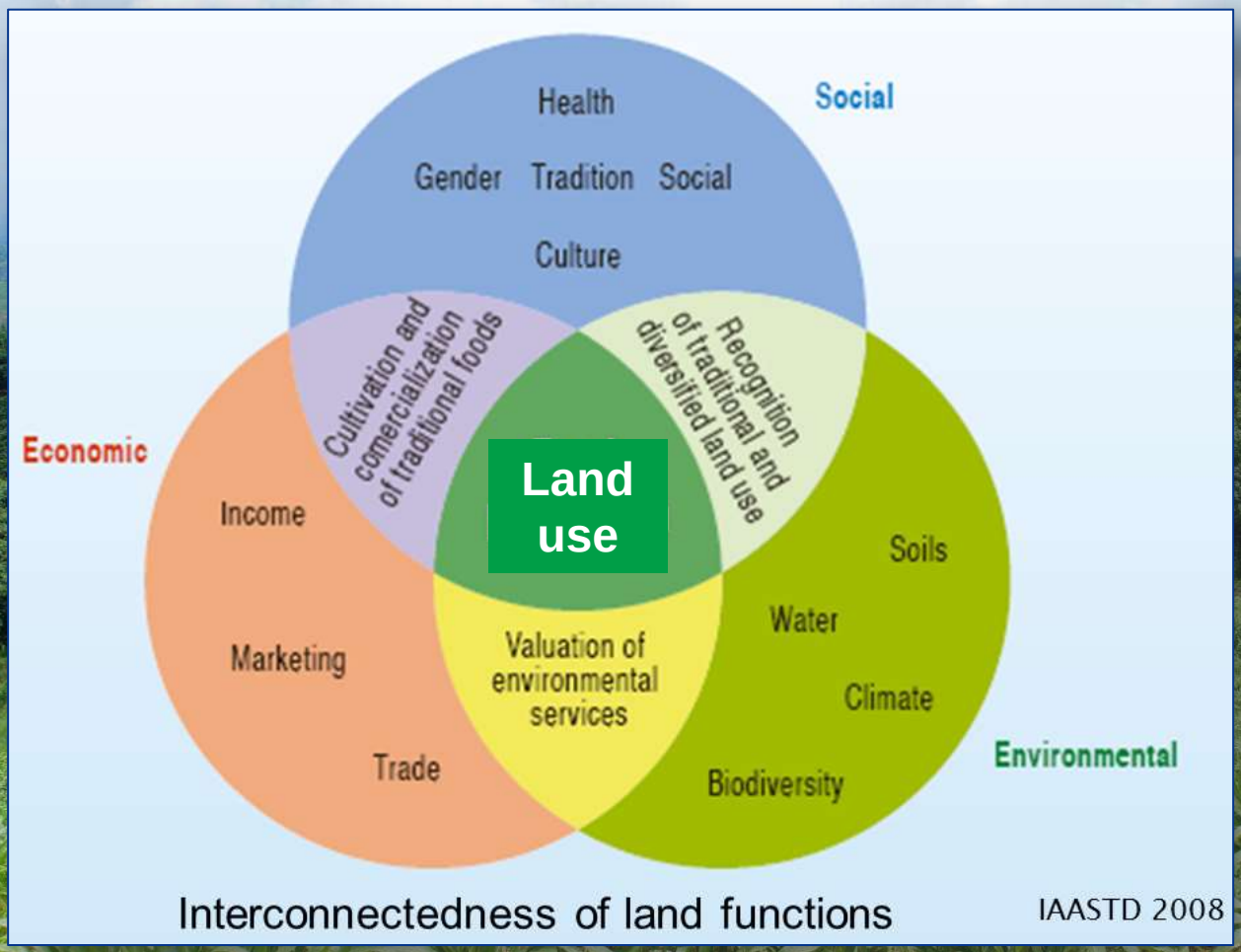
Land use change modelling:
State-of-the-art

Department
of Earth Sciences

Peter Verburg


1 NO POVERTY
2 ZERO HUNGER
3 GOOD HEALTH AND WELL-BEING
4 QUALITY EDUCATION
5 GENDER EQUALITY
6 CLEAN WATER AND SANITATION
7 AFFORDABLE AND CLEAN ENERGY
8 DECENT WORK AND ECONOMIC GROWTH
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE
10 REDUCED INEQUALITIES
11 SUSTAINABLE CITIES AND COMMUNITIES
THE GLOBAL GOALS
For Sustainable Development
12 RESPONSIBLE CONSUMPTION AND PRODUCTION
13 CLIMATE ACTION
14 LIFE BELOW WATER
15 LIFE ON LAND
16 PEACE, JUSTICE AND STRONG INSTITUTIONS
17 PARTNERSHIPS FOR THE GOALS

Understanding sustainability perspectives

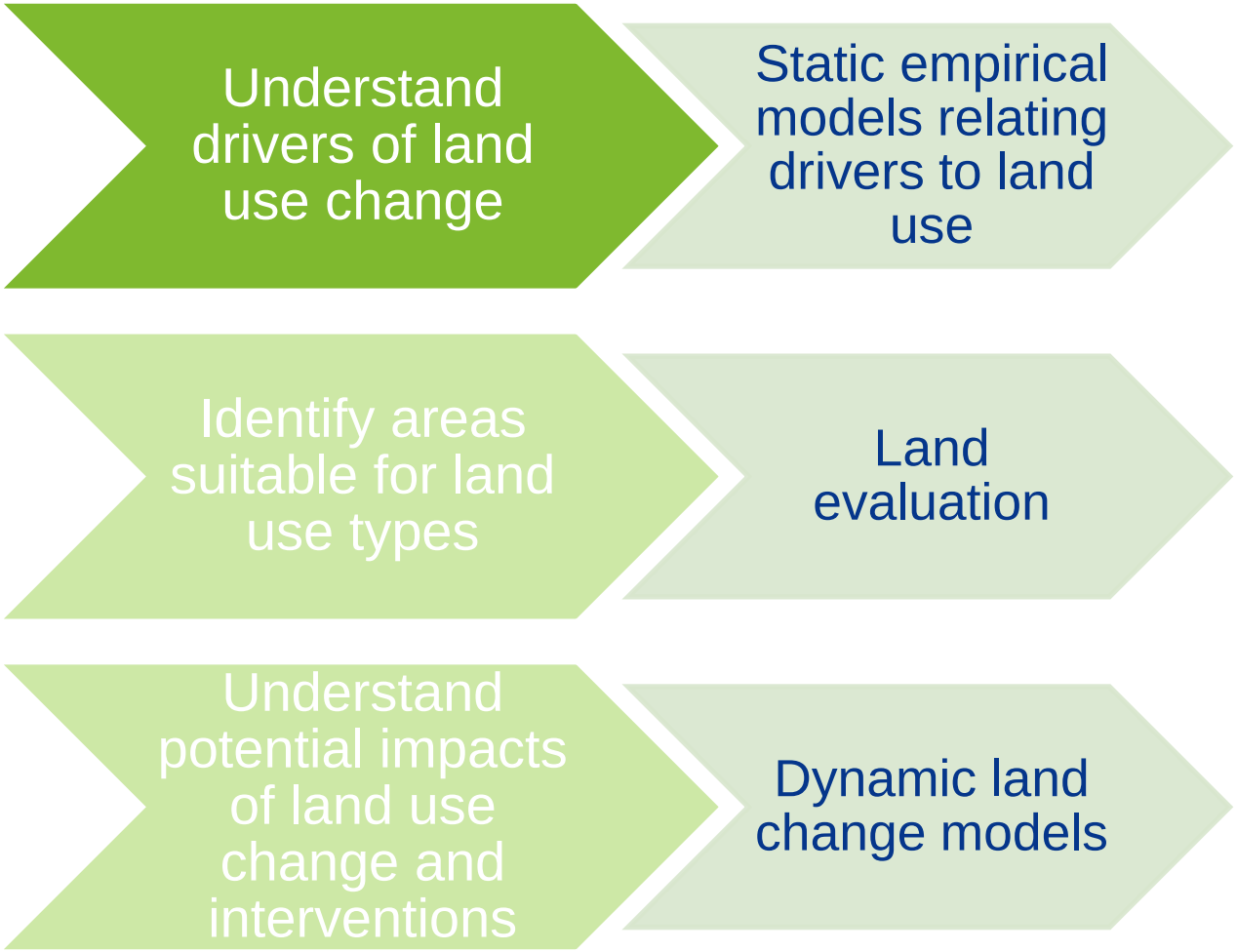


Tools for planning and policy support in land use

- (participatory) Spatial planning
- Land use policy making
- Targeted investments and region development
- Zoning
- Nature conservation

- Land evaluation
- Socio-economic assessments
- **Land use models**

Types of models

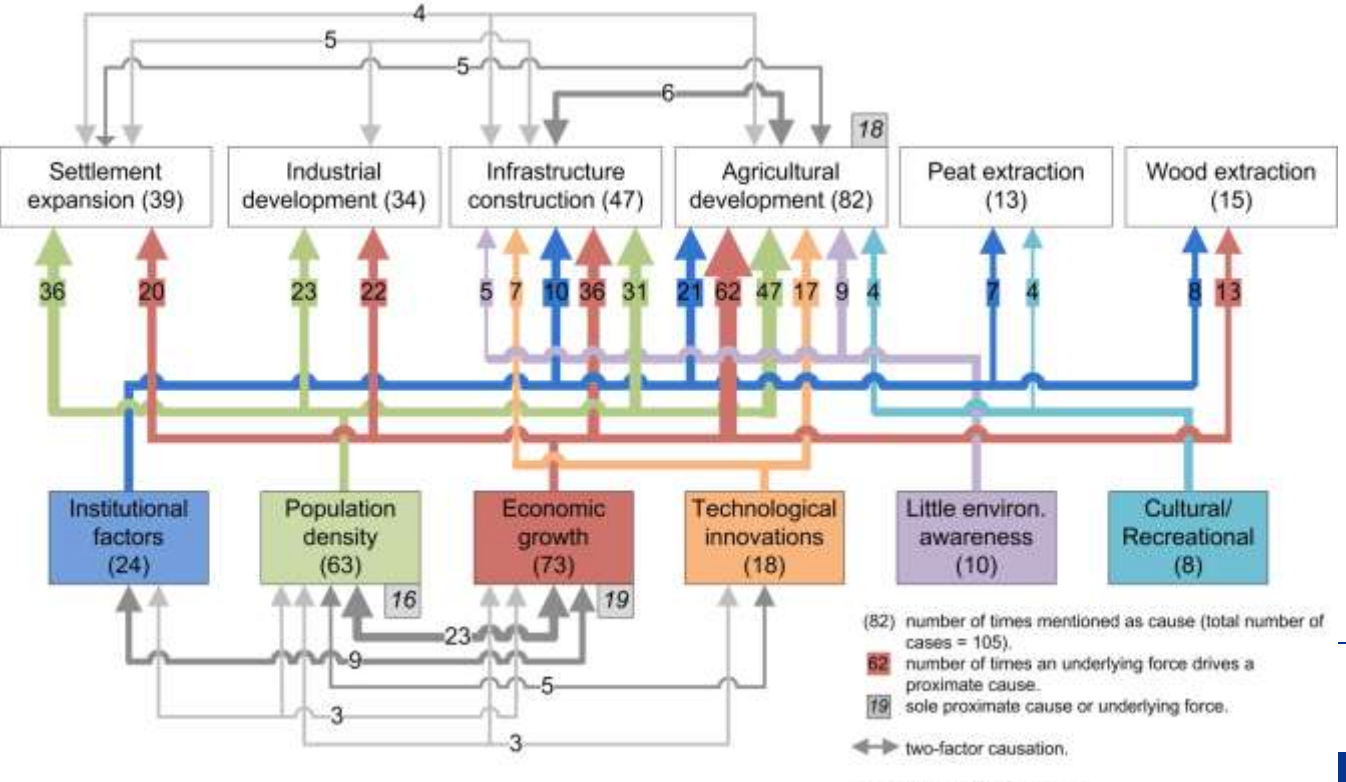


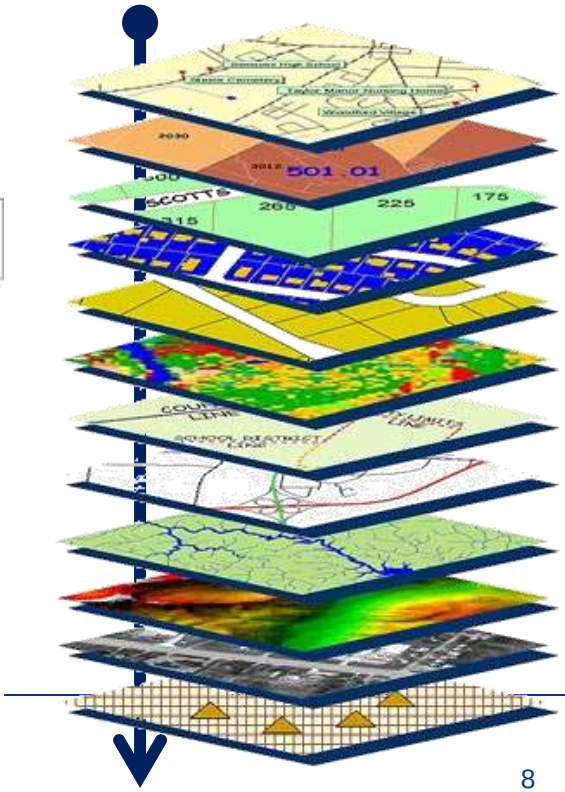
Empirical models of land use drivers

Model: *Land use = f(environmental, social, economic, cultural)*

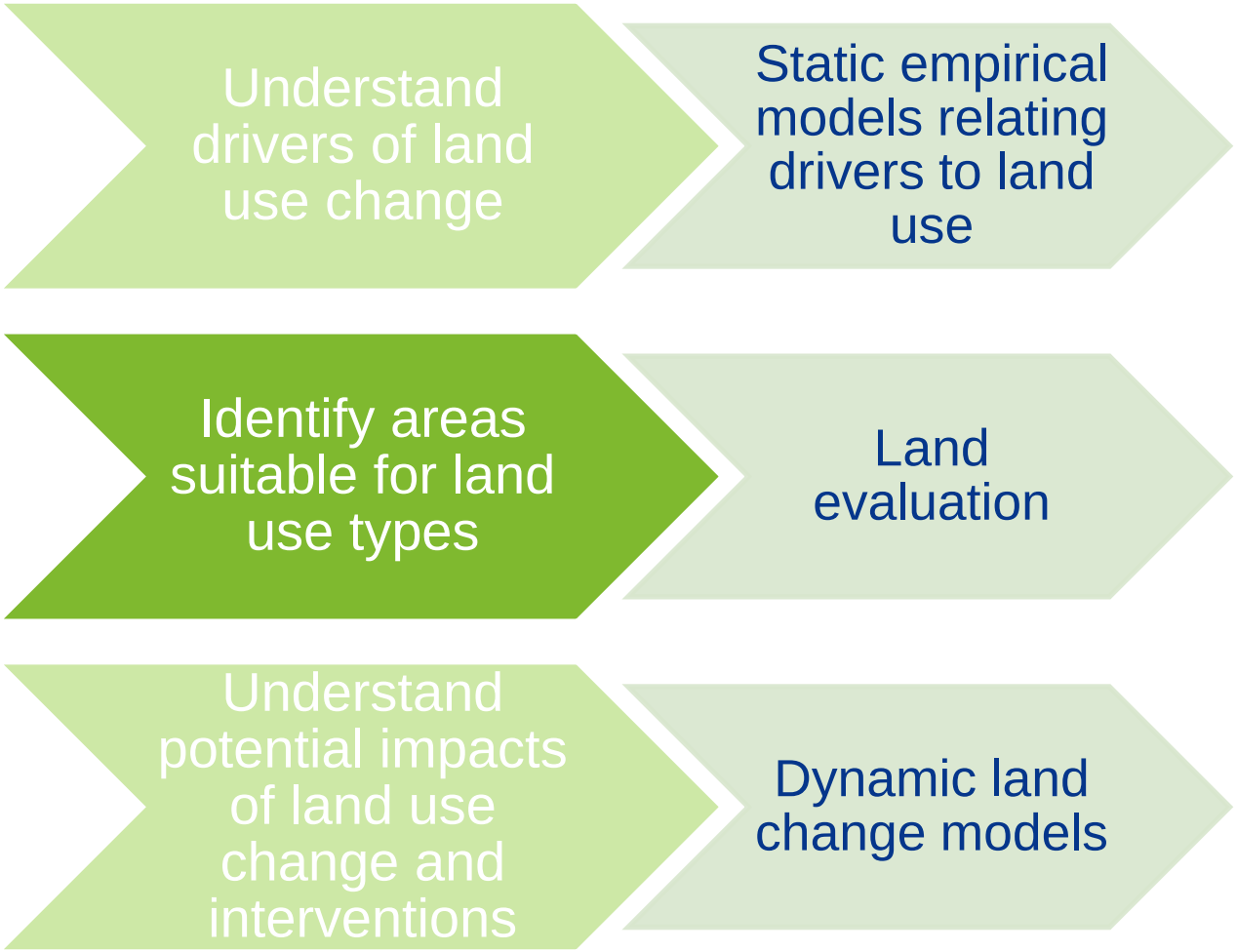
Methods: *(spatial) statistics, econometrics*

