



How science can help inform policies & decisions on climate & biodiversity

Professor Koh Lian Pin

Director, Centre for Nature-based Climate Solutions



Centre for Nature-based
Climate Solutions

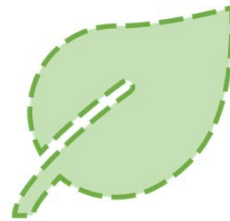
“... there are known knowns... and known unknowns...”

-Secretary Donald Rumsfeld, 2002





What we
know



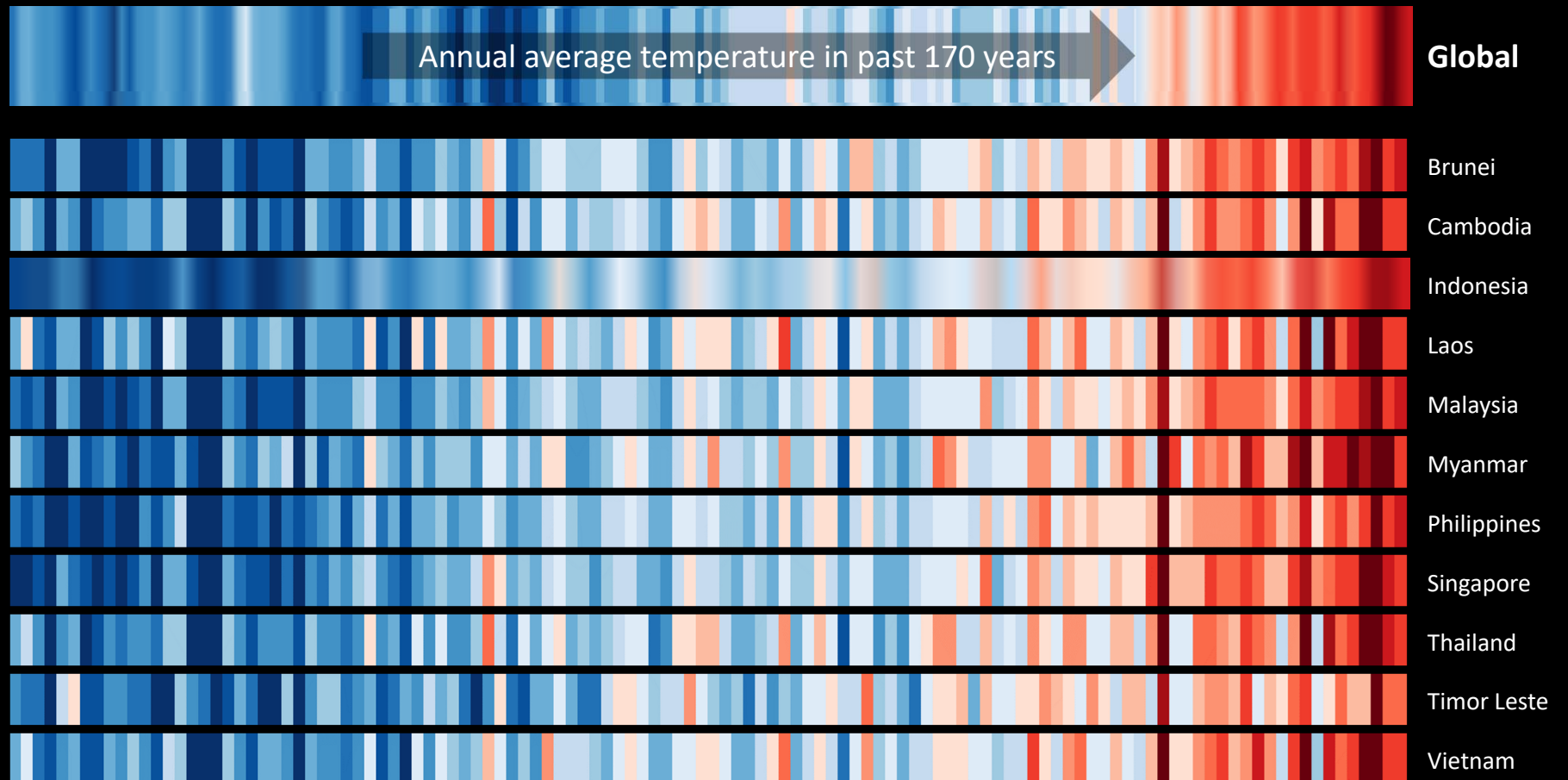
What we are
beginning to
know



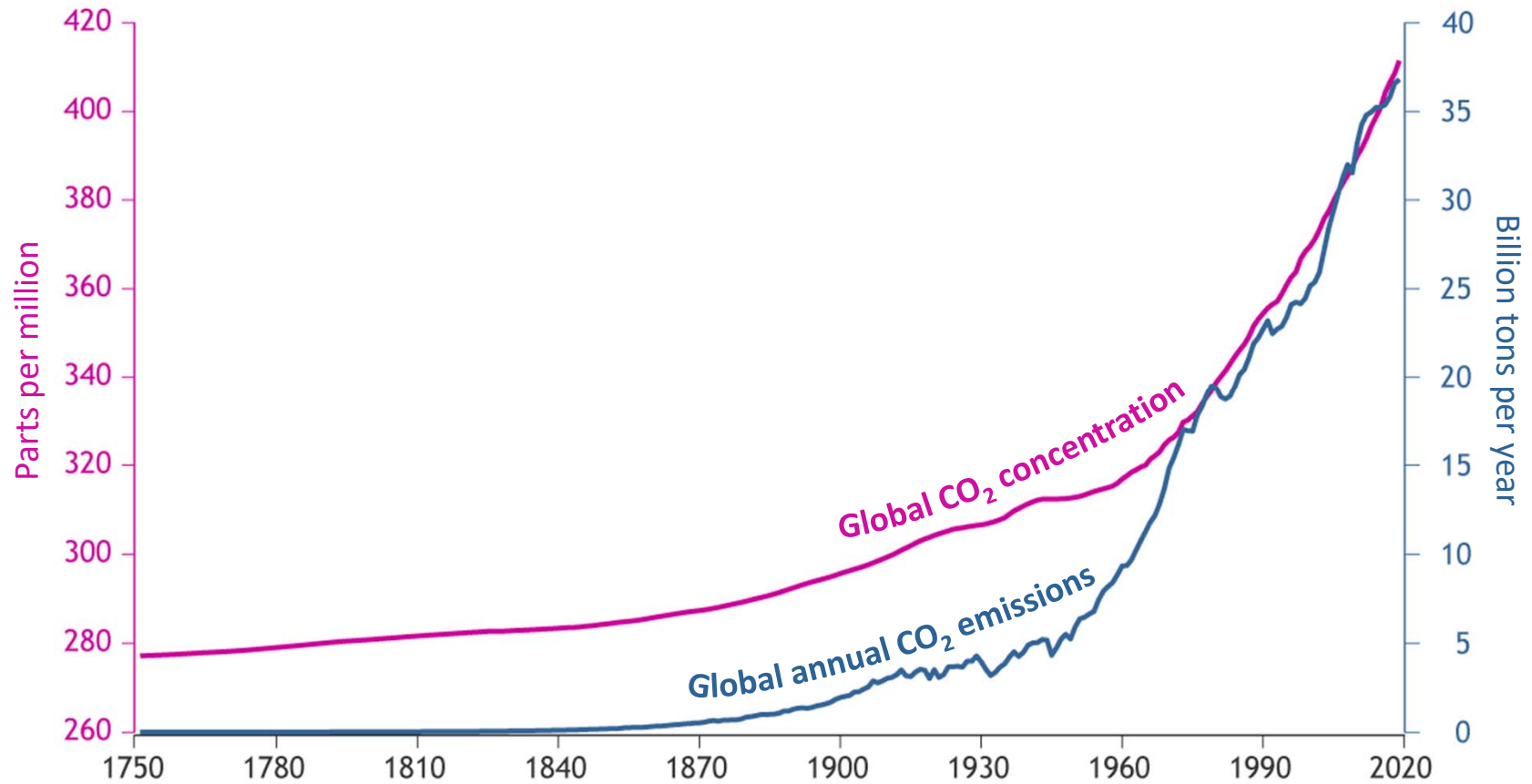
What we don't
know... but urgently
need to know

What do we know? 

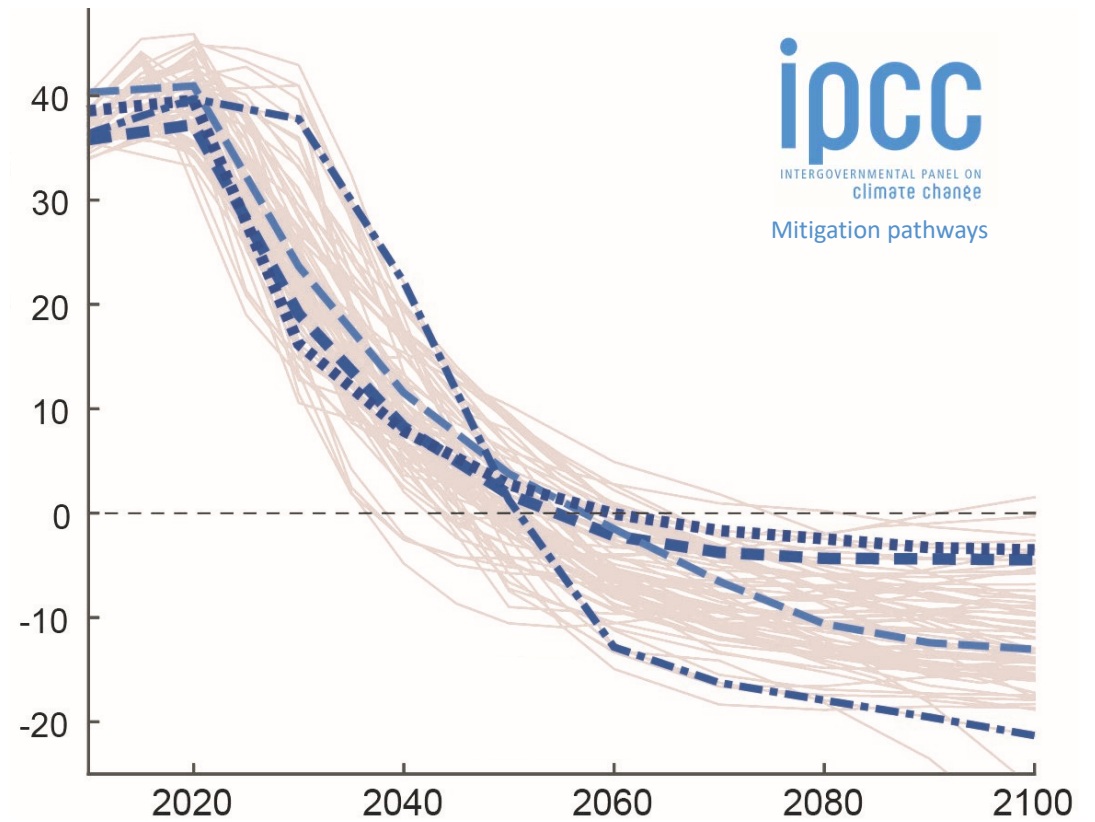
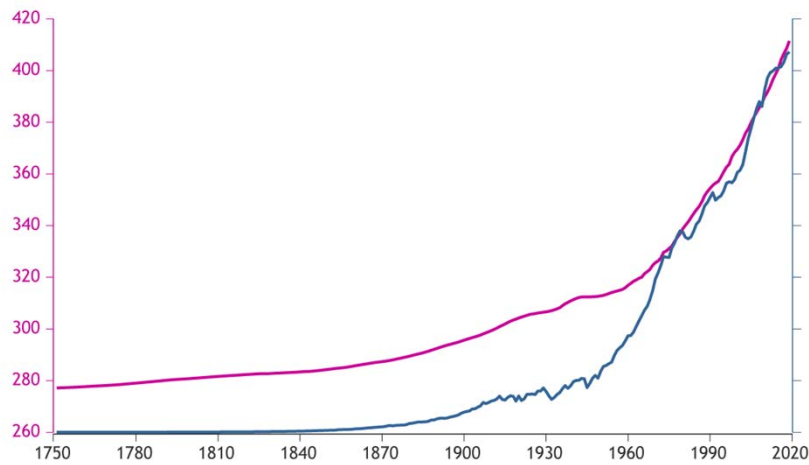
Problem



