projection and scenarios.

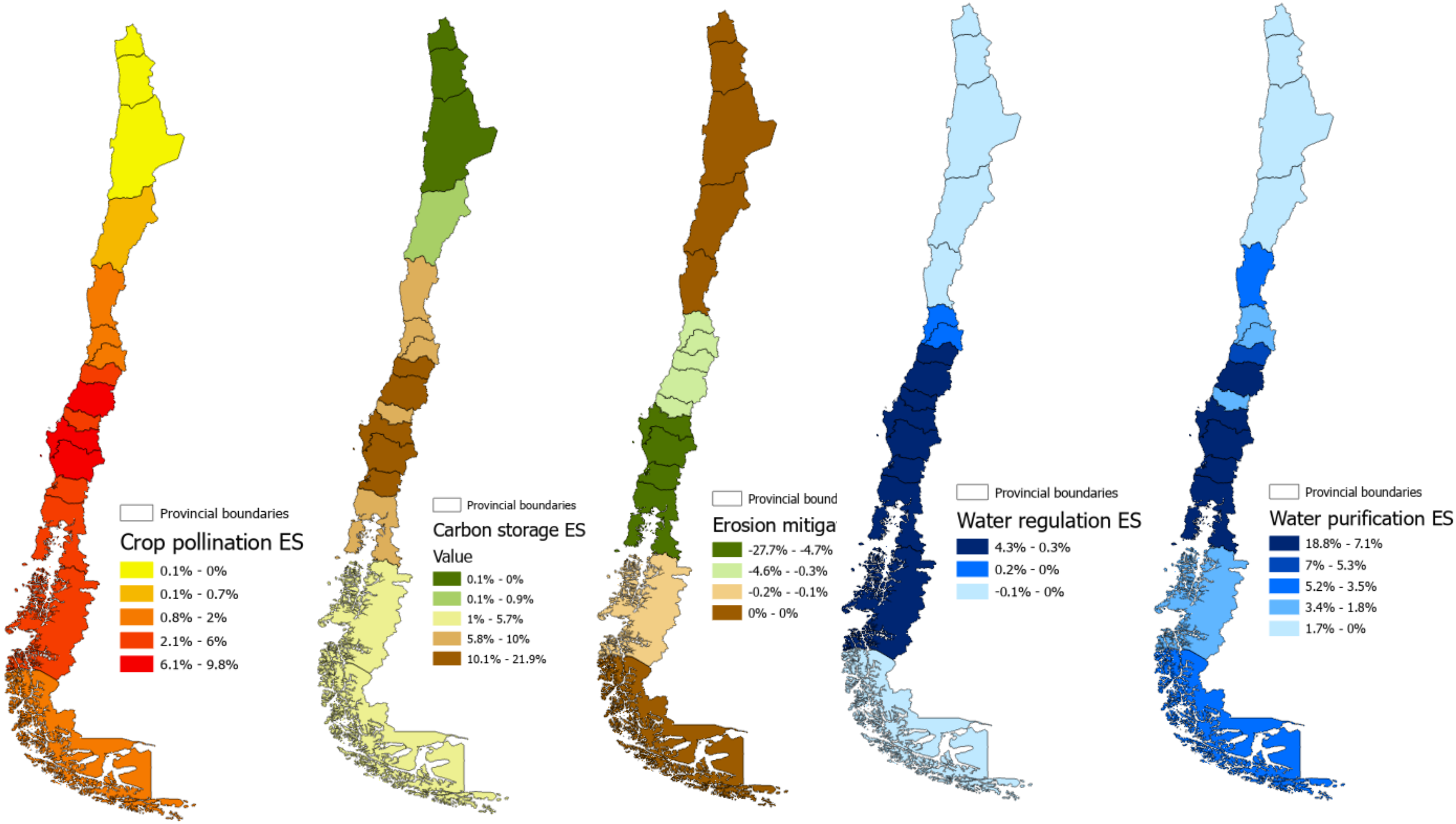




ES IMPACTS

- ES model runs based on Dyna-CLUE generated maps.
- Input preparation for some ES models is demanding. Efficiency gains via country Datapackets or pre-assembling global datasets and developing GIS tools to assist in data processing. Can substitute global for local where available.