Goal: *understanding why observed land change happens at what location*

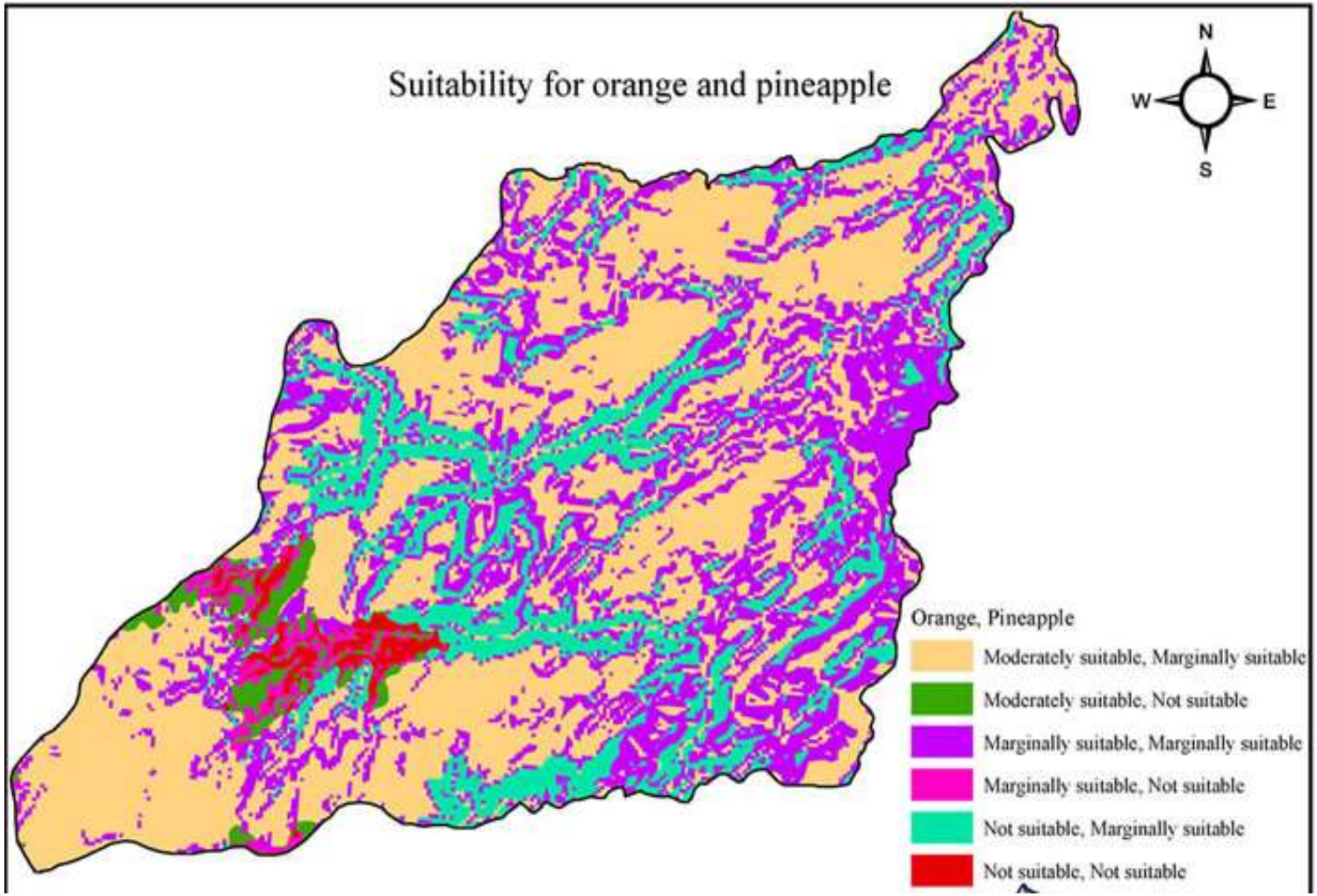




Types of models



Land (suitability) evaluation



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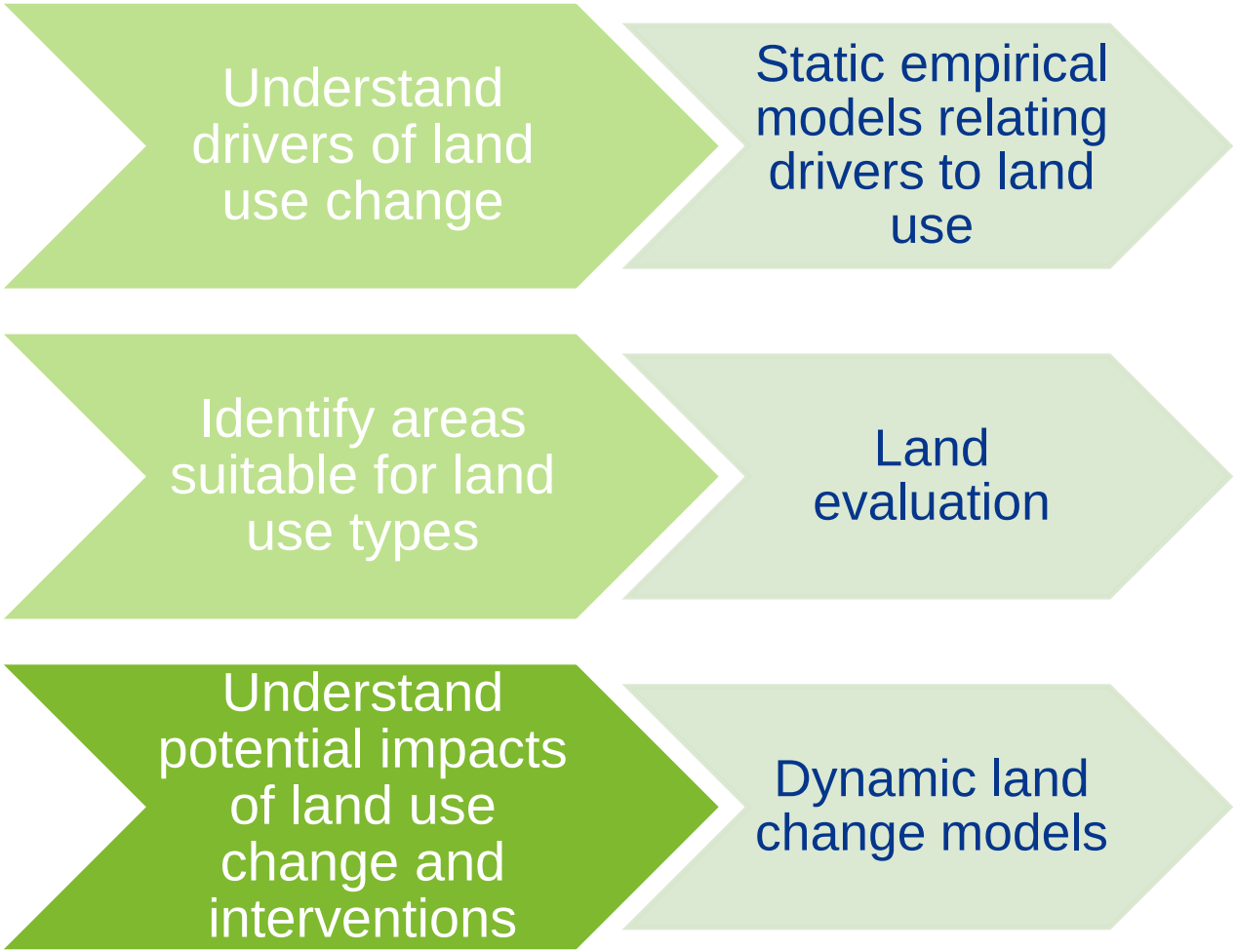
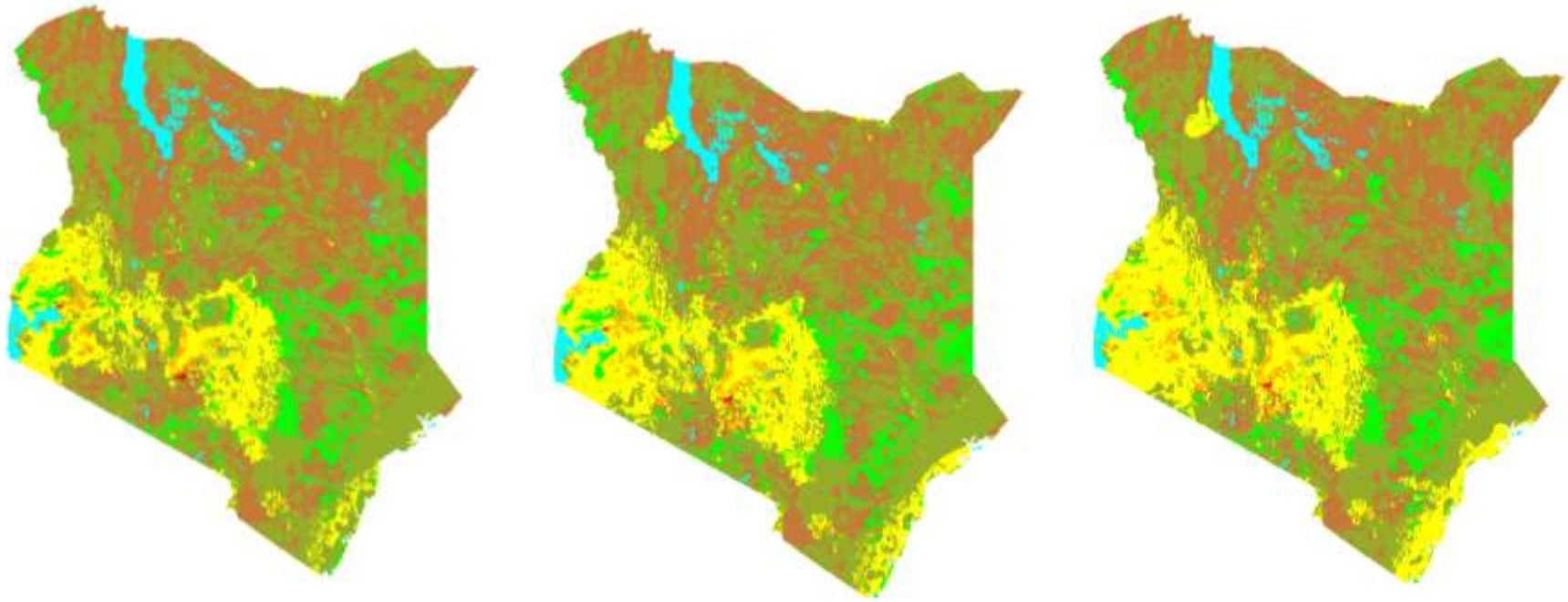


2000 2015 2030

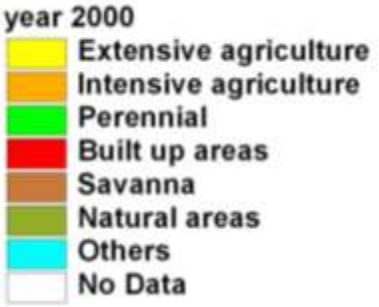
Kenya



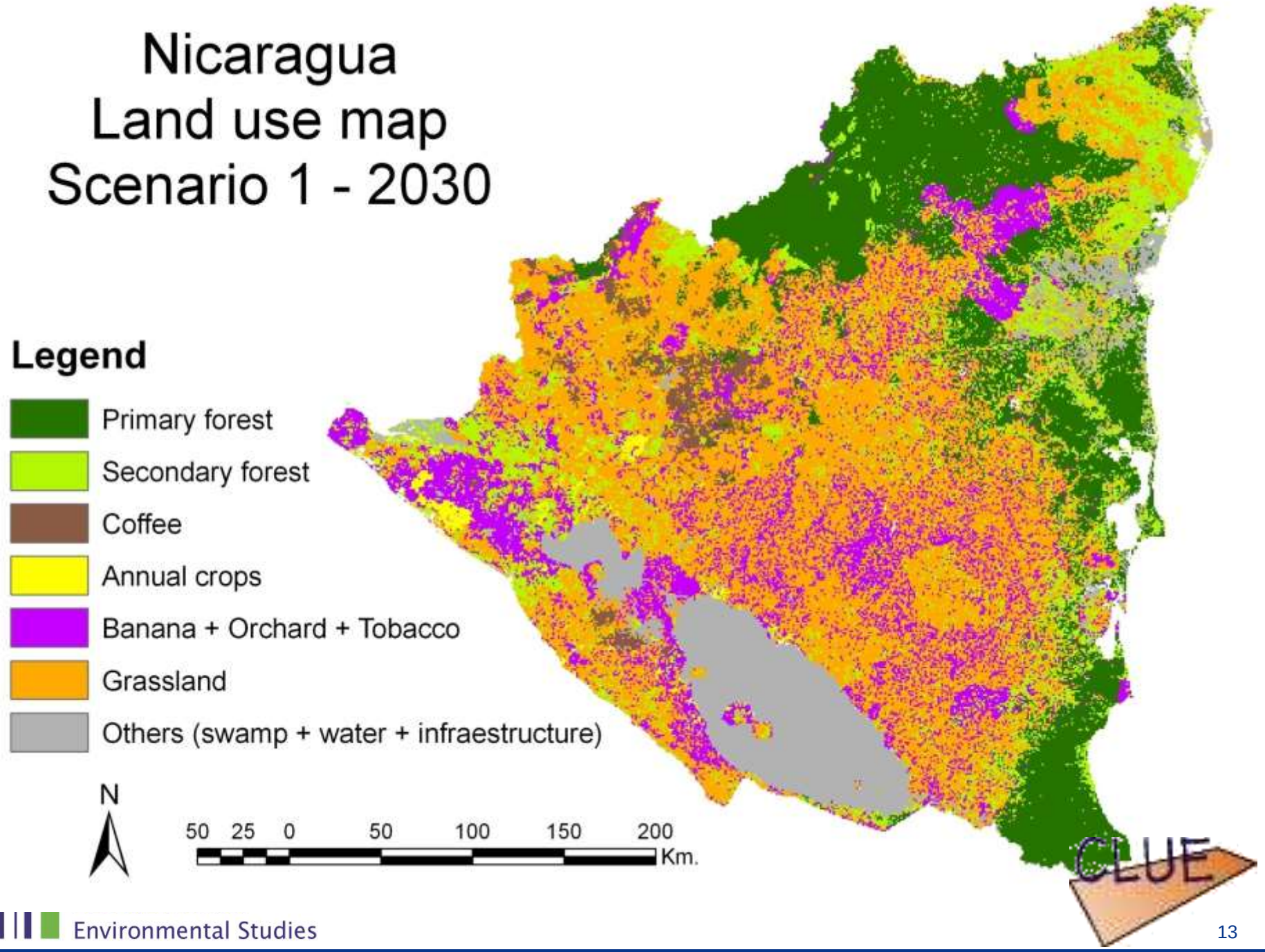
Increasing of extensive agriculture near Lake Turkana& mombasa

New built up areas in north

Increasing of perennials in northeastern



Nicaragua
Land use map
Scenario 1 - 2030



Characteristics of dynamic land use models

- Account for different land use types (competition)
- Simulate past and/or future dynamics
- Can answer ‘what if….’ questions and scenarios

INTEGRATE information on:

-societal demands for land-based products

-driving factors of land change

-suitability of land for different uses

Types of dynamic models

Local land use decisions

- Multi-agent models
- Decision making central

Regional land use patterns

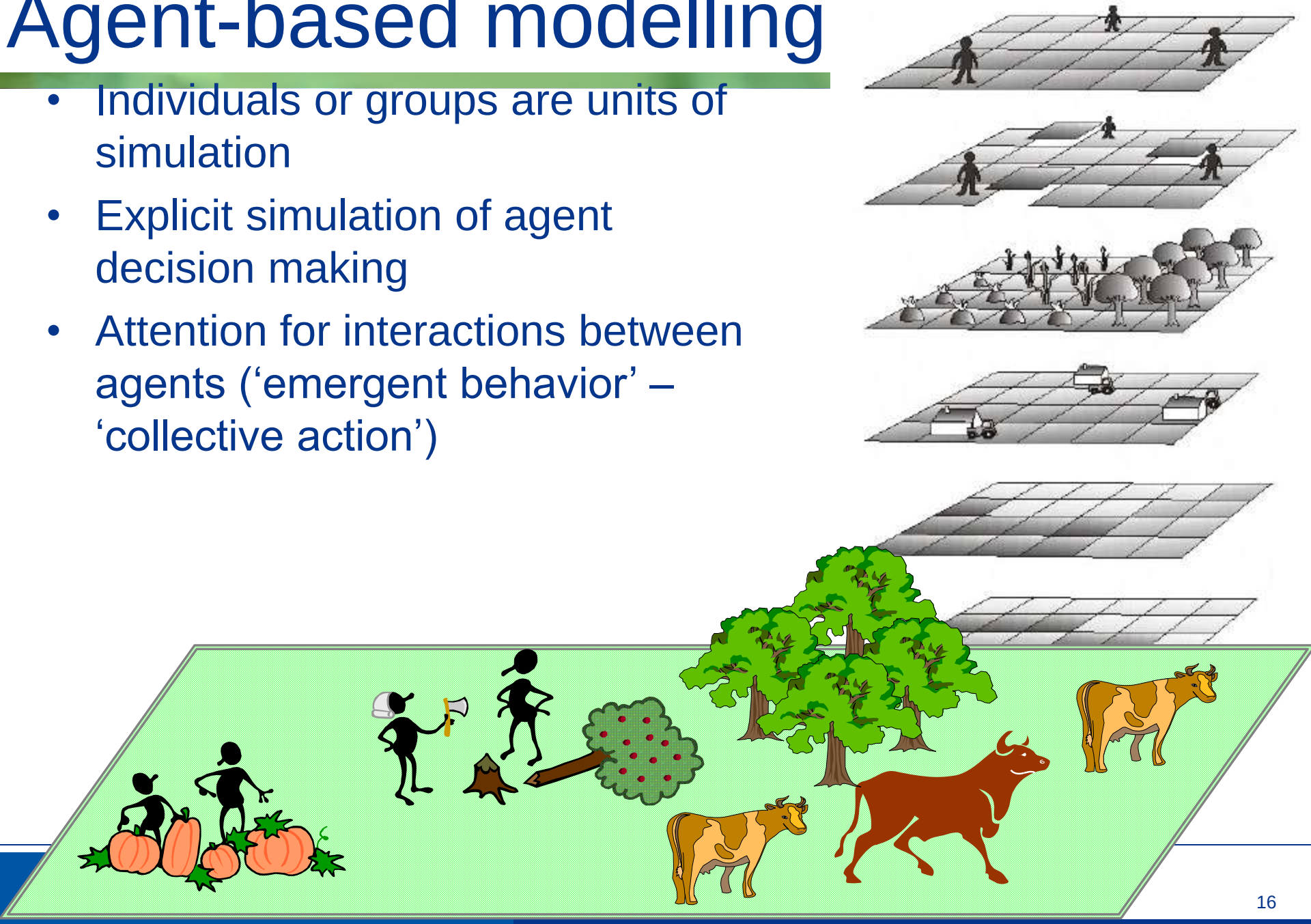
- Pixel-based models
- Driven by external demands