Cause



Solution



Climate change is a global emergency



THE STRAITS TIMES

Singapore Parliament declares climate change a global emergency

PUBLISHED FEB 1, 2021, 10:56 PM SGT



THE STRAITS TIMES

Budget debate: Sentosa to become carbon-neutral destination by 2030

PUBLISHED MAR 4, 2021, 1:46 PM SGT



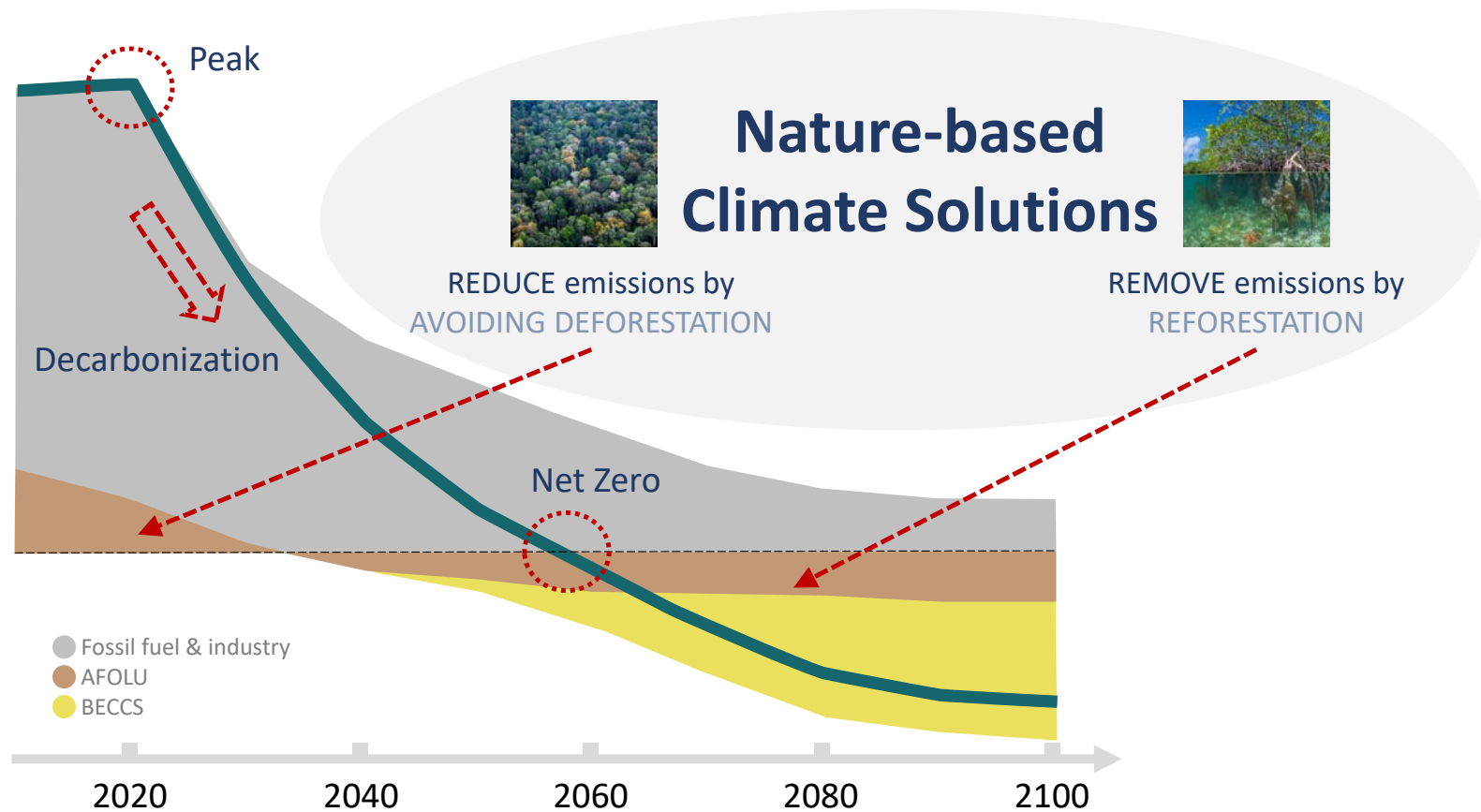
THE STRAITS TIMES

SIA Group pledges to achieve net zero carbon emissions by 2050