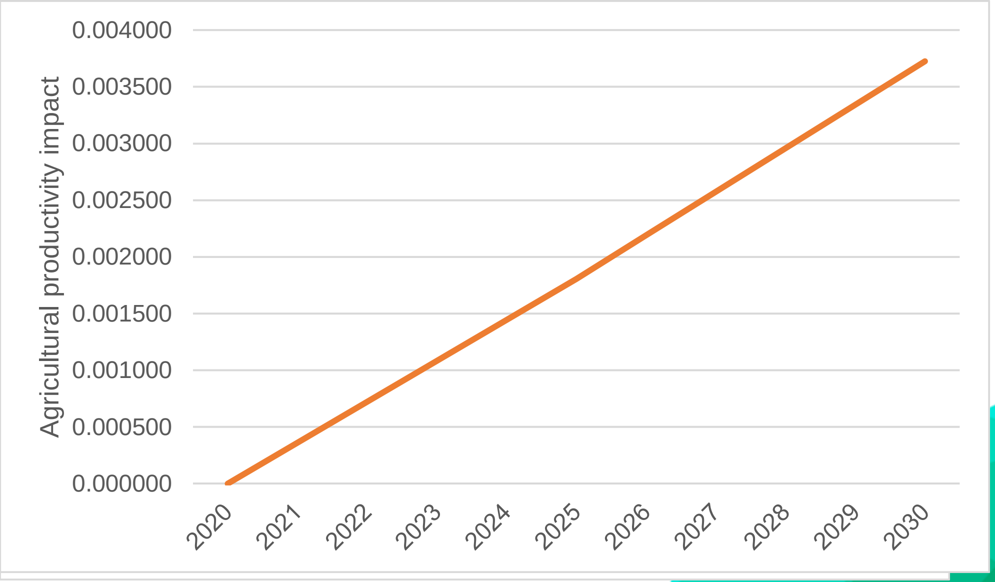
CALCULATING AND IMPLEMENTING THE ES PRODUCTIVITY SHOCK

	BASE20		BASE25	COMBI25		BASE30		COMBI30	
EROSION <> 11tons/ha	**<11**	**>11**	**<11**	**<11**	**>11**	**<11**	**>11**	**<11**	**>11**
National, in hectares	43,812,657	28,212,165	43471737	43566849	28457973	43126155	28898667	43322355	28702467

$$LPL_{rg} = \frac{SER_{rg}}{TAA_{rg}} \cdot 0.08$$

Where:

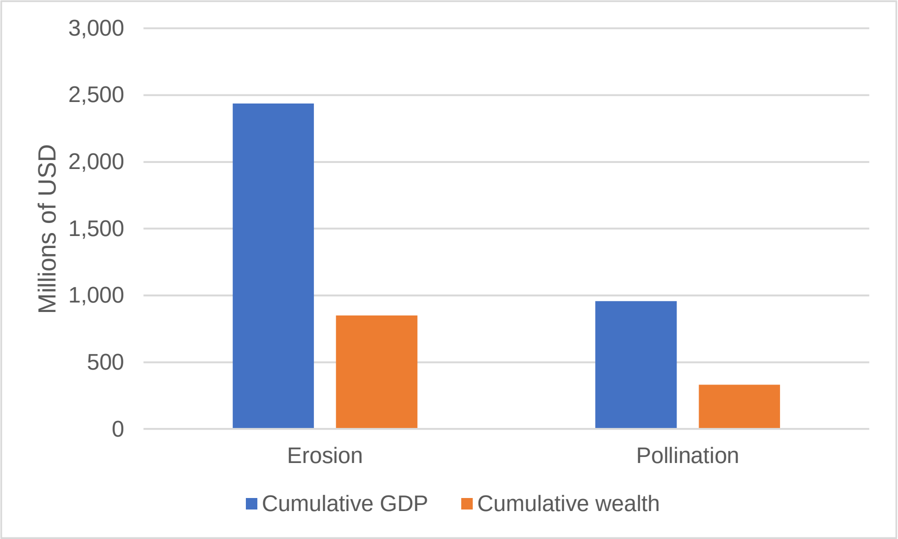
- LPL_{rg} is the land productivity loss by subscript *rg* region;
- SER_{rg} is the agricultural land area (hectares) subject to erosion >11t/ha/year in each region;
- TAA_{rg} is the total agricultural area, both crop and livestock, by region and;
- 0.08 is the agricultural productivity shock (meta-analysis of literature).