National and global interactions

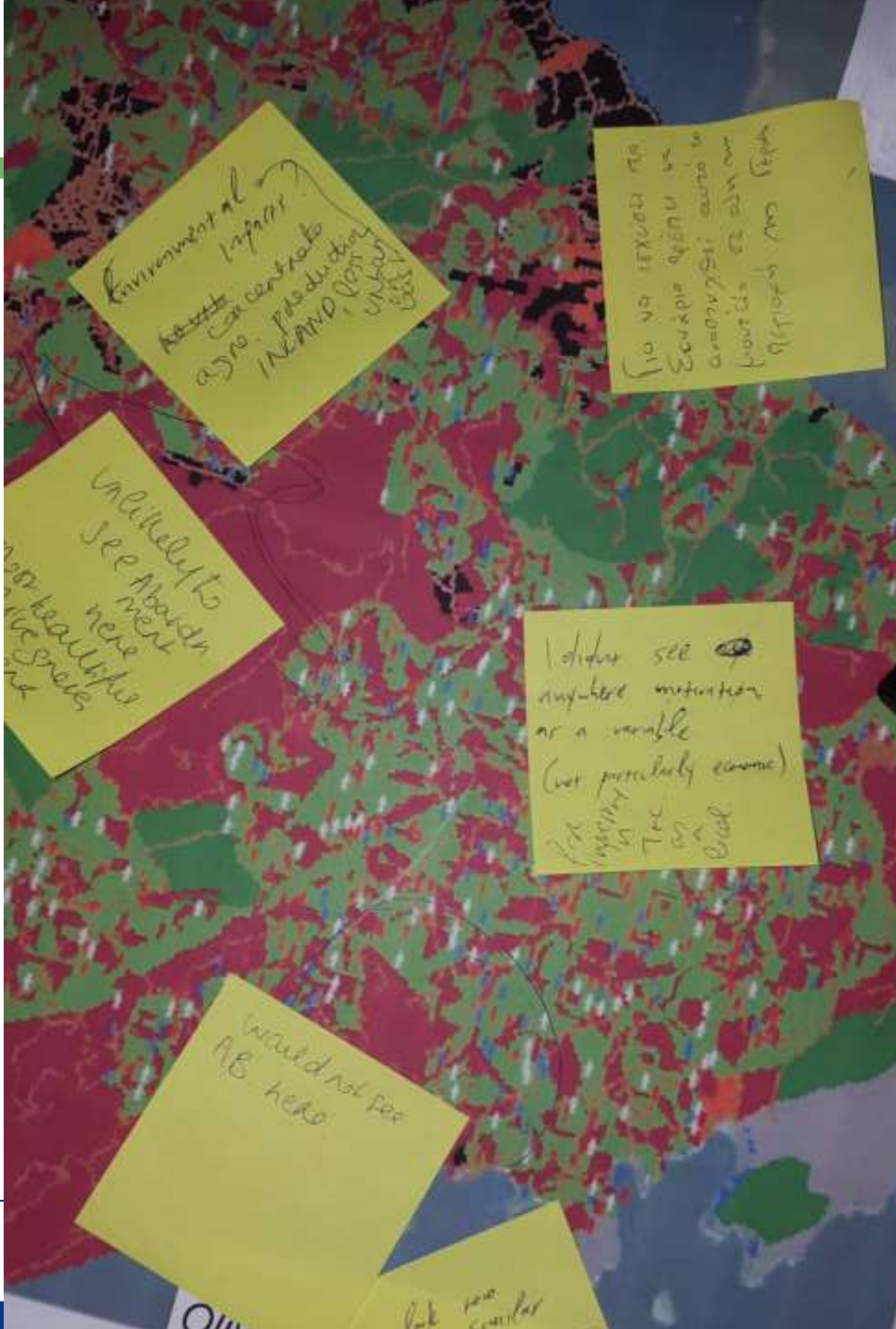
- (Macro) economic land use models
- Accounting for trade

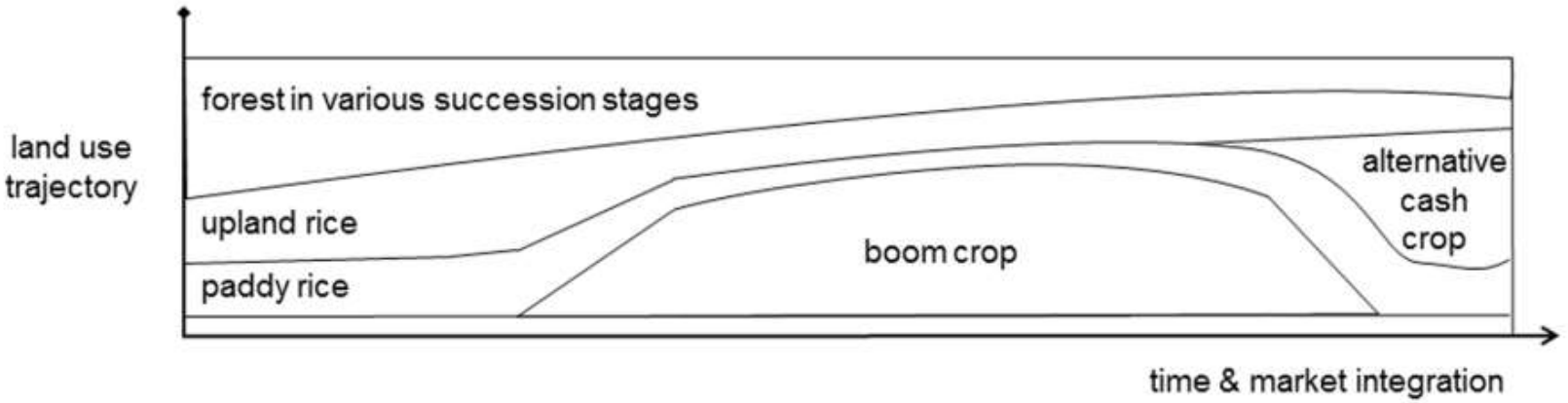
Agent-based modelling

- Individuals or groups are units of simulation
- Explicit simulation of agent decision making
- Attention for interactions between agents (‘emergent behavior’ – ‘collective action’)




Legend
Olive plantations
Forest
Wooded grassland and shrubs
Urban
Meadows and pastures
Agricultural mosaic
Natural rock
Roads
Υπόμνημα, Χρήσεις γης:
Ελαιώνες
Δάσος
Ξυλώδης βλάστηση και θάμνοι
Αστική
Λιβάδια και βοσκότοποι
Γεωργικές εκτάσεις
Βραχώδεις εκτάσεις
Οδικό δίκτυο
Now
Τώρα
5 years
5 έτη


Environmental impacts
concentrate agro. production INLAND
Unlikely to see Abandonment here
I didn't see anywhere motivation as a variable
(not particularly economic)
Would not see AB here

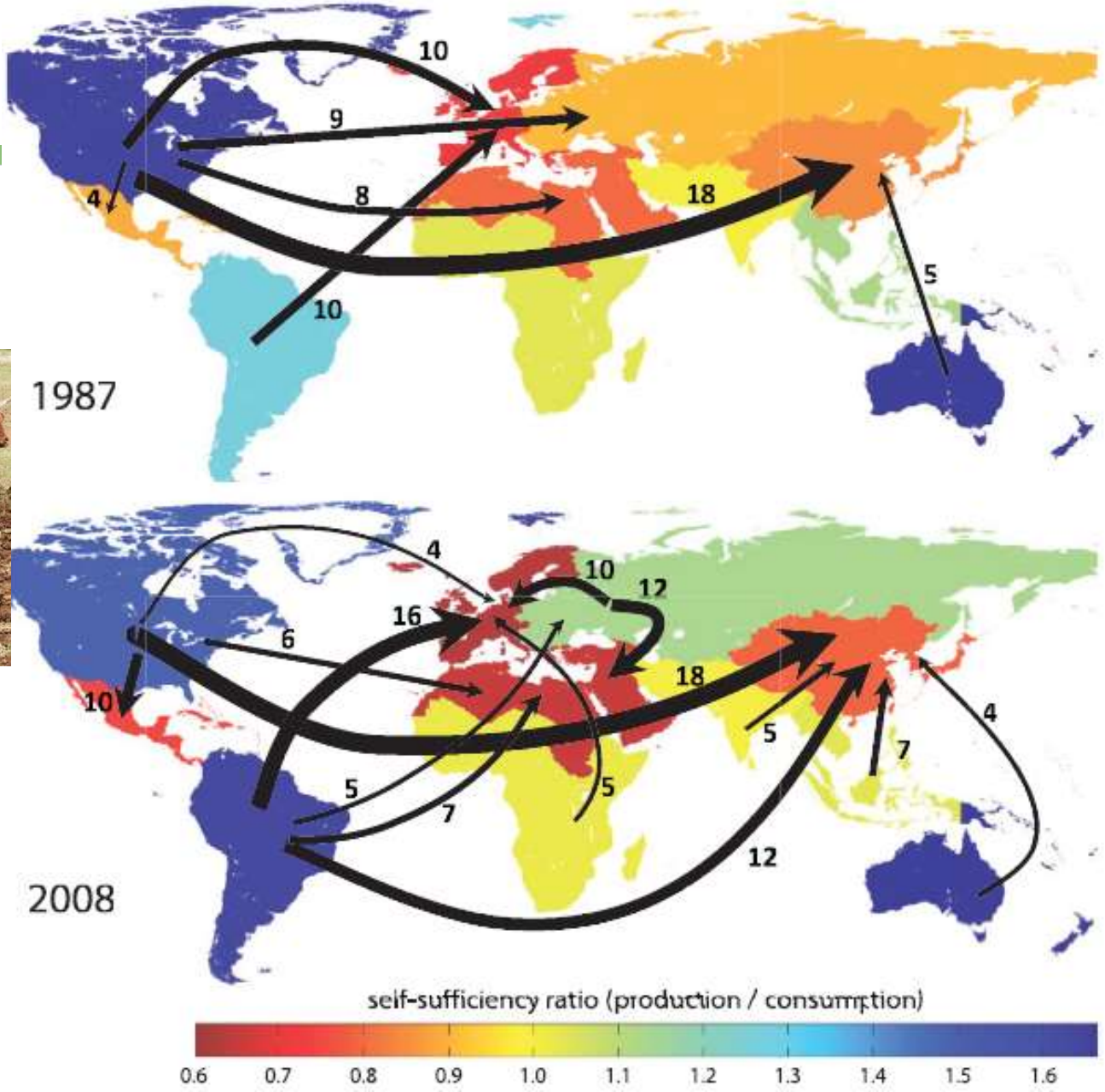


cluster	factor	adopt	expand	intensify	diversify	abandon
boom crop market	opportunity of market outlet					
	price stability and trust in trader					
feasibility	labor, capital, knowledge					
	land resources					
comparative profitability	profitability of boom crop					
	competitive alternative(s)					

Types of dynamic models

Local land use decisions	• Multi-agent models • Decision making central
Regional land use patterns	• Pixel-based models • Driven by external demands
Supra-National and global interactions	• (Macro) economic land use models • Accounting for trade

Flows of cropland (Mha)



Types of dynamic models

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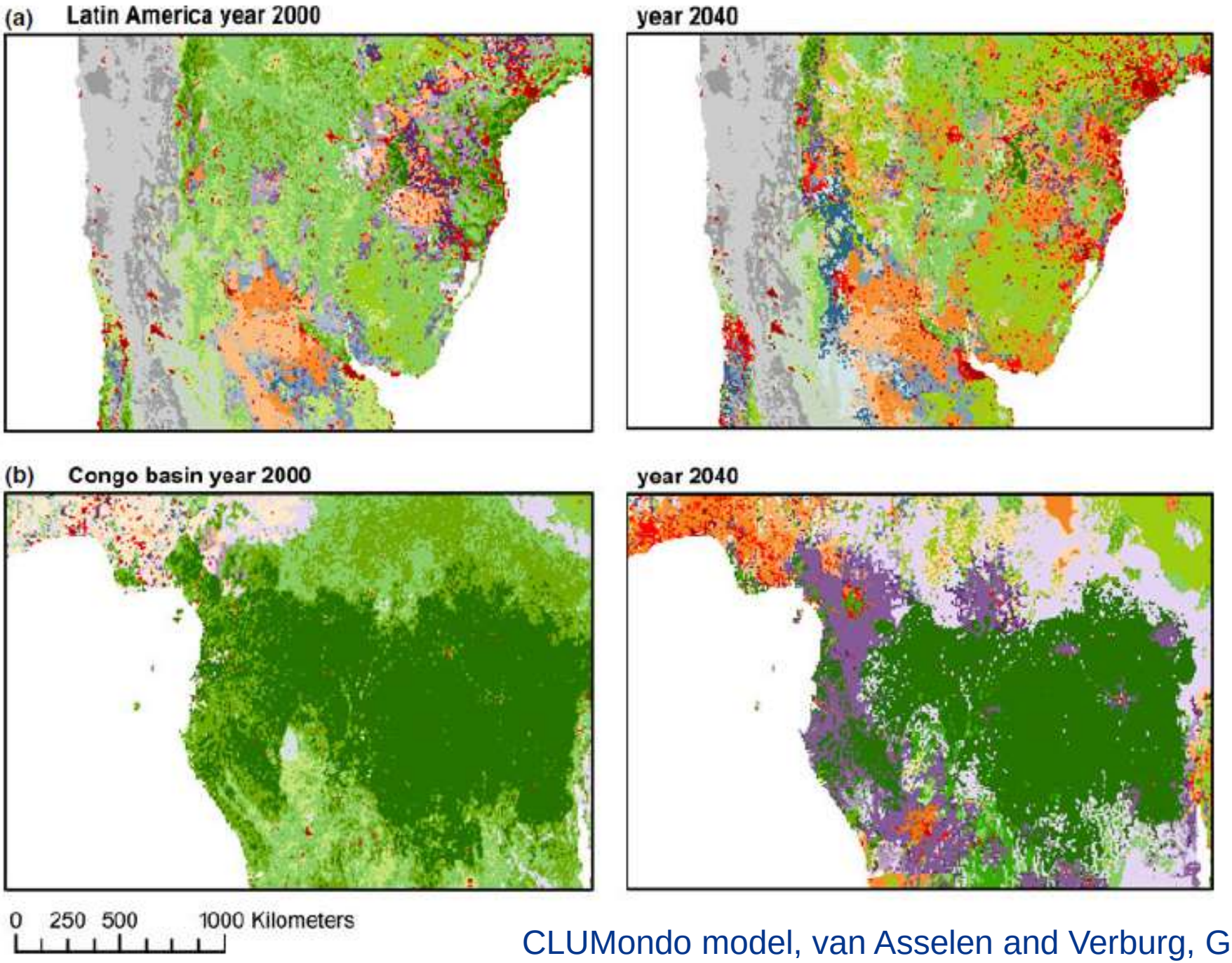
National and global interactions	• (Macro) economic land use models • Accounting for trade



CLUMondo model, van Asselen and Verburg, GCB

CLUE model family

1996-2000

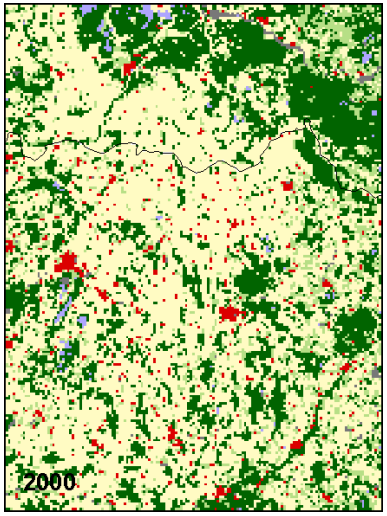
CLUE

Land cover (%)

2001-2010

CLUE-s

Dyna-CLUE



Land cover (dominant)