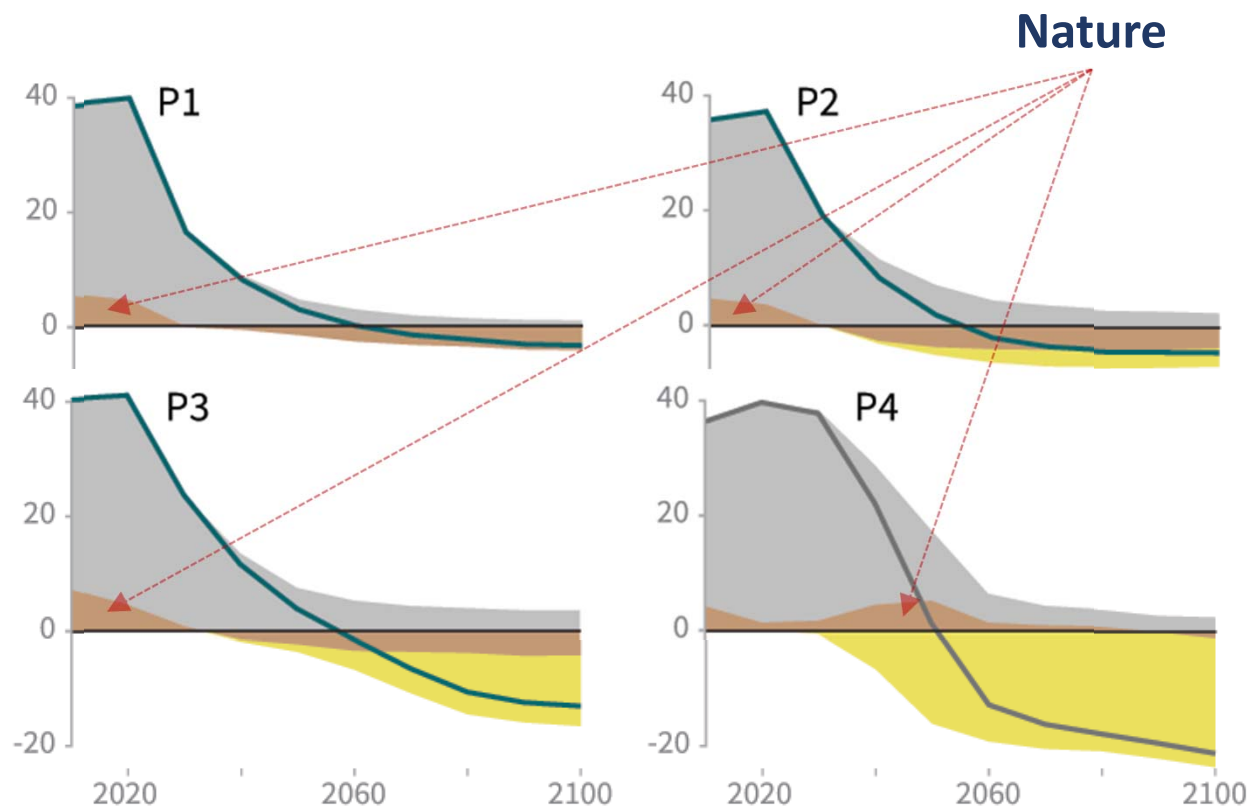
PUBLISHED MAY 24, 2021, 7:52 PM SGT

Intergovernmental Panel on Climate Change

Mitigation Pathway (P3) for achieving Paris Climate Goal



Nature is Integral Part of the Solution



What are we finding out? 

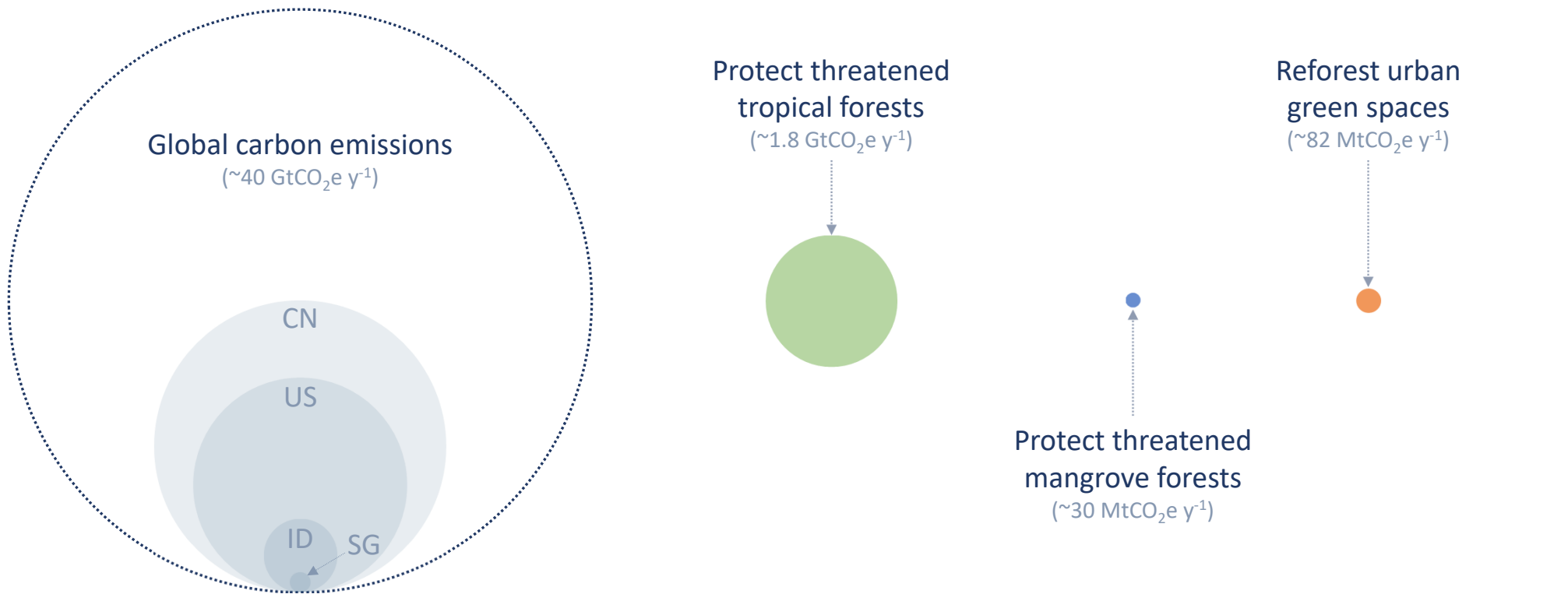
“... numbers don’t lie.”

-Dr Anthony Fauci, 2020



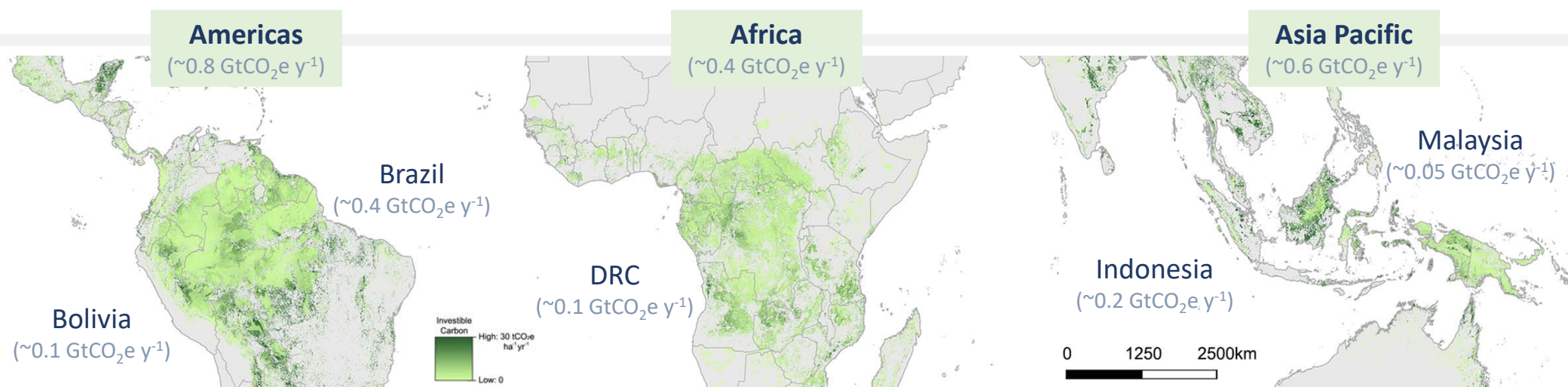
What is the potential of Nature-based Solutions?