COMBI scenario	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Productivity Shock	0.0000	0.0004	0.0007	0.0011	0.0014	0.0018	0.0022	0.0026	0.0030	0.0033	0.0037

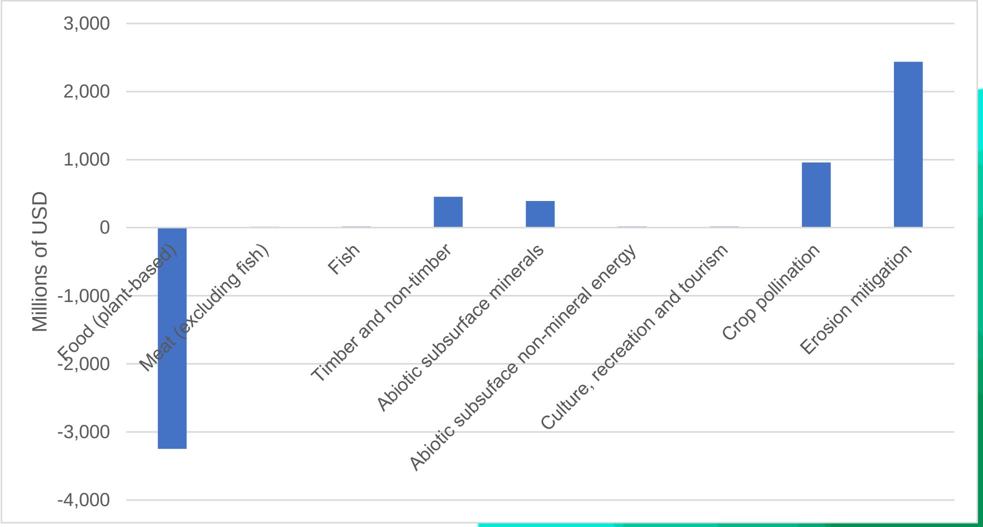
CHILE NDC EXAMPLE ES IMPACTS

- ES values calculated are consistent with country's System of National Accounts.
- Standard economic impacts, plus: wealth; distributional impacts; other ES and LULC change metrics.



Chile, NDC scenario impacts on ES in millions of USD.

ES Section	ES Class	Scenario				Code	
		REDEFOR	AFFOR	RESTORE	COMBI	CICES	IPBES
Provision ecosystem services							
	Food (plant-based)	-5,775	96	163	-3,248	1.1.1.1	12
	Meat (excluding fish)	13	2	2	14	1.1.3.1	12
	Fish	22	1	0	17	1.1.4.1	12
	Timber and non-timber	16	164	299	455	1.1.1.2, 1.1.5.1, 1.1.5.2	12, 13, 14
	Abiotic subsurface minerals	624	17	-12	391	4.3.1.3	
	Abiotic subsuface non-mineral energy	-4	5	8	18	4.3.2.2	
Cultural and recreational ecosystem services							
	Culture, recreation and tourism	-64	34	48	16	3.1.1.1	6, 16
Regulating ecosystem services							
	Crop pollination				958	2.2.2.1	2
	Erosion mitigation				2,436	2.2.1.1, 2.2.1.2	9



CONCLUDING REMARKS (all underlined in blue).

- We don't see a second-best solution. Instead, strategic planning and investment can reduce costs/time/effort required for each country application. OPEN IEEM is an example.
- Specifically, invest in: (i) making models and data readily available (open access models and datapackets); (ii) developing tools for processing data for ES and LULC modeling; (iii) tighter coupling between IEEM/MANAGE+LULC+ES; (iv) **identification and quantification of transmission pathways between changes in ES and the economy and development of heuristics for implementation;** (v) people: multi-disciplinarity is important to understand results from each modeling component, though deep disciplinary expertise is also required (collaborate).
- Time required to implement one country application and reporting can be as little as 1 week once scenarios are defined and models are parameterized. In the Chile application, with the Central Bank to define scenarios, we developed/implemented the application and structured a 4-day workshop around the IEEM+ESM implementation in about one month.
- Some model customization may be required depending on policy question.
- It is best practice, however, to have sufficient time for error detection, validating results with stakeholders, revising results, etc.
- Starting from 'scratch' for each new country application, the time and effort required is much greater.

Developing IEEM Modeling Infrastructure and Capacity Around the World.

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KEY QUESTIONS

1. Whether their model allows for endogenous land demand estimations and if so, how;
2. Whether there are any concerns regarding the macroeconomic model's ability to estimate endogenously land demand in a manner consistent with sector characteristics.
3. How land demand is linked with spatially explicit land allocation;
4. What happens if demand for land cannot be met due to physical constraints? What would be the response to this in the case of endogenous demand for land and exogenous demand for land?
5. How spatially explicit LULC allocations are linked with ES modeling
6. If a complete, iterative link between aggregate demand for land, spatially explicit allocation of that demand across the landscape and ecosystem services model, is not possible or is too time consuming, do experts recommend to use "second best" solution.
7. Data requirements/availability.
8. Average resource / time requirements.
9. Taking into account the time and resources costs of setting up the complete suite of tools for endogenizing land use change and spatializing it at a high level of resolution, what are the situations in which the benefits in terms of model robustness and of policy-relevant insights outweigh the costs?