2012-

CLUMondo

Land systems

Multiple demand types

Advances in the CLUMondo model during the project

➔Land systems instead of land cover

➔Demands for multiple commodities and ecosystem services

Expansion vs intensification

Global scale

↓

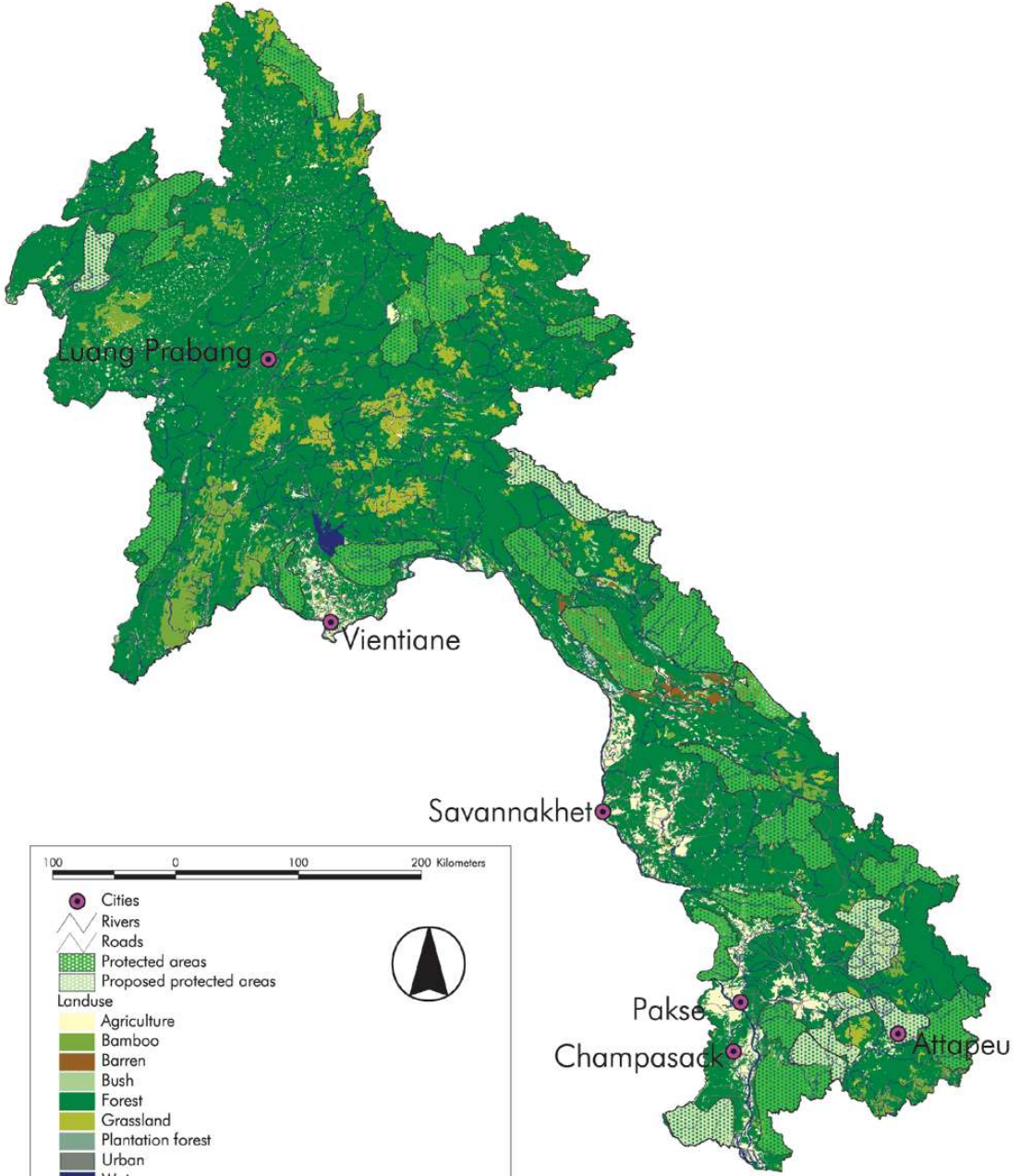
Landscape scale

Increased agricultural demand

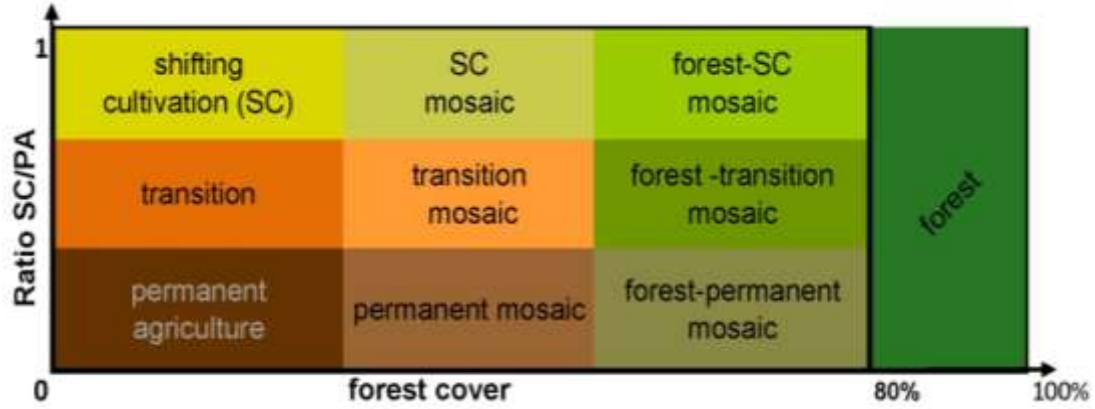
↙ ↘

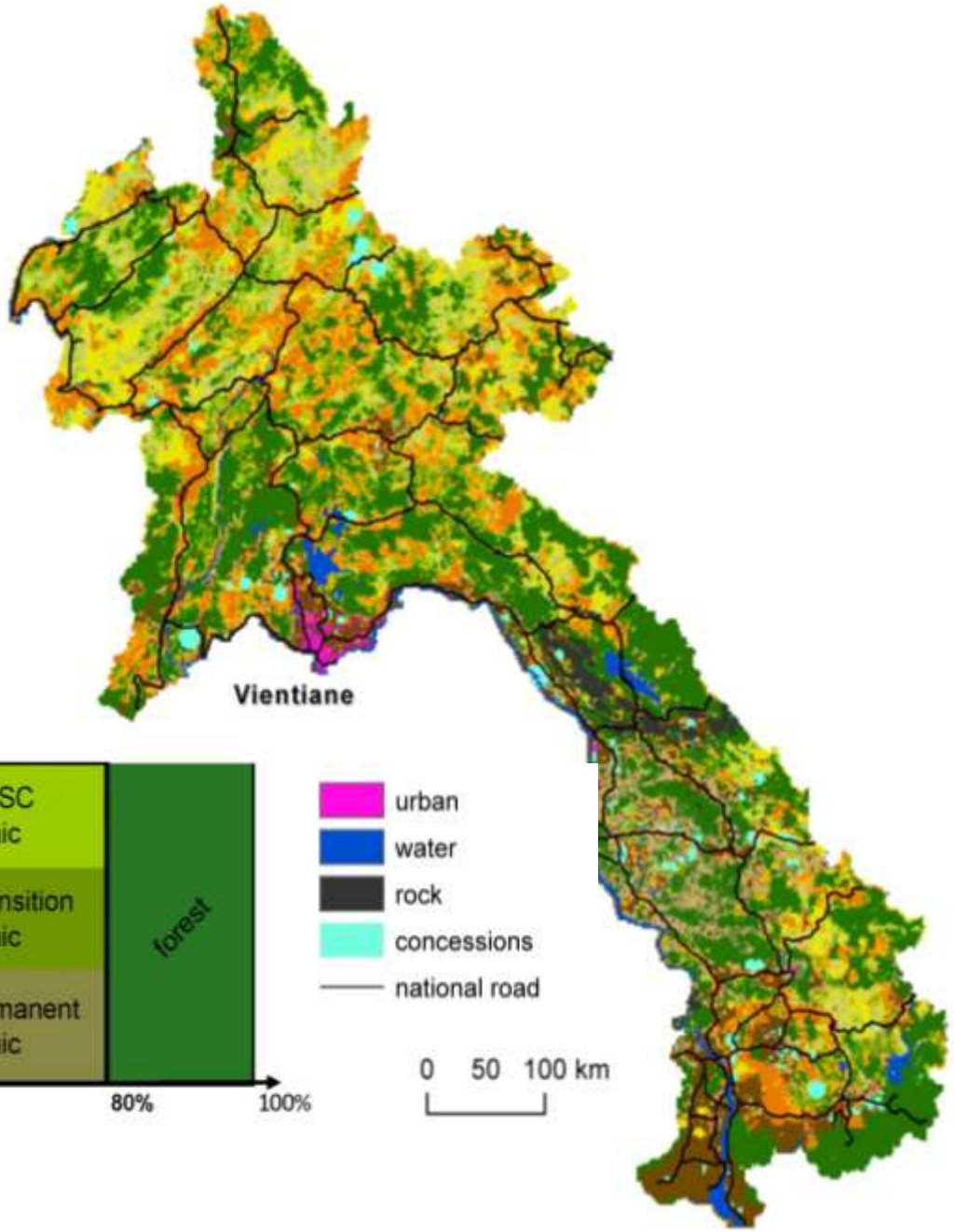
Expansion Intensification

Land cover map of Laos

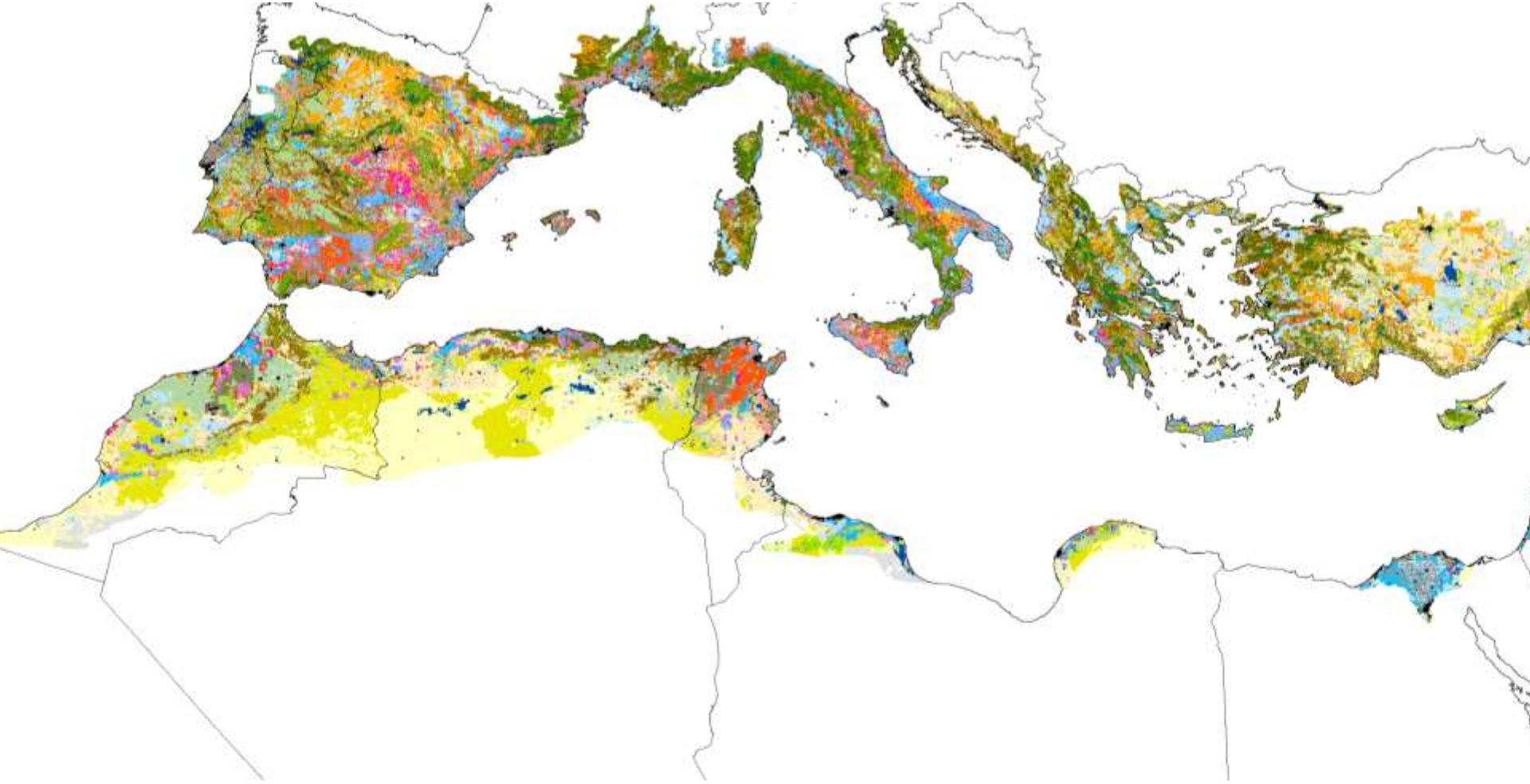


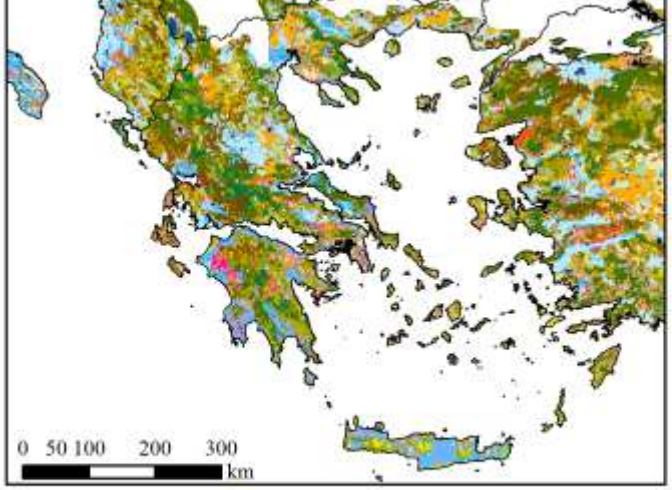
Land Systems map

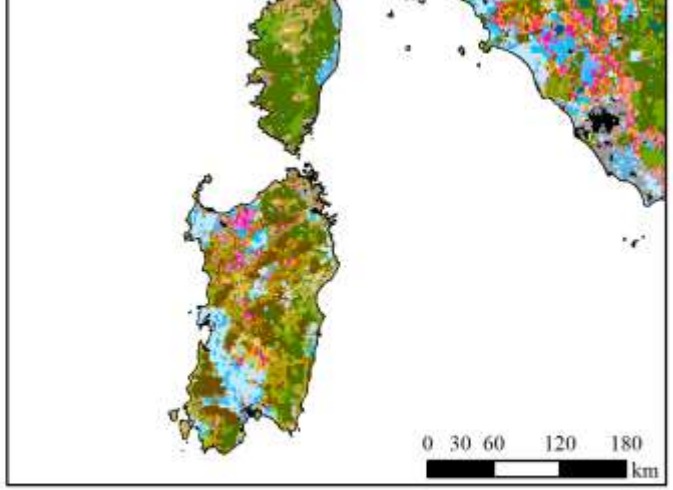


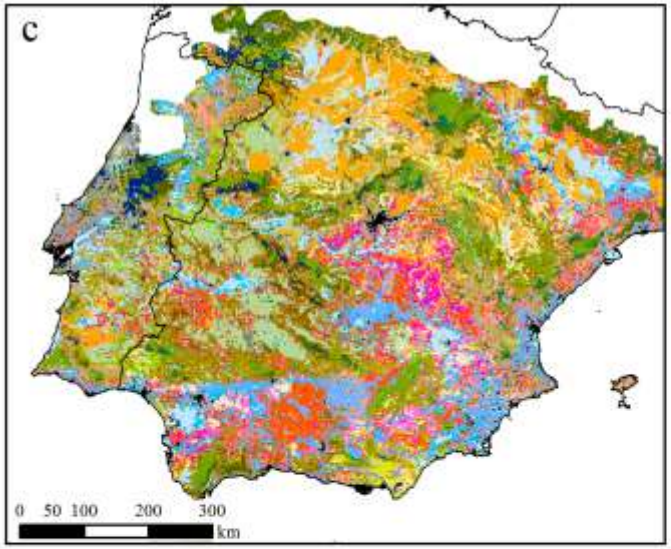


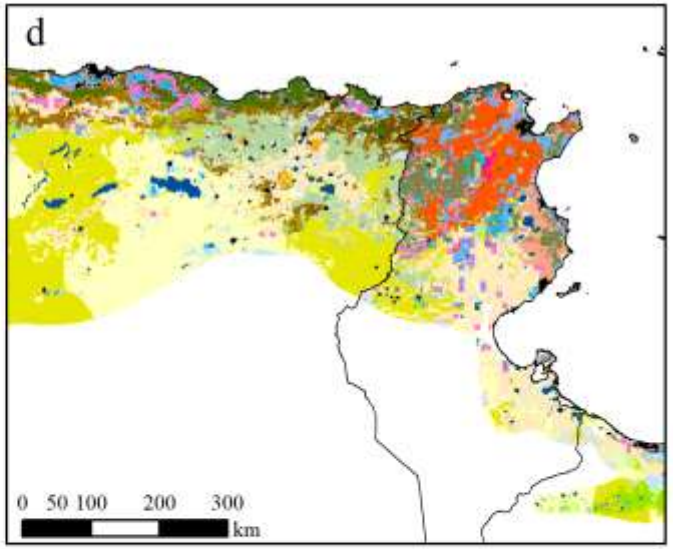
Ornetsmeuller et al., in prep

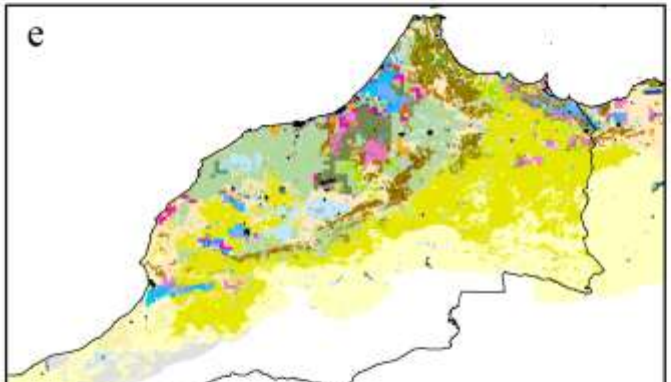

bare / desert
open rangeland
extensive arid grazing
intensive open rangeland
intensive arid grazing
wetlands
extensive annual crops
cropland and rangeland
open woodland
open wooded rangeland
cropland and wooded rangeland
extensive permanent crops
extensive ann-perm mosaic
rainfed intensive annual crops
rainfed intensive permanent crops
rainfed intensive ann-perm mosaic
irrigated annual crops
irrigated permanent crops
irrigated ann-perm mosaic
permanent crops and rangeland
mediterranean medium intensity forest
mediterranean natural and semi-na
mediterranean high-intensity forest
mediterranean planted forests
closed wooded rangeland
peri-urban
urban