(Scale of the Solution versus Scale of the Problem)



Where is the potential of Nature-based Solutions?

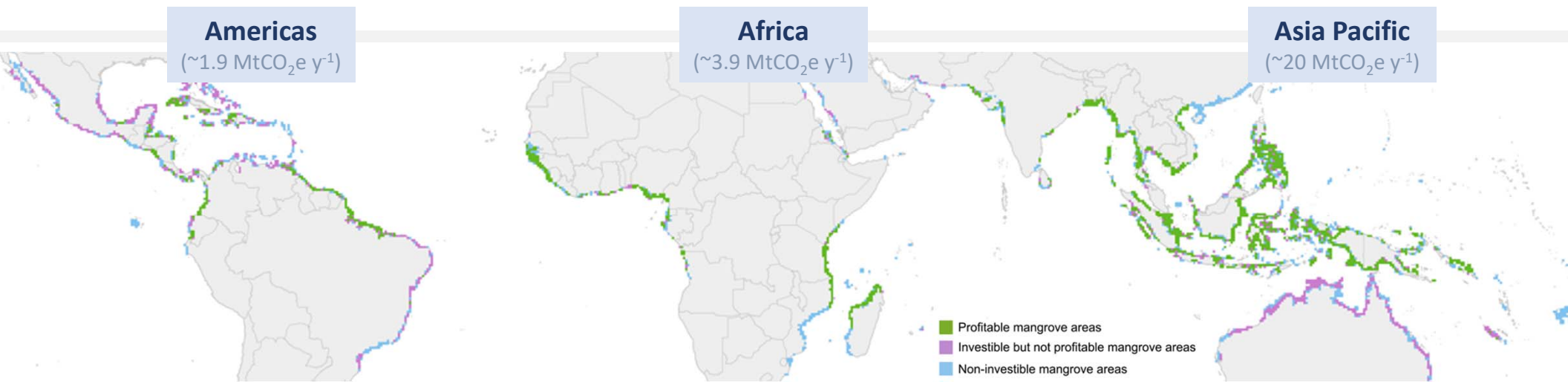
(Where to invest in forest protection to avoid carbon emissions)



Carbon Prospecting Map (potential climate mitigation)

Where is the potential of Nature-based Solutions?

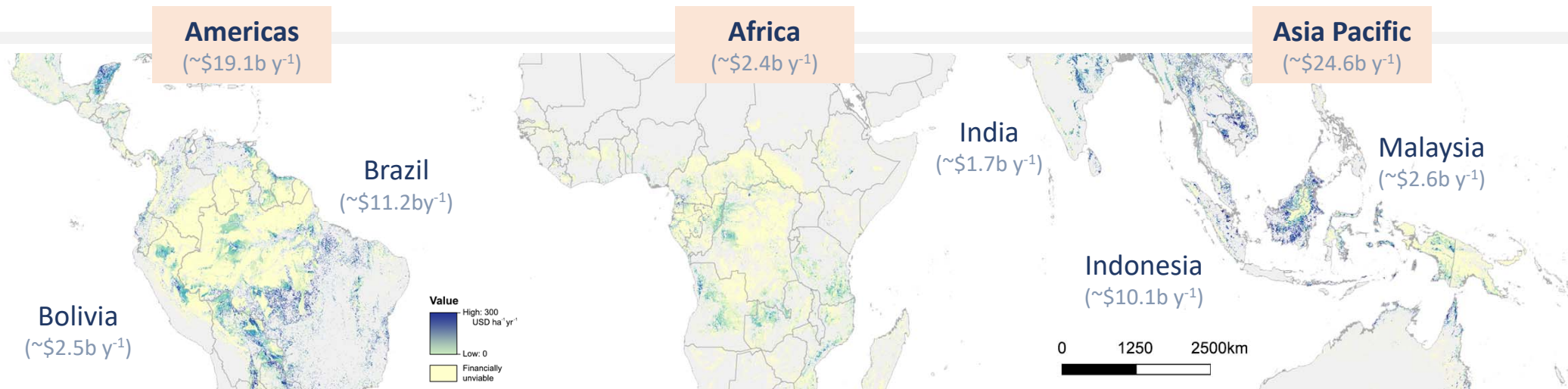
(Where to invest in forest protection to avoid carbon emissions)



Blue Carbon Prospecting Map (mangrove protection)

What is the ROI of Nature-based Carbon Projects?