0 50 100 200 300
km


0 30 60 120 180
km


c
0 50 100 200 300
km

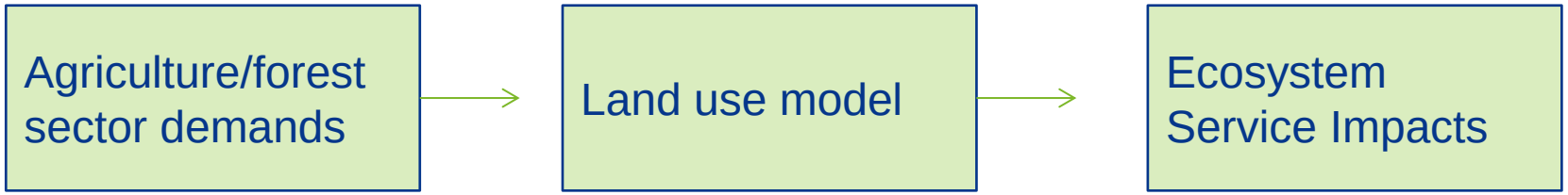

d
0 50 100 200 300
km


e

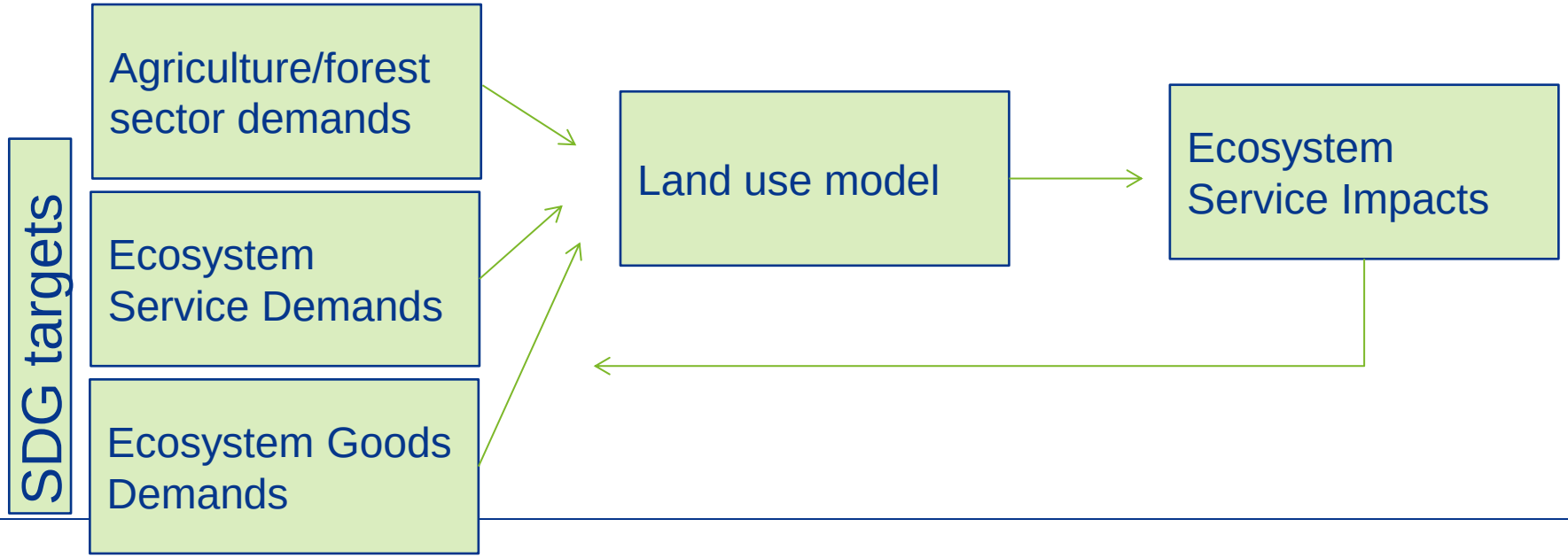

f

Demands for other land-based products and services

Classical representation

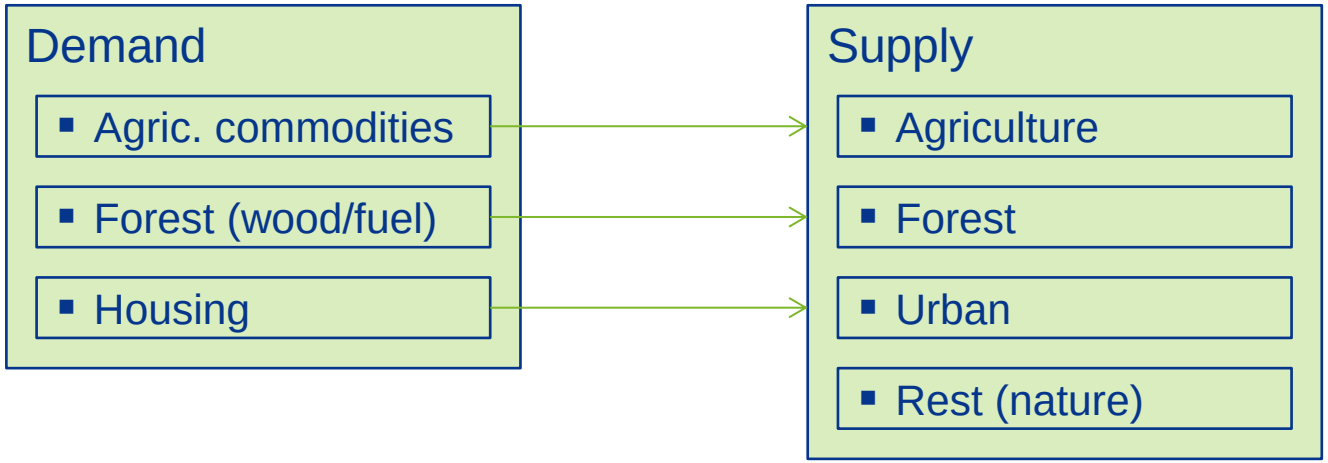


CLUMondo representation

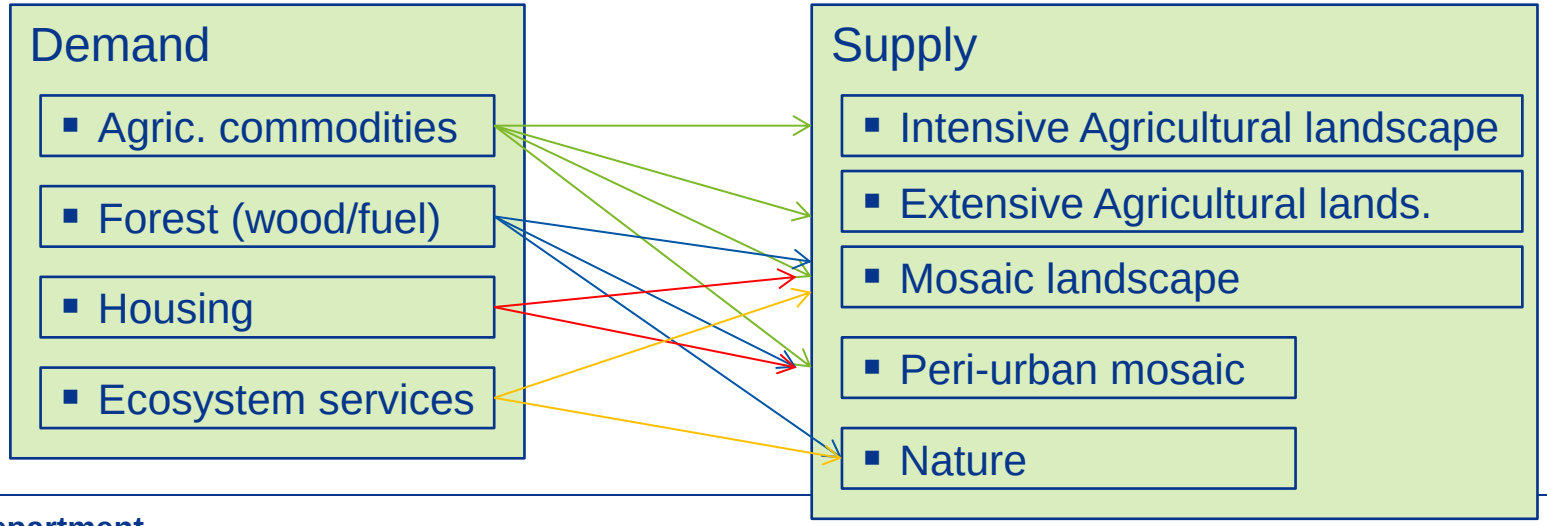


CLUMondo model

traditional



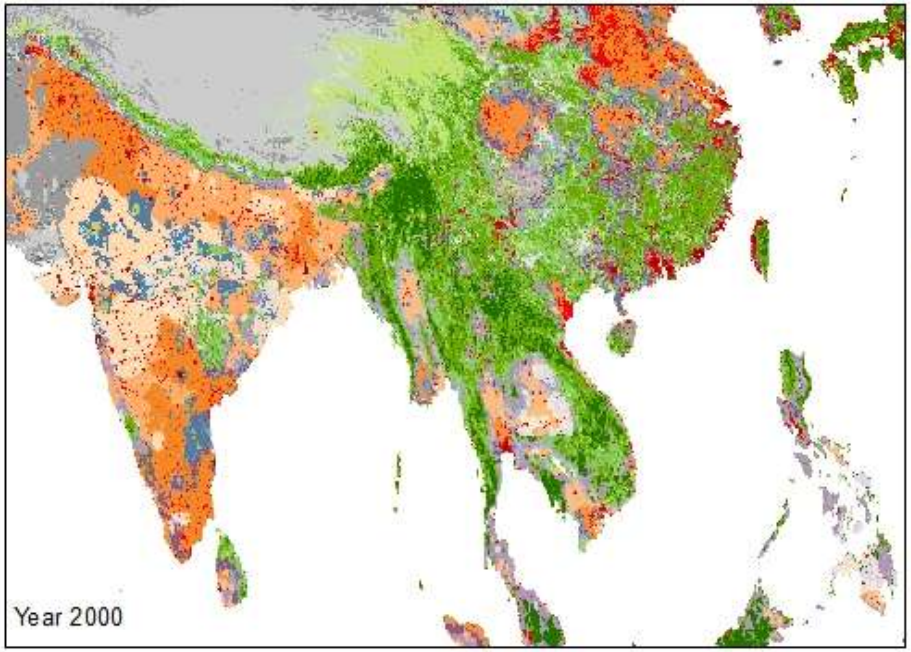
CLUMondo

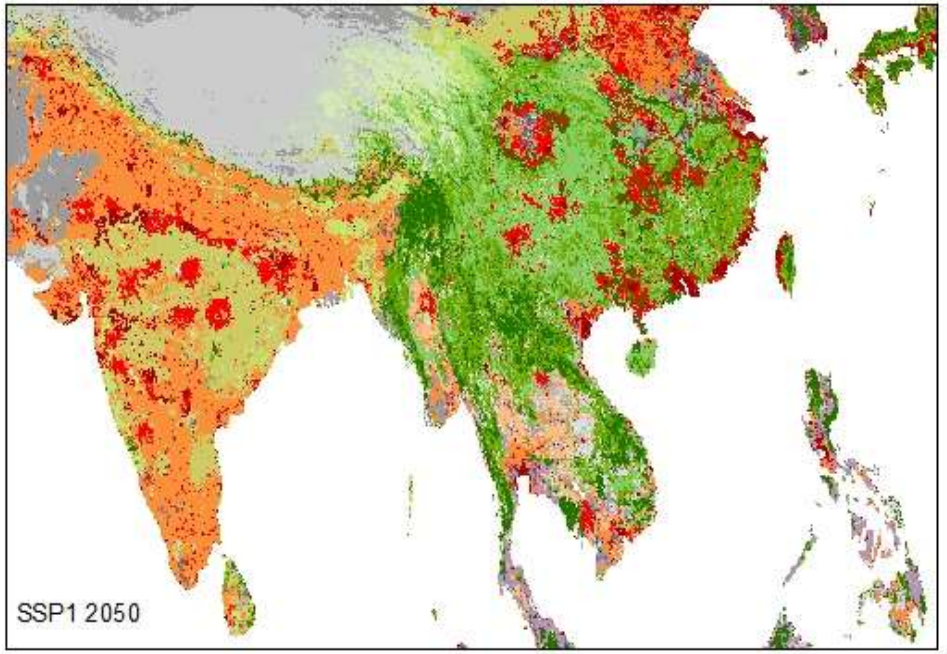


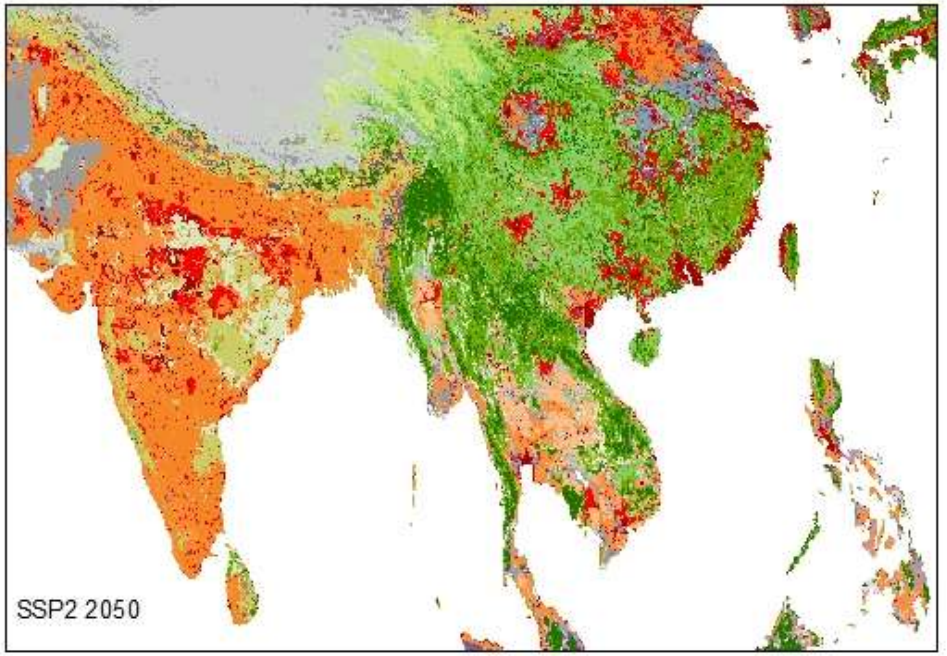
Ecosystem service demands in scenarios

Relative demand in 2030 as compared to 2010.

Scenario	Built-up area	Staple crops	Arable cash crops	Tree cash crops	Biodiversity conservation	Cultural services
TREND	223%	130%	236%	190%	n.a.	n.a.
ASEAN	223%	123%	269%	242%	8% increase of dense forest	n.a.
GREEN	223%	130%	180%	180%	Max. 18% decrease of forest cover (total of dense forest and forest mosaic land systems)	Maintenance of minimally 50% of the 2010 area of traditional shifting cultivation land systems





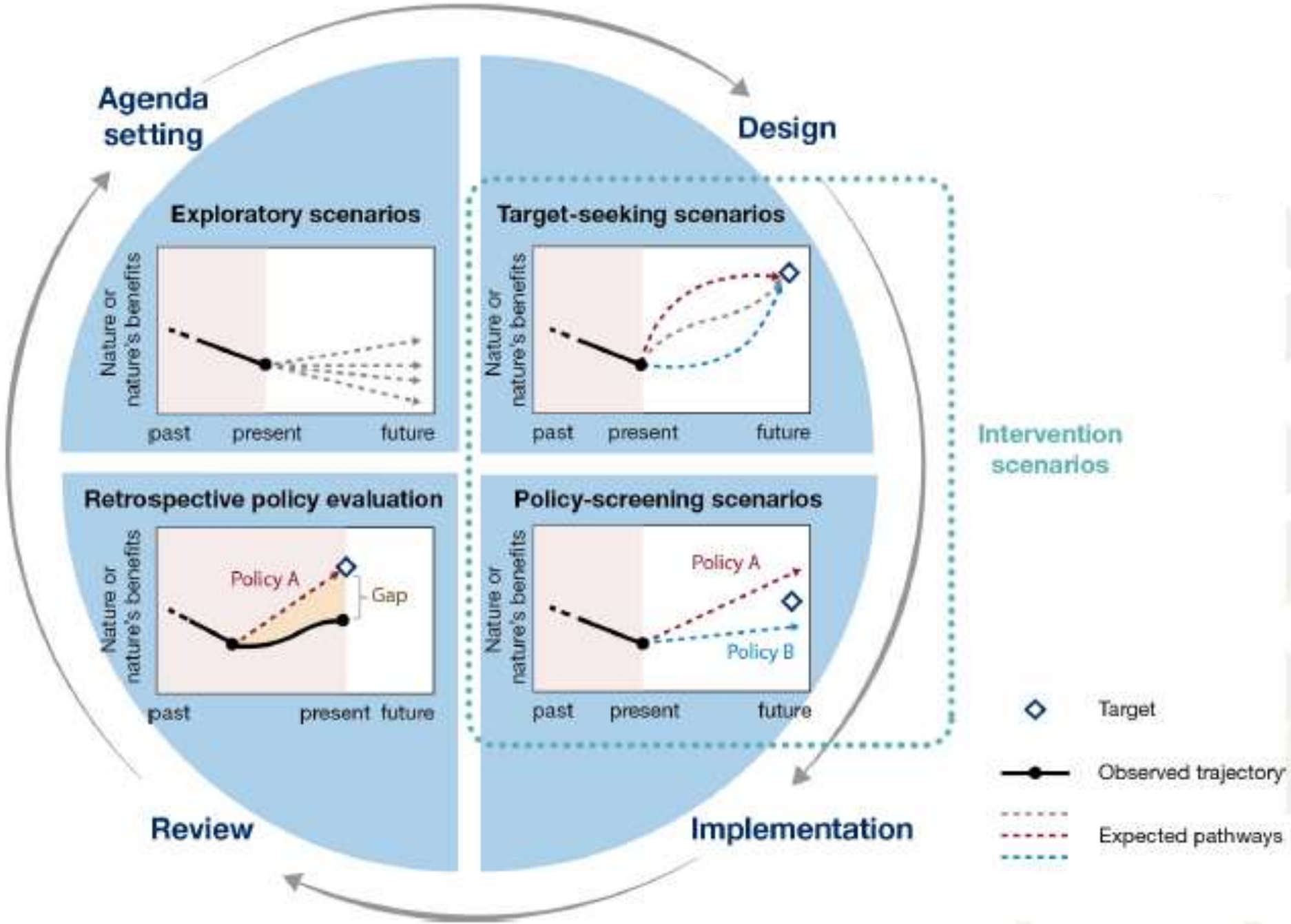


Legend

- Cropland ext.; few livestock
- Cropland ext.; bovines, goats & sheep
- Cropland med. int.; few livestock
- Cropland med. int.; bovines, goats & sheep
- Cropland int.; few livestock
- Cropland int.; bovines, goats & sheep
- Mosaic cropland & grassland; bovines, goats & sheep
- Mosaic cropland ext. & grassland; few livestock
- Mosaic cropland med. int. & grassland; few livestock
- Mosaic cropland int. & grassland; few livestock
- Mosaic cropland ext. & forest; few livestock
- Mosaic cropland med. int. & forest; few livestock
- Mosaic cropland int. & forest; few livestock
- Desnse forest
- Open forest; few livestock
- Mosaic grassland & forest
- Mosaic grassland & bare
- Natural grassland
- Grassland; few livestock
- Grassland; bovines, goats & sheep
- Bare
- Bare; few livestock
- Peri-urban & villages
- Urban

Why Model?

- Be prepared for the future!
- Test suitability of interventions under different scenarios
- We shape land use: simulations as a tool to discuss the future we want
- Assess impacts and avoid conflicts


Agenda setting
Design
Exploratory scenarios
Target-seeking scenarios
Nature or nature's benefits
past
present
future
Intervention scenarios
Retrospective policy evaluation
Policy-screening scenarios
Policy A
Gap
Policy B
Review
Implementation
Target
Observed trajectory
Expected pathways

Thank you!

Department
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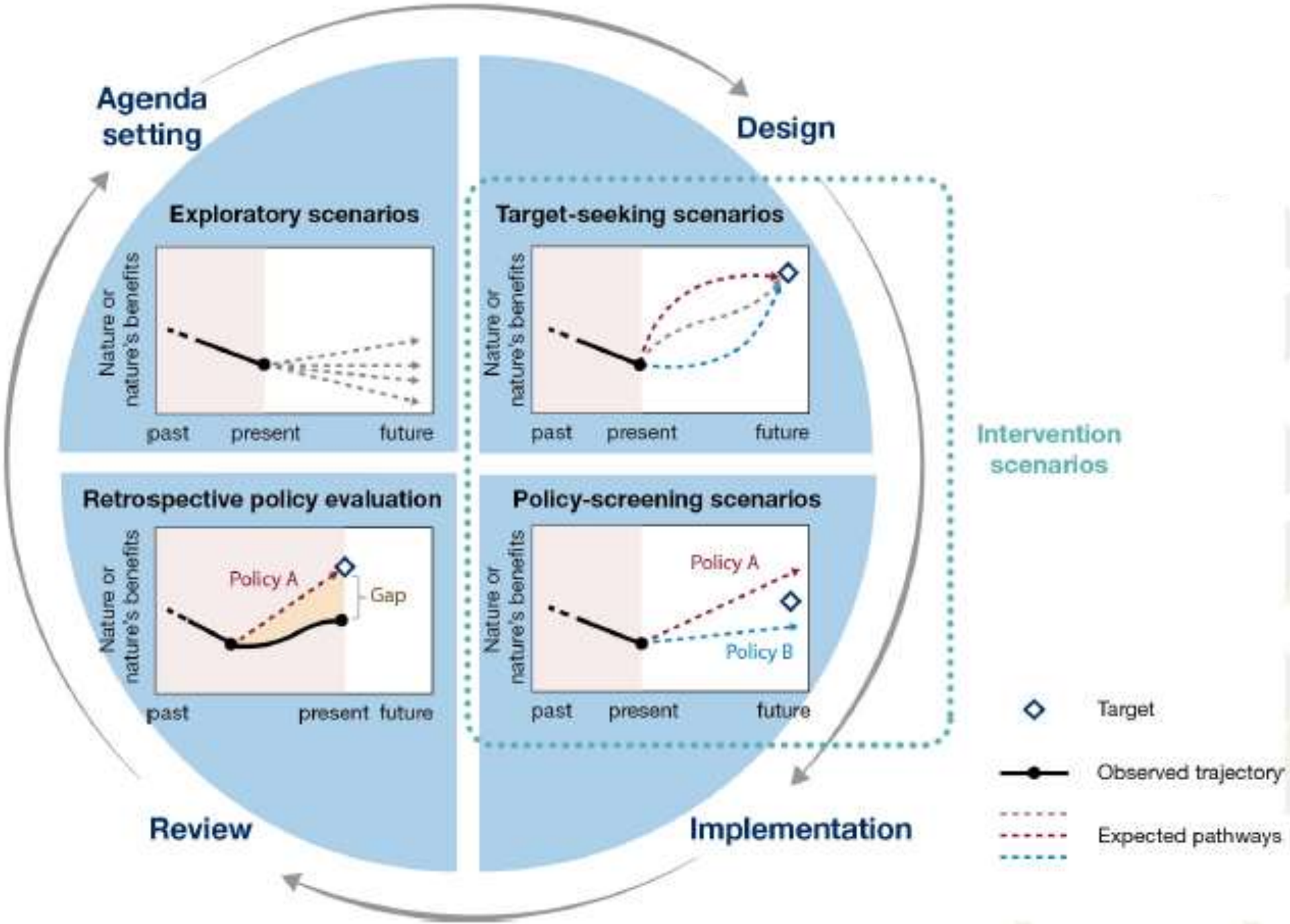
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The problem studying with the future

- We can’t observe it, but …
- We know that it’ll be different (probably)
- We cannot use traditional scientific methods
- We need a set of tools to tackle the unknowns and uncertainties of the future