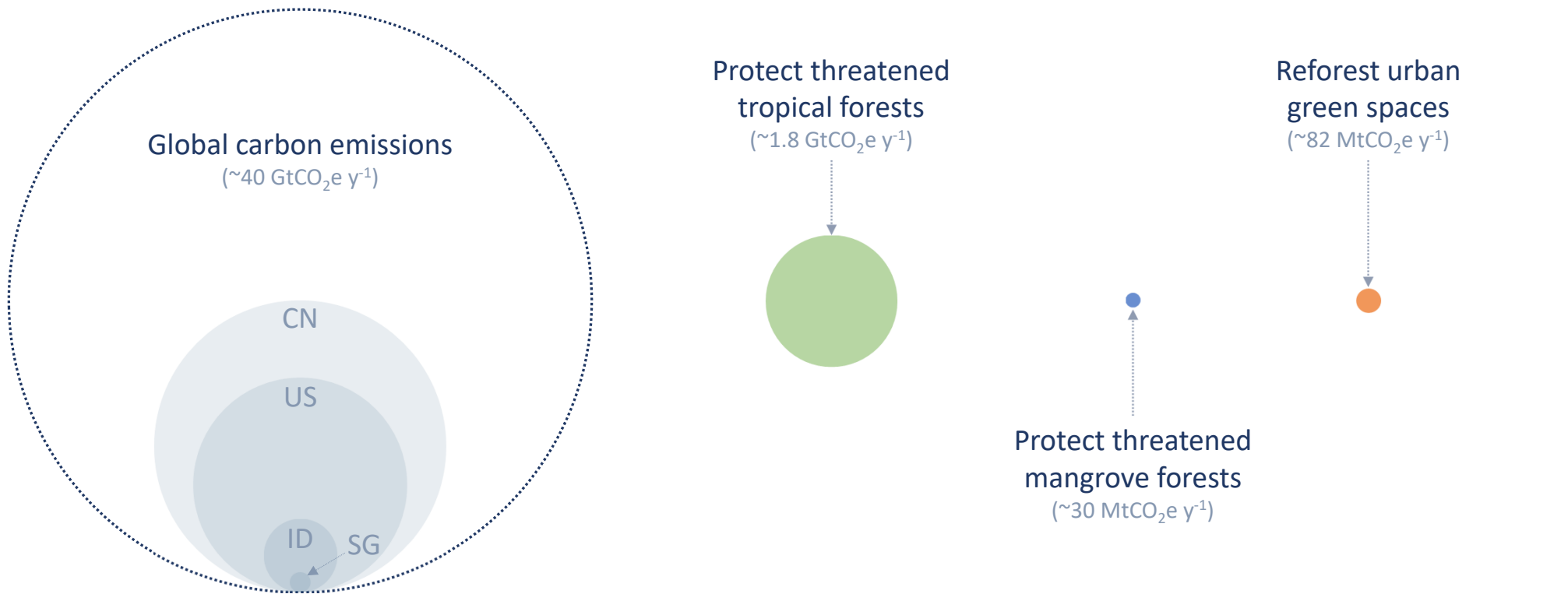
(Nature-based carbon products as investible and tradable commodities)



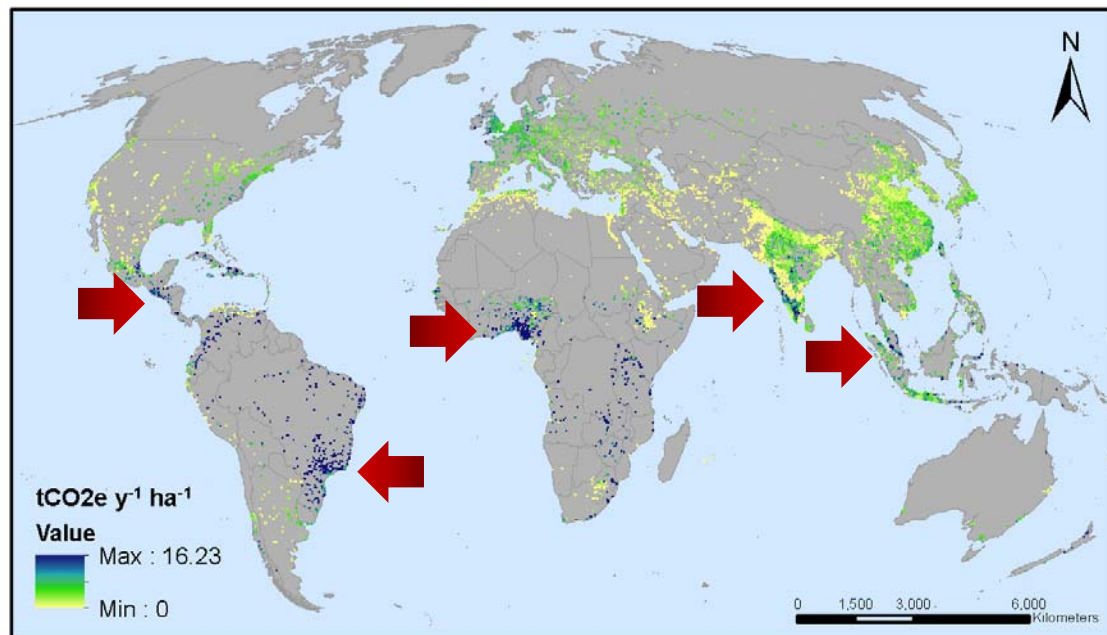
Carbon Prospecting Map (potential financial ROI)

What is the potential of Nature-based Solutions?

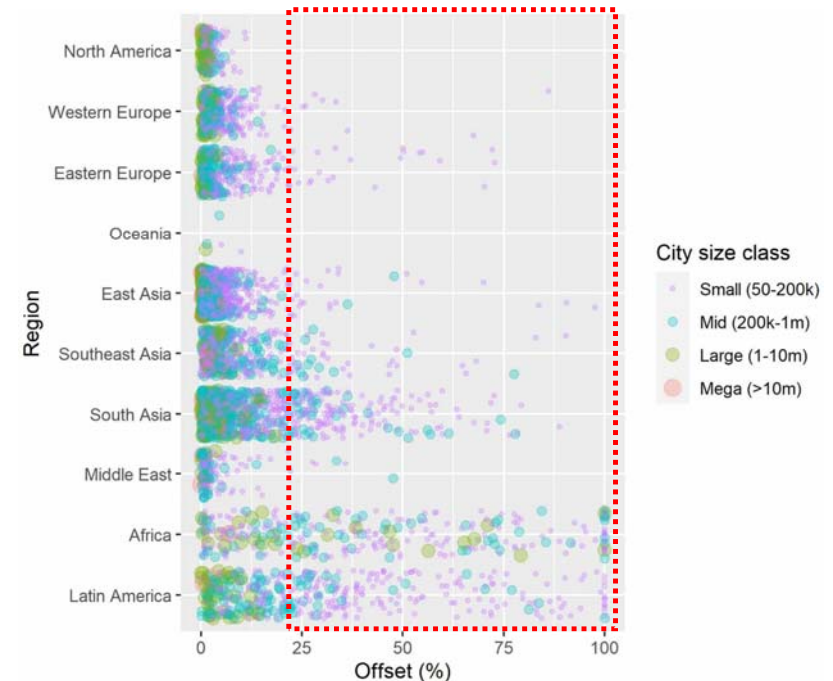
(Scale of the Solution versus Scale of the Problem)



Where is the potential of Nature-based Solutions?



Climate mitigation potential from urban reforestation

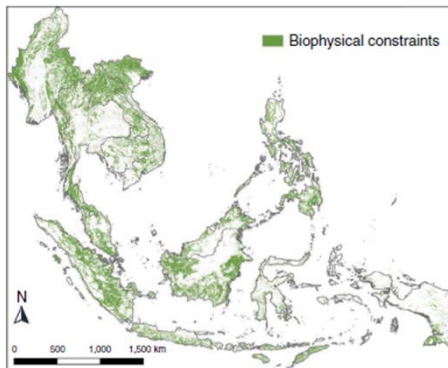


For 1,200 cities, urban reforestation can offset >25% of local emissions.

What are the Constraints?

Restoration of degraded forests, peatlands and mangroves in Southeast Asia

Biophysical



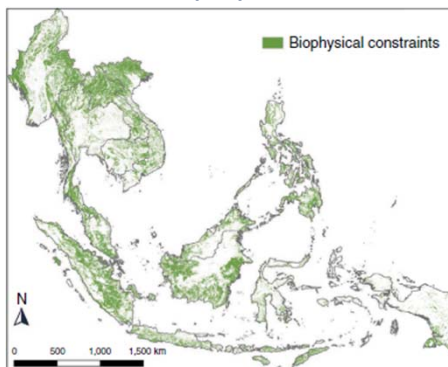
Unconstrained

121 million hectares
~3.4 GtCO₂e y⁻¹

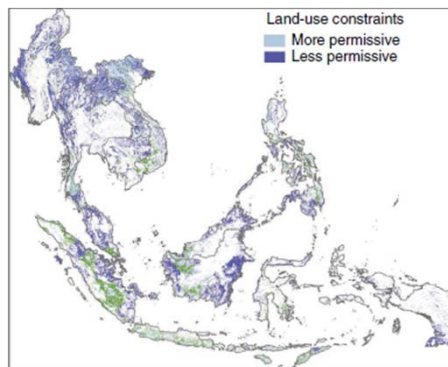
What are the Constraints?

Restoration of degraded forests, peatlands and mangroves in Southeast Asia

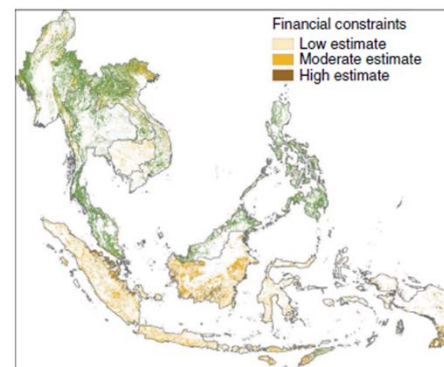
Biophysical



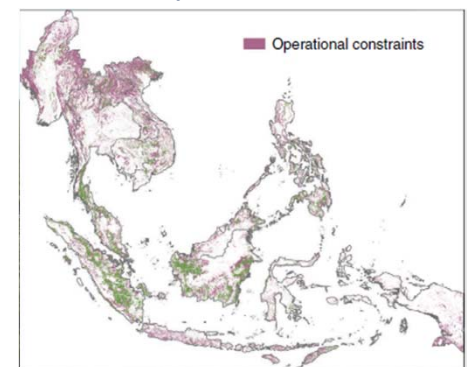
Land use



Financial



Operational



Unconstrained

121 million hectares
~3.4 GtCO₂e y⁻¹

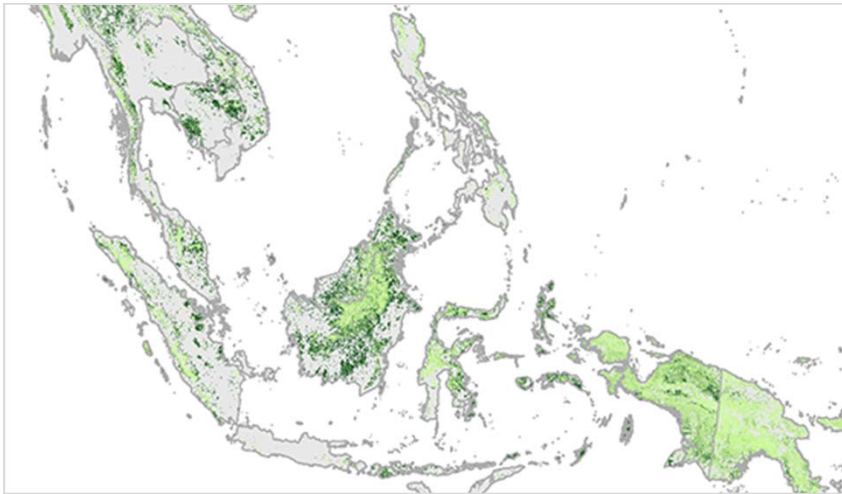
Land use, direct & opportunity costs, operational constraints