Different objectives for using scenarios

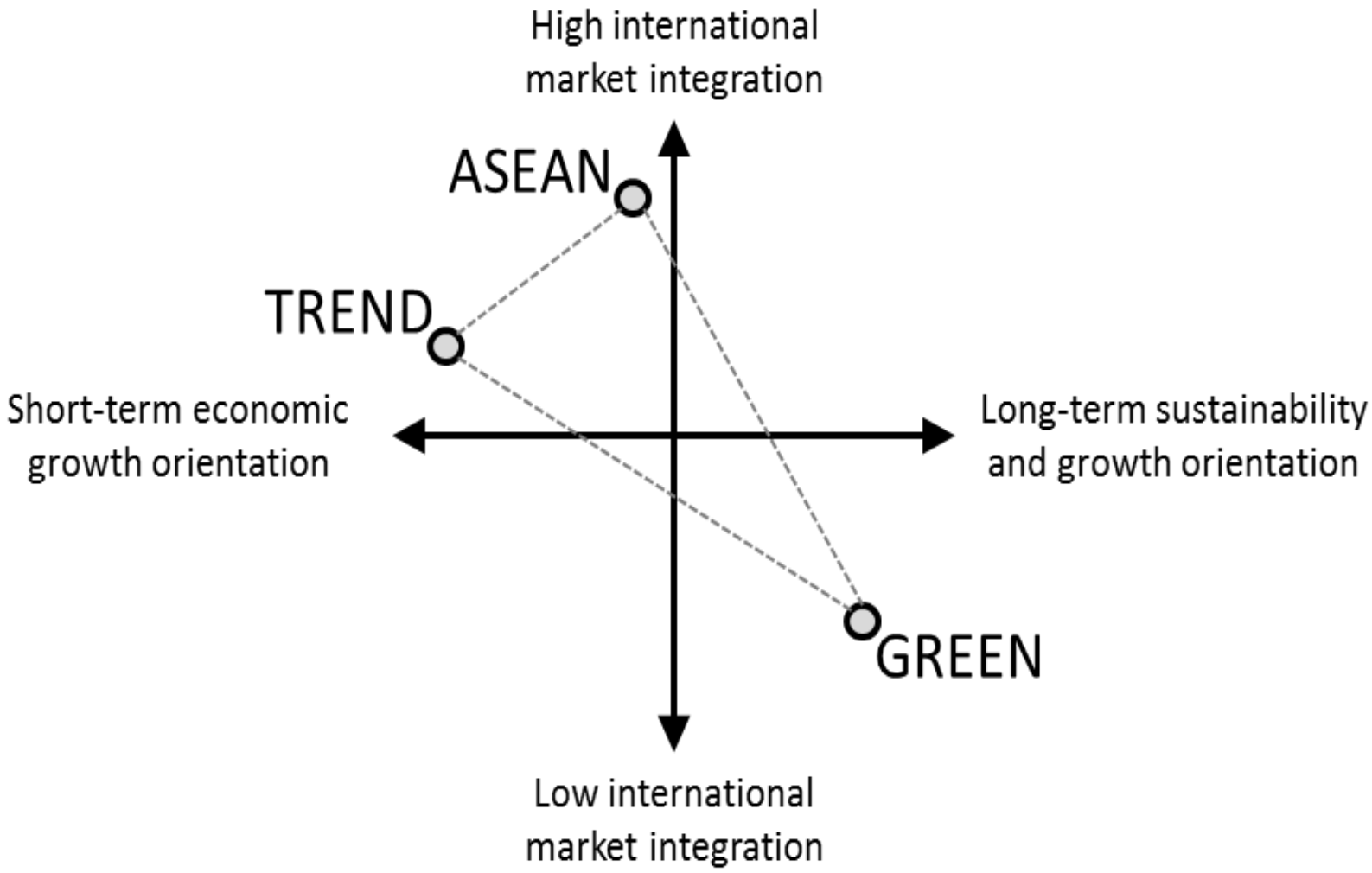
- Discussion
- Raising awareness
- Planning
- Multidisciplinary integration
- or a combination of these

Policy questions	Policies
Where to plan more trees?	Woodland Expansion Strategy
Where to plan new infrastructure?	National Planning Framework
Where to locate renewables?	Renewables Routemap
How to anticipate changing water supply and demand?	Water Framework Directive
How to plan against pest, diseases and invasive species?	Wildlife & Natural Environment Act
How to plan flood defense?	Flood Management Act
How to plan Ecological Networks ?	Biodiversity Strategy
How to deliver realistic conservation?	Biodiversity Strategy
Which pathways lead to a low carbon economy?	Climate Change Act
How to integrate these objectives across sectors?	Land Use Strategy

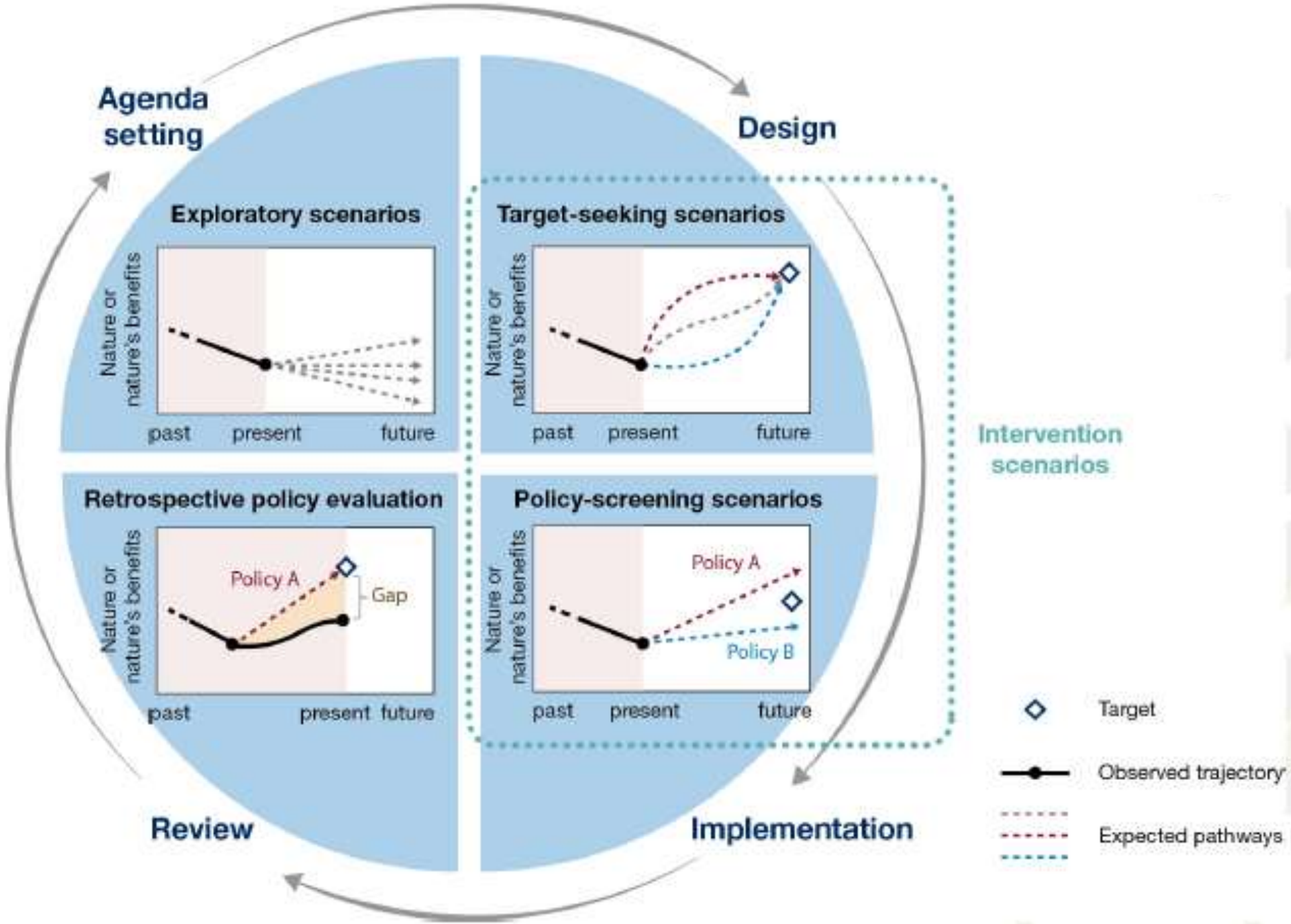
Types of scenarios

1. **Exploratory** - what could happen
   describe alternative, hypothetical (but plausible) long term futures
2. **Normative** - what we would like to happen
   describe desired futures, and how to get there
3. **Business-as-Usual** - best guess
   describe what we think is going to happen in the future based on extrapolating what we know now; policy evaluation (short-term)

Scenario narratives



	V-A1	V-A2	V-B1	V-B2
Population	9 billion people in 2050, 7 billion in 2100	15 billion people in 2100	9 billion people in 2050, 7 billion in 2100	10 billion people in 2100
Trade	Trade liberalisation	Continuous trade patterns	Trade liberalisation	Highly regionally self-sufficient
Food Demand	Increasing demand per capita for calories & livestock products (linked to income growth)	Increasing demand per capita for calories & livestock products (linked to income growth)	Equal per capita consumption around the world, sustainable diet ("contraction and convergence")	Increasing demand per capita for calories & livestock products (related to income growth)
Land-Use	Weak regulation, e.g. declining intact forest area	Weak regulation, e.g. declining intact forest area	Global land use regulation for climate mitigation, forest protection & biodiversity conservation (constant intact forest area)	Regionally specific land use regulation for climate mitigation, forest protection & biodiversity conservation (constant/declining intact forest area)
Bioenergy	Bioenergy (global supply) for baseline use [no global agreement on CC mitigation]; biofuel targets phased out	Bioenergy (regional supply) for baseline use [no global agreement on CC mitigation]; biofuel targets phased out	Bioenergy (global supply) for CC mitigation [global agreement on CC mitigation]; medium bioenergy shares	Bioenergy (regional supply) for baseline [regional agreements on CC mitigation]; medium bioenergy shares
Climate Change	Medium level of emissions (CC: ca. +3C in 2100); medium climate impacts	High level of emissions (CC: GMT ca. +4C in 2100); medium climate impacts	Low Level of Emisions (CC: ca. +2C in 2100); medium climate impacts	Low to medium level of emissions; medium climate impacts
CAP reform (until 2020 plus extrapolation)	Fully liberalized: full abolition of Pillar 1 and 2. CAP budget will be zero.	No change. CAP budget constant.	Abolition Pillar 1, 33% of the reduced Pillar 1 budget shift to pillar 2 (linked to environmental and social targets)	33% of Pillar 1 budget will be shifted to pillar 2 (linked to environmental and social targets)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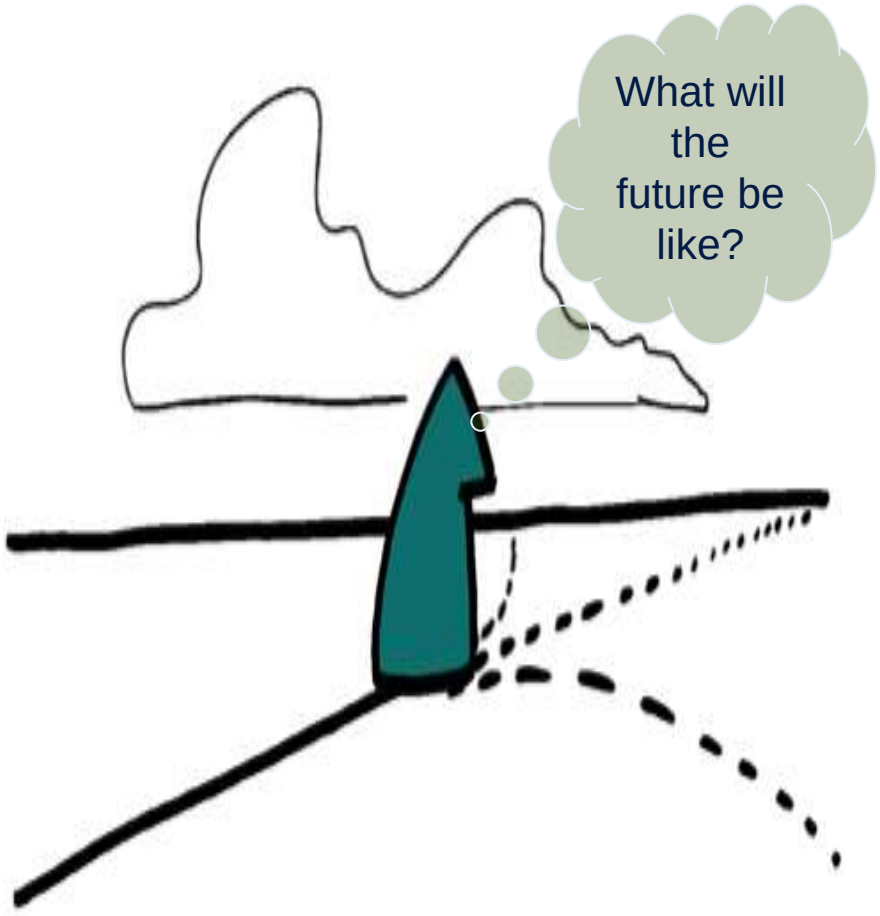
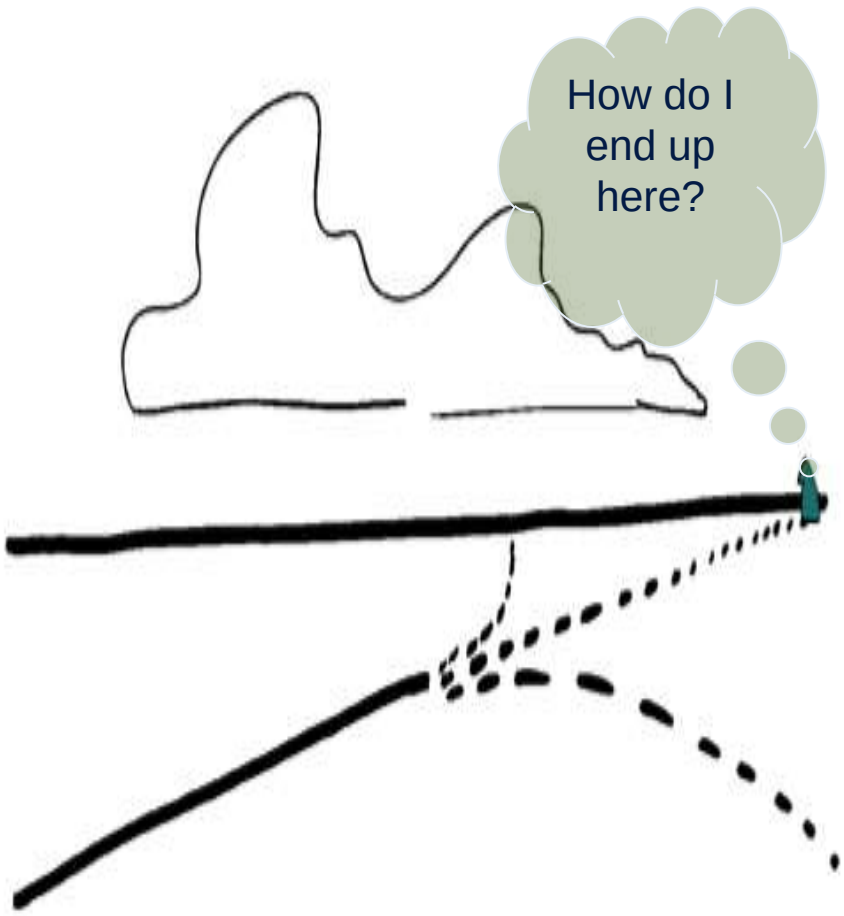
Scenario approaches

- Explorative scenarios



- Goal-oriented scenarios

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9 INDUSTRY, INNOVATION AND INFRASTRUCTURE
10 REDUCED INEQUALITIES
11 SUSTAINABLE CITIES AND COMMUNITIES
THE GLOBAL GOALS
For Sustainable Development
12 RESPONSIBLE CONSUMPTION AND PRODUCTION
13 CLIMATE ACTION
14 LIFE BELOW WATER
15 LIFE ON LAND
16 PEACE, JUSTICE AND STRONG INSTITUTIONS
17 PARTNERSHIPS FOR THE GOALS

The Aichi Biodiversity Targets

Strategic Goal A: *Address the underlying causes of biodiversity loss by mainstreaming biodiversity across government and society*

By 2020, at the latest, people are aware of the values of biodiversity and the steps they can take to conserve and use it sustainably.

By 2020, at the latest, biodiversity values have been integrated into national and local development and poverty reduction strategies and planning processes and are being incorporated into national accounting, as appropriate, and reporting systems.

By 2020, at the latest, incentives, including subsidies, harmful to biodiversity are eliminated, phased out or reformed in order to minimize or avoid negative impacts, and positive incentives for the conservation and sustainable use of biodiversity are developed and applied, consistent and in harmony with the Convention and other relevant international obligations, taking into account national socio economic conditions.

By 2020, at the latest, Governments, business and stakeholders at all levels have taken steps to achieve or have implemented plans for sustainable production and consumption and have kept the impacts of use of natural resources well within safe ecological limits.

Strategic Goal B: *Reduce the direct pressures on biodiversity and promote sustainable use*

By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced.

By 2020 all fish and invertebrate stocks and aquatic plants are managed and harvested sustainably, legally and applying ecosystem based approaches, so that overfishing is avoided, recovery plans and measures are in place for all depleted species, fisheries have no significant adverse impacts on threatened species and vulnerable ecosystems and the impacts of fisheries on stocks, species and ecosystems are within safe ecological limits.

By 2020 areas under agriculture, aquaculture and forestry are managed sustainably, ensuring conservation of biodiversity.

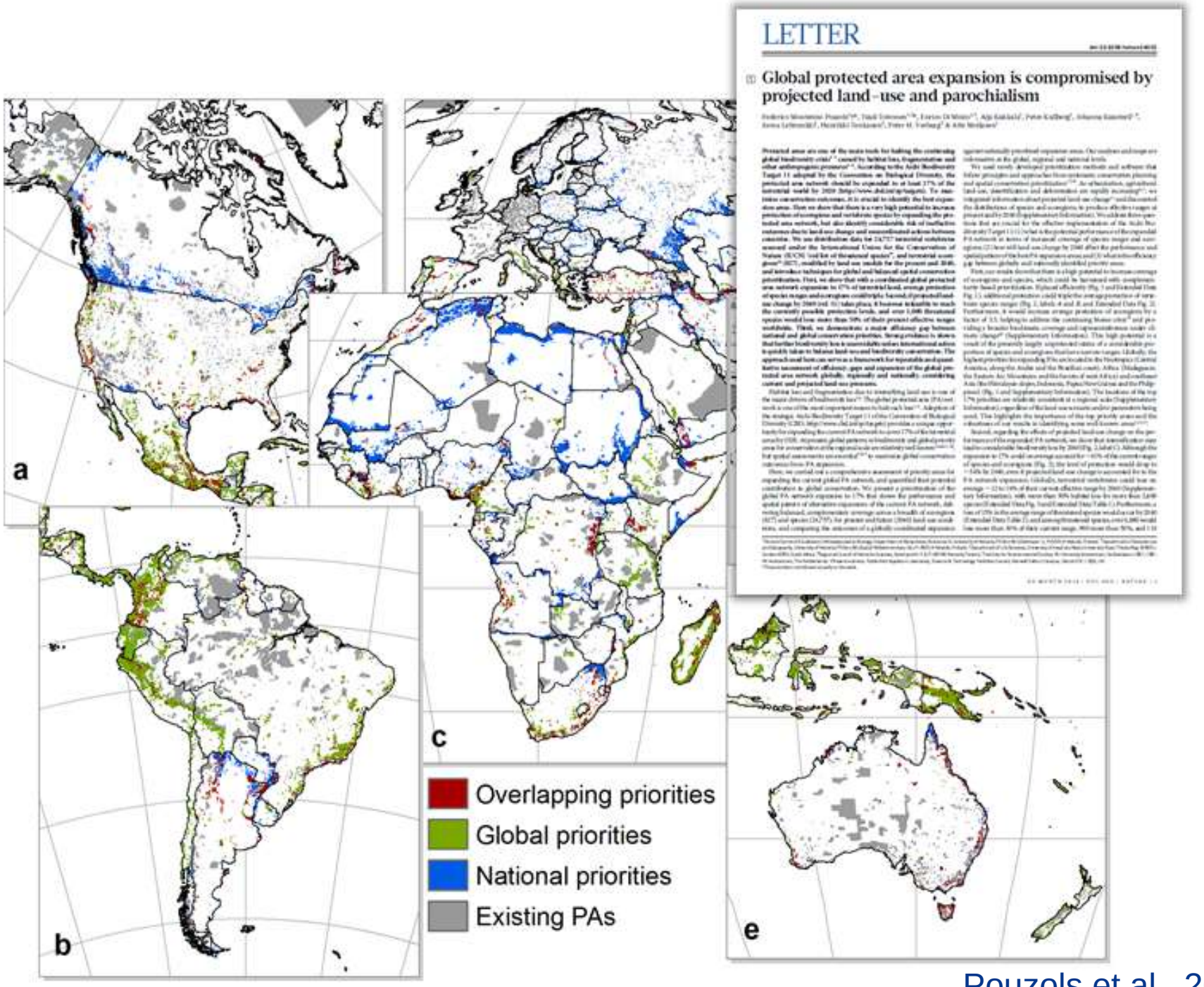
By 2020, pollution, including from excess nutrients, has been brought to levels that are not detrimental to ecosystem function and biodiversity.

By 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment.

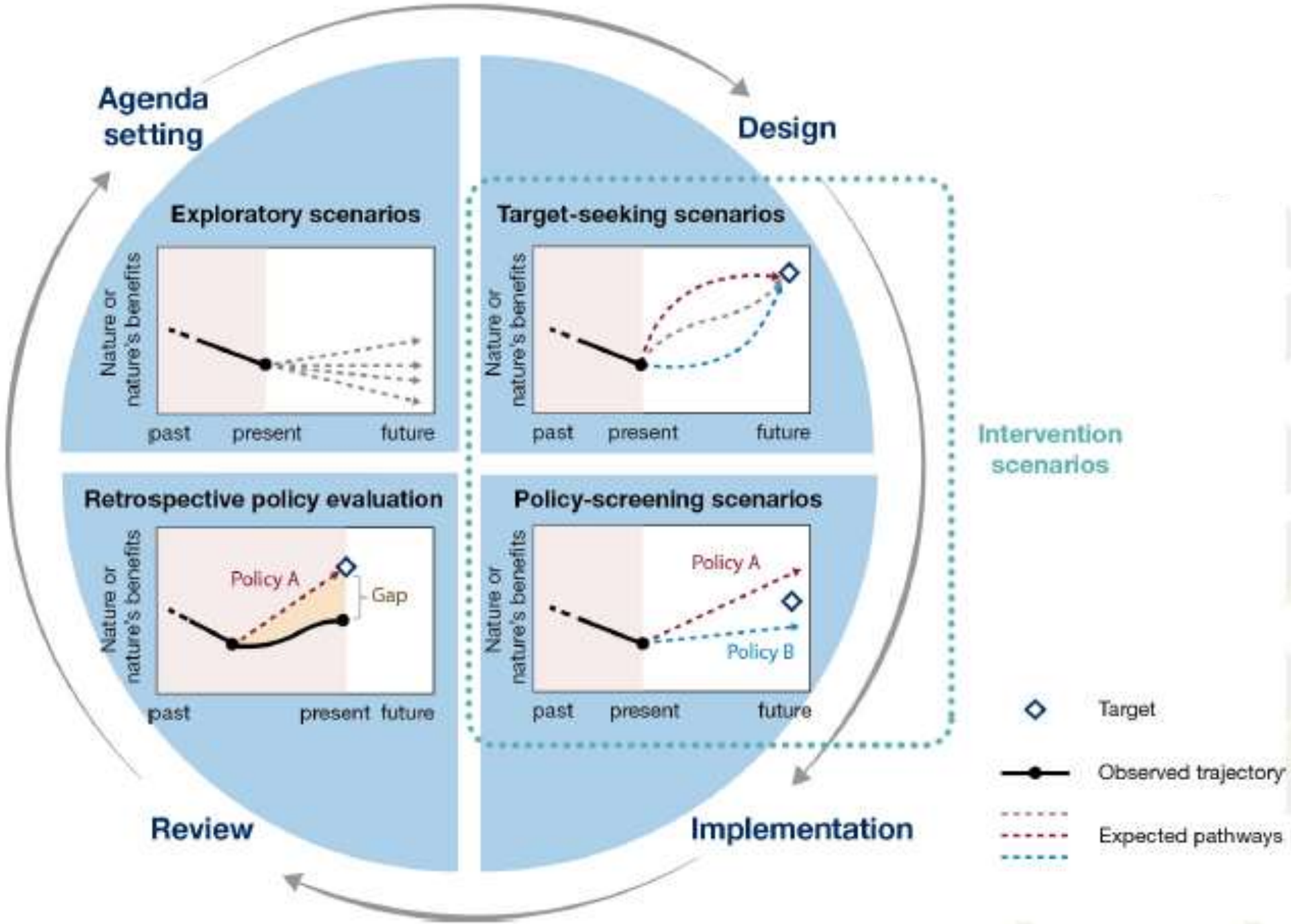
By 2015, the multiple anthropogenic pressures on coral reefs, and other vulnerable ecosystems impacted by climate change or ocean acidification are minimized, so as to maintain their integrity and functioning.

Strategic Goal C: *Improve the status of biodiversity by safeguarding ecosystems, species and genetic diversity*

By 2020, at least 17 per cent of terrestrial and inland water, and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well connected systems

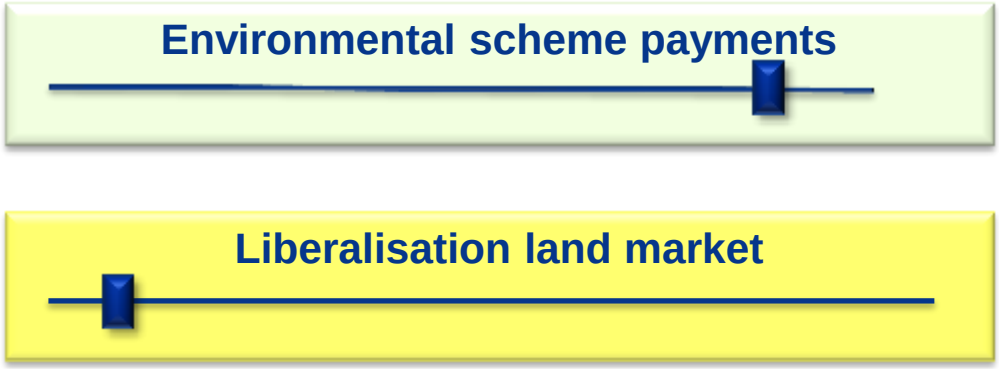


Pouzols et al., 2014


Agenda setting
Design
Exploratory scenarios
Target-seeking scenarios
Nature or nature's benefits
past
present
future
Intervention scenarios
Retrospective policy evaluation
Policy-screening scenarios
Policy A
Gap
Policy B
Review
Implementation
Target
Observed trajectory
Expected pathways

Examples of ex-ante assessment questions

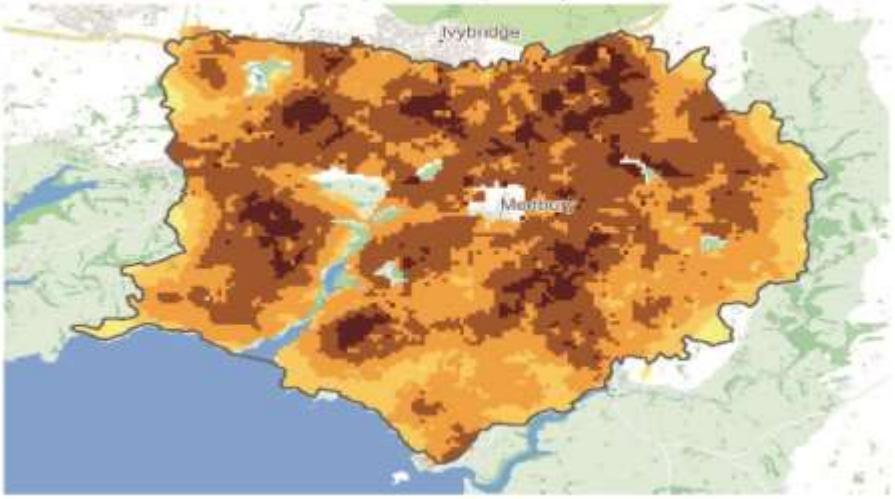
- What are the land use effects of building a new road?
- What are the land use effects of allowing new concessions?
- What are the land use effects of import tariffs on food?
- What are the land use effects of new conservation areas?


Environmental scheme payments
Liberalisation land market

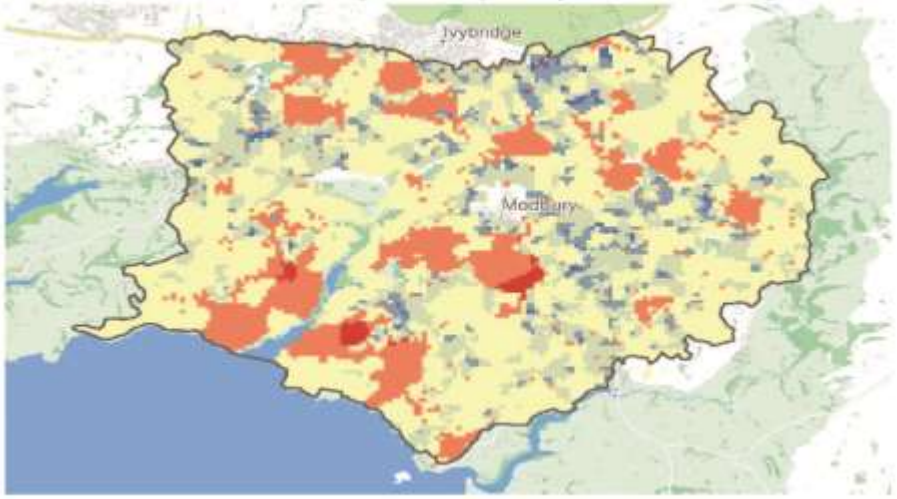
Scenario results

HERCULES

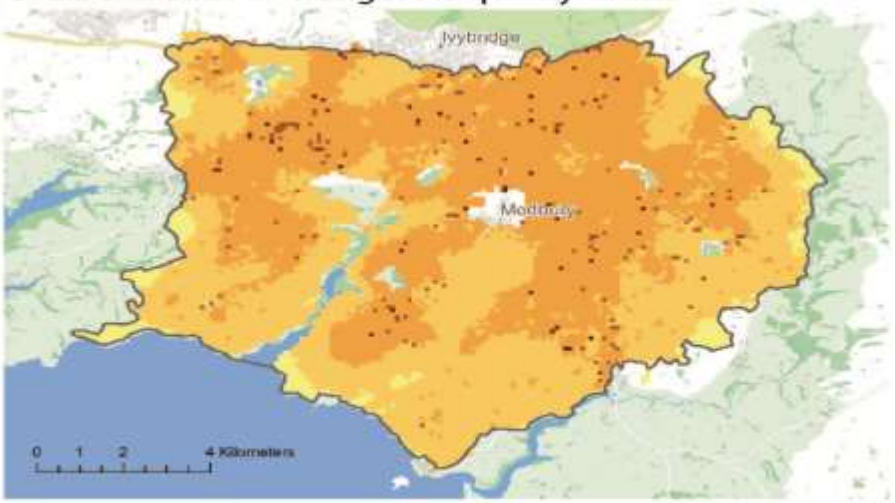
A. Conservation - hedgerow quality index



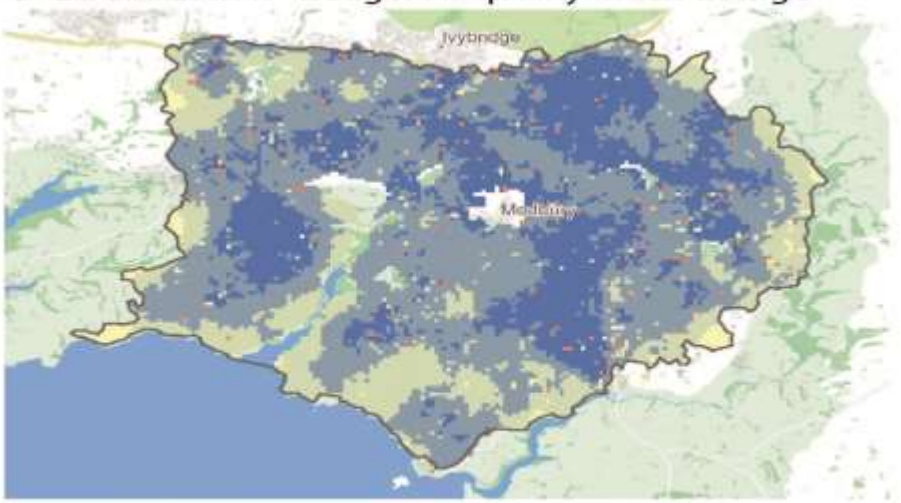
C. Conservation - hedgerow quality index change



B. Liberalization - hedgerow quality index



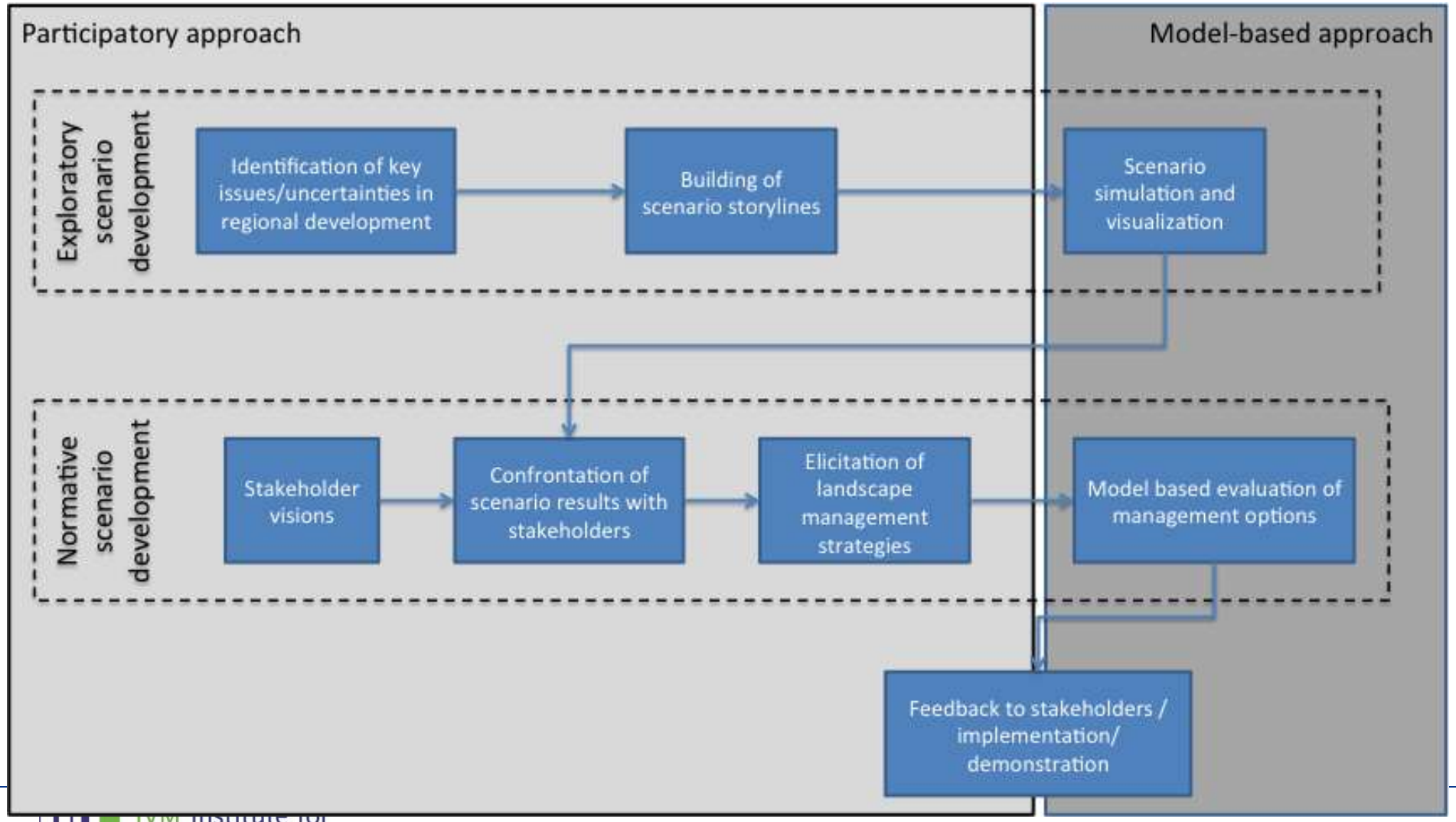
D. Liberalization - hedgerow quality index change