Constrained

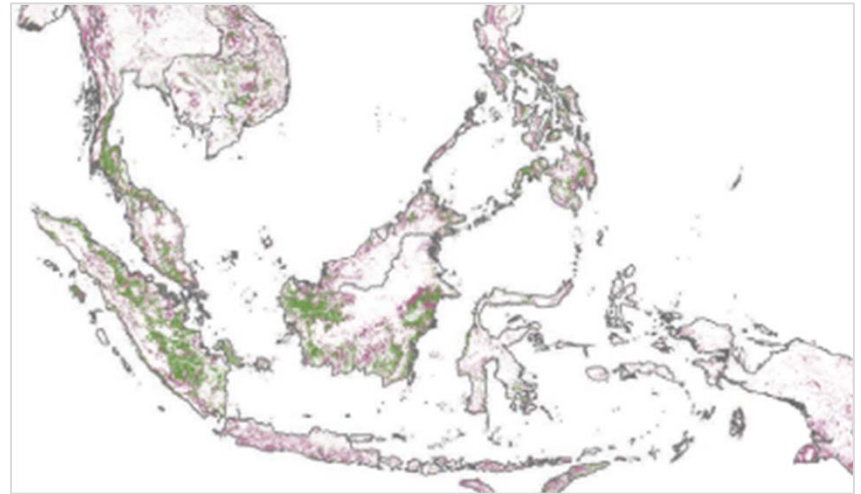
< 8 million hectares
< 0.25 GtCO₂e y⁻¹

Policy Relevant Science

Opportunities



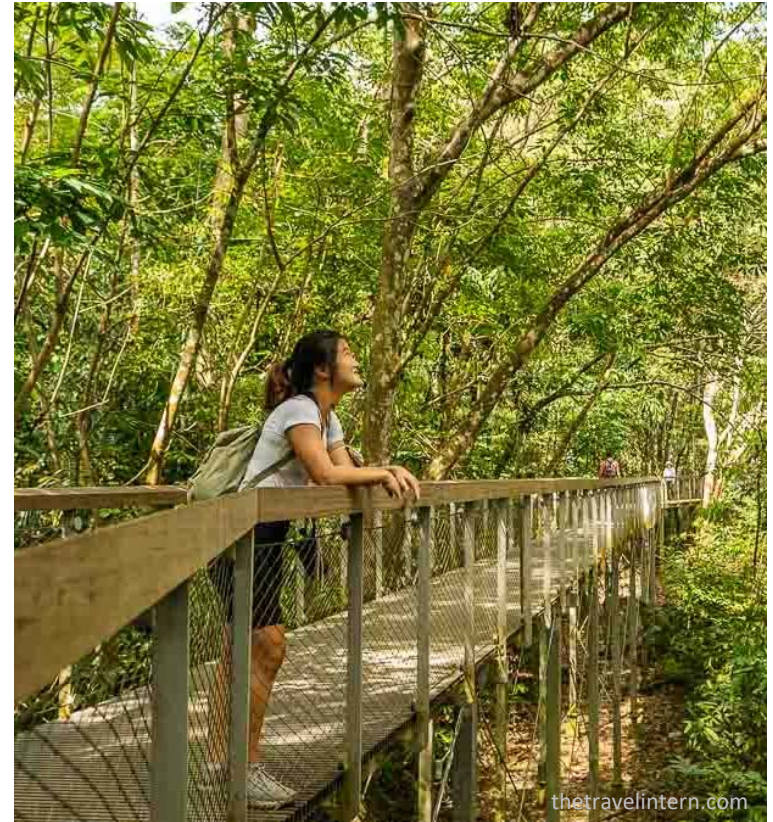
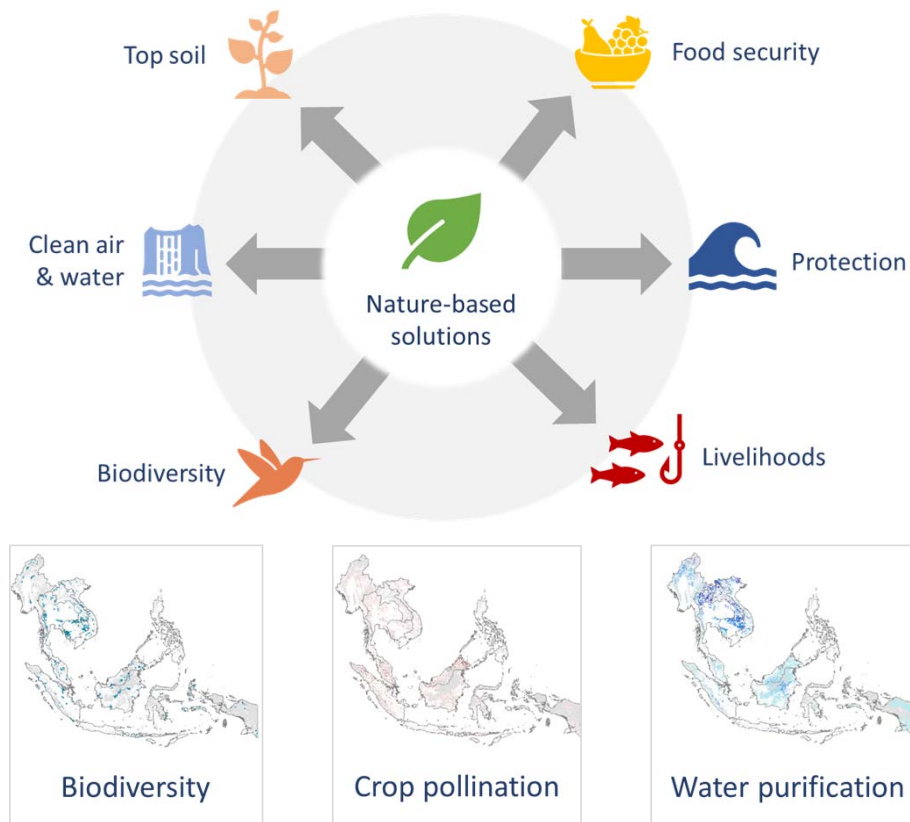
Constraints



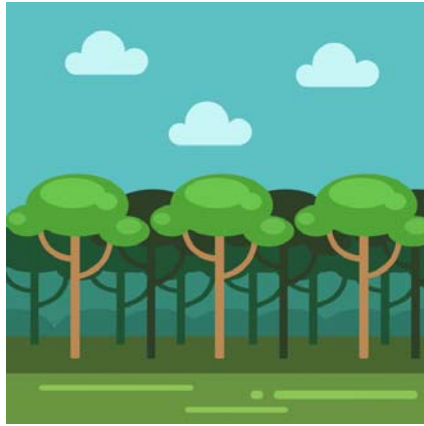
What we need to know



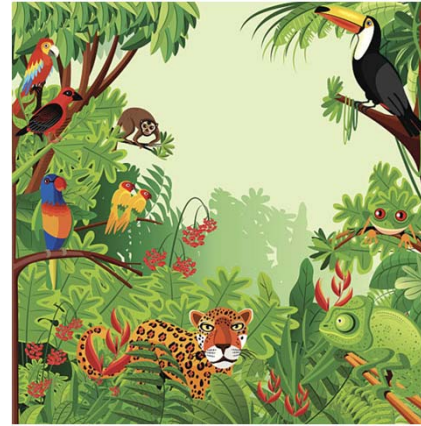
Multiple Co-benefits of Nature-based Solutions



Biodiversity as Building Blocks



Forest monoculture



Pristine rainforest