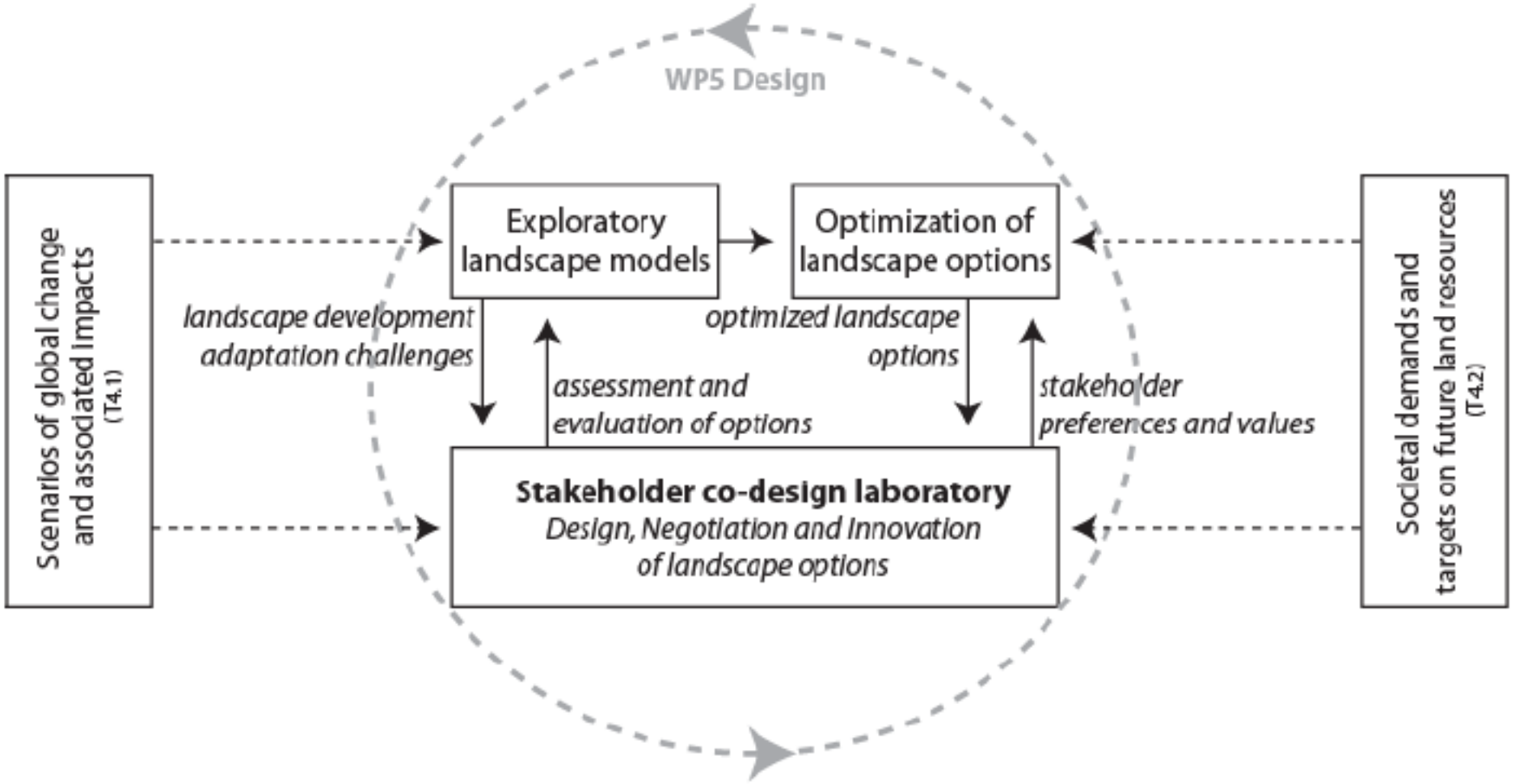
0 - 0.2 | 0.2 - 0.4 | 0.4 - 0.6 | 0.6 - 0.8 | 0.8 - 1

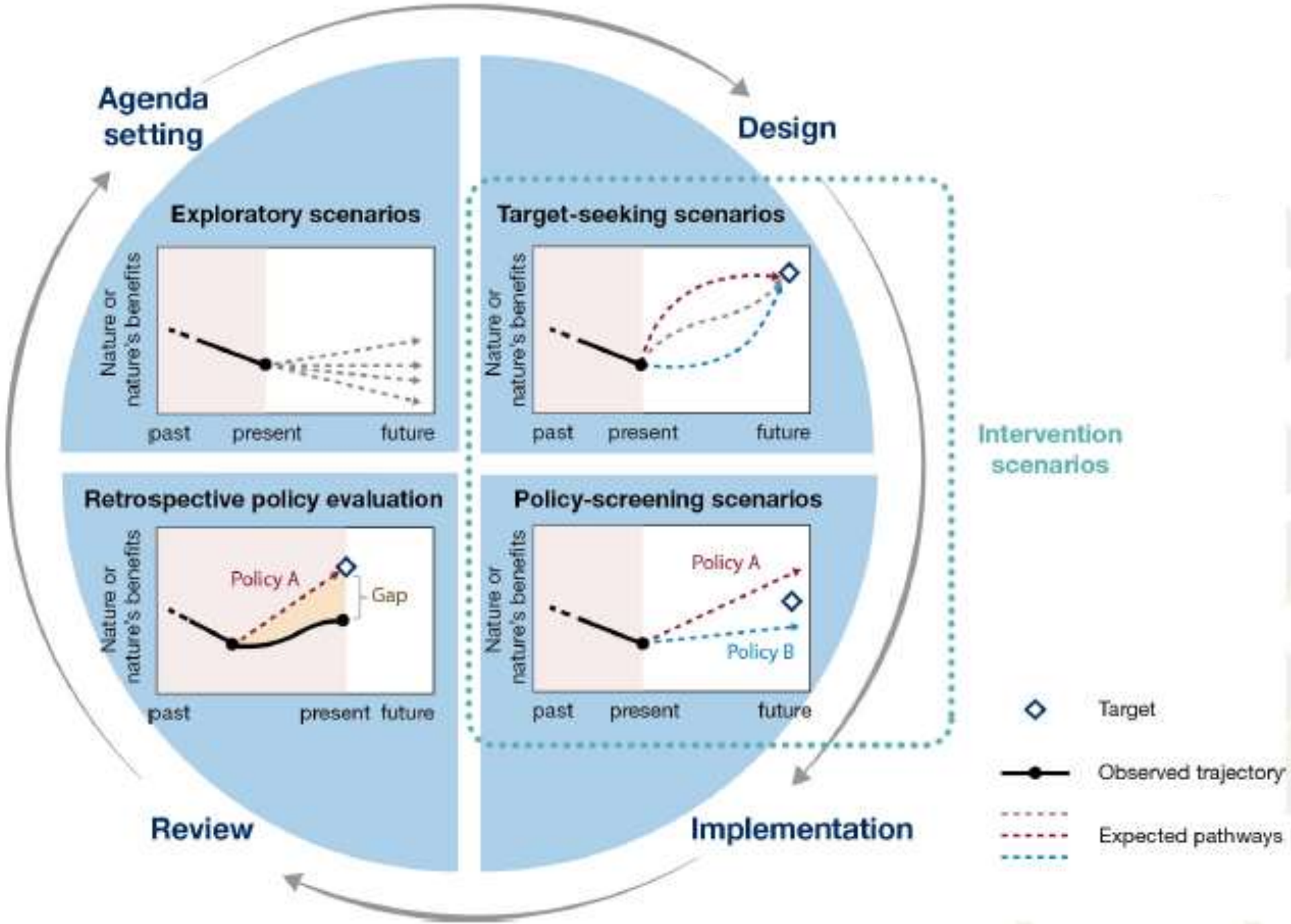
< -0.25 | -0.25 - -0.15 | -0.15 - -0.05 | -0.05 - 0.05 | 0.05 - 0.15 | 0.15 - 0.25

Workshop


Participatory approach
Model-based approach
Exploratory scenario development
Identification of key issues/uncertainties in regional development
Building of scenario storylines
Scenario simulation and visualization
Normative scenario development
Stakeholder visions
Confrontation of scenario results with stakeholders
Elicitation of landscape management strategies
Model based evaluation of management options
Feedback to stakeholders / implementation/ demonstration

Combining method to 'design' new land use options

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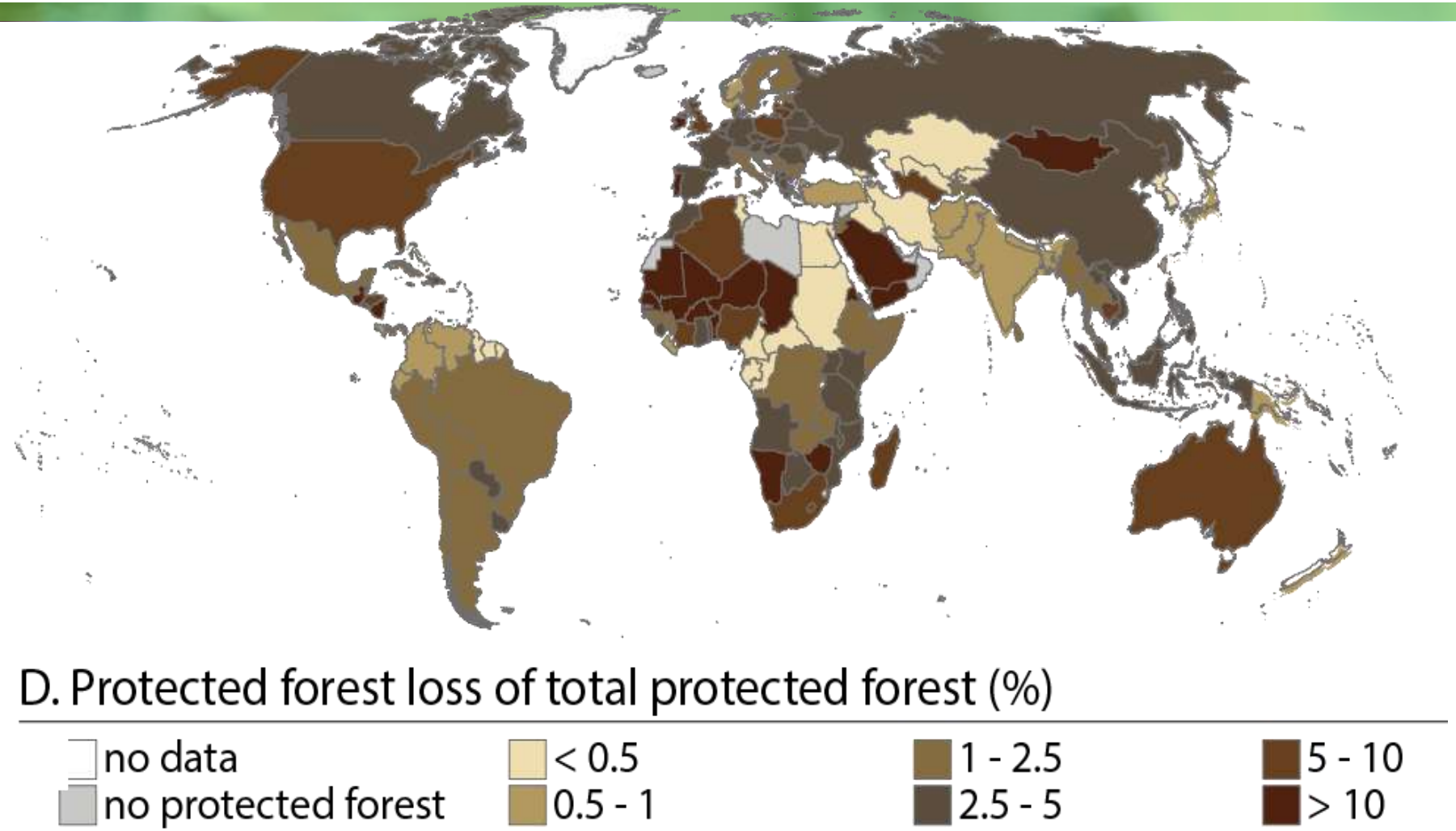
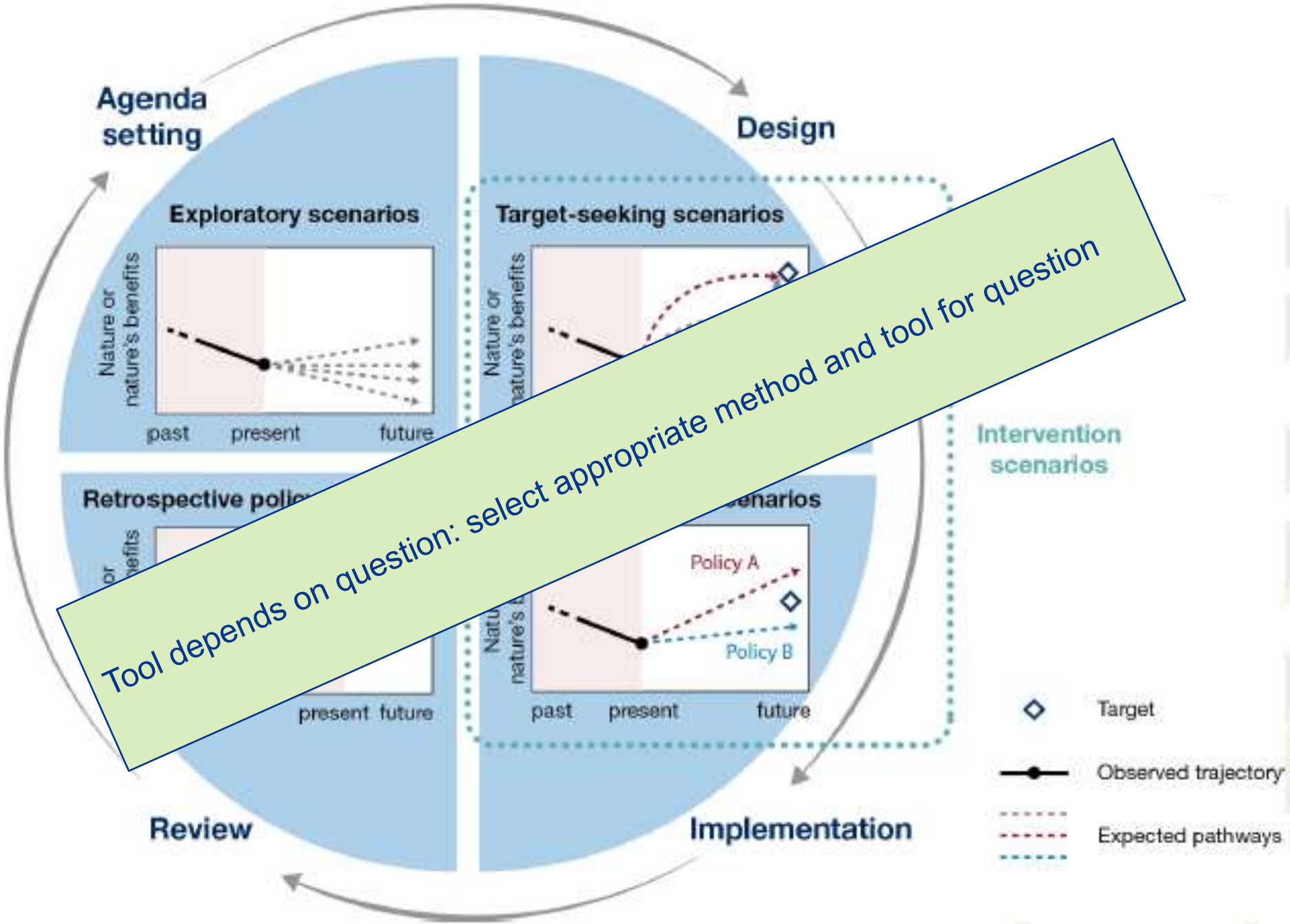
Ex-post assessment of protected area effectiveness



Kummu et al., Plos One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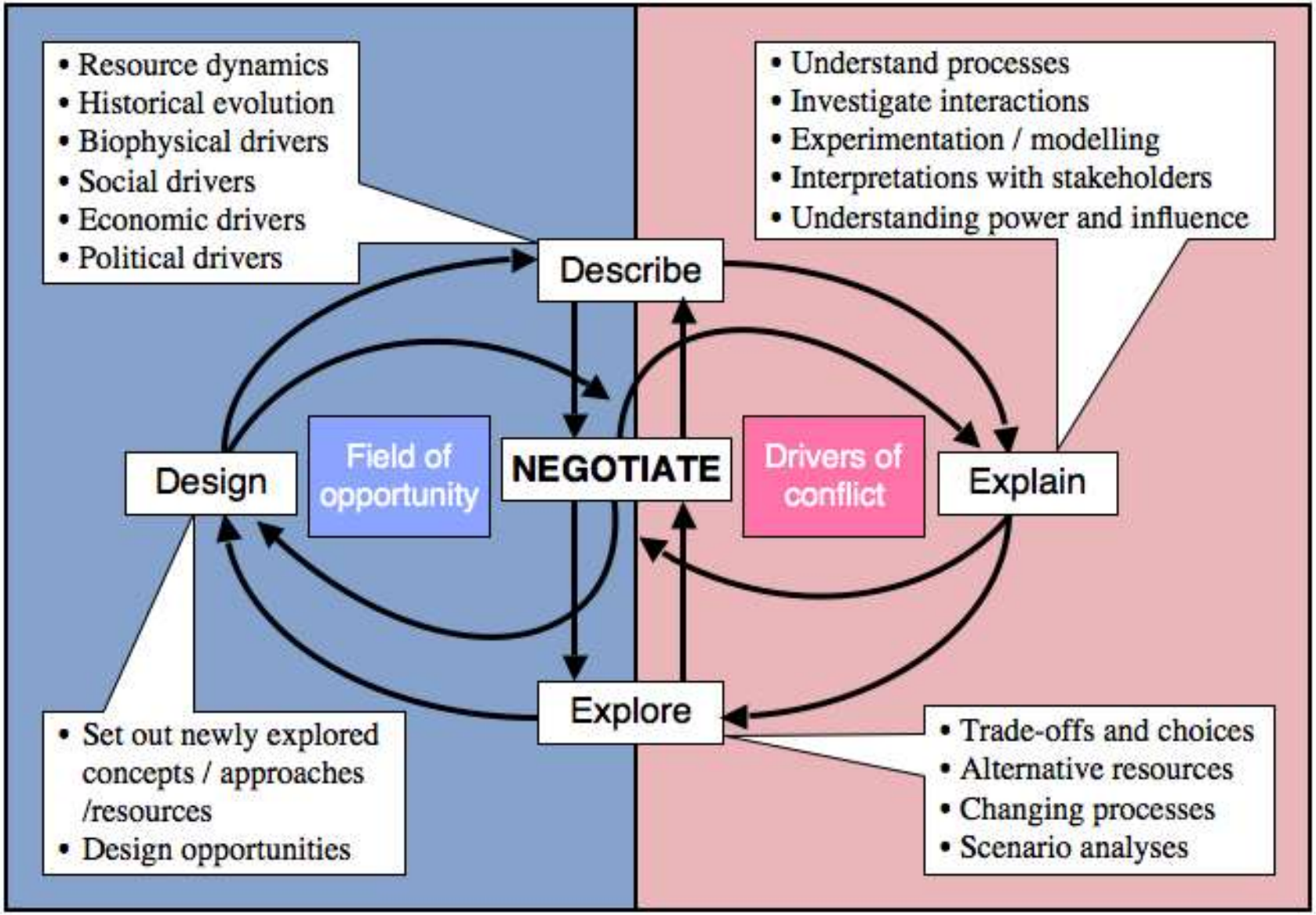
Tool depends on question: select appropriate method and tool for question

Land use modelling areas

- **Exploratory scenarios:**
  - What change to anticipate in the future?
  - What are land management/policy needs to avoid unfavourable futures?
  - What is the likely impact of external drivers on land use?
  - How robust are policy measures under different scenarios?
- **Ex-ante assessment:**
  - What are the impacts on land use of specific policy measures or incentives?
  - What are the longer-term (indirect) effects of infrastructure investments?
  - What are the ‘displaced’ impacts of land use planning or zoning?

The role of Science in Sustainable Land Use



Giller et al., 2008

Co-design and co-production

Thank you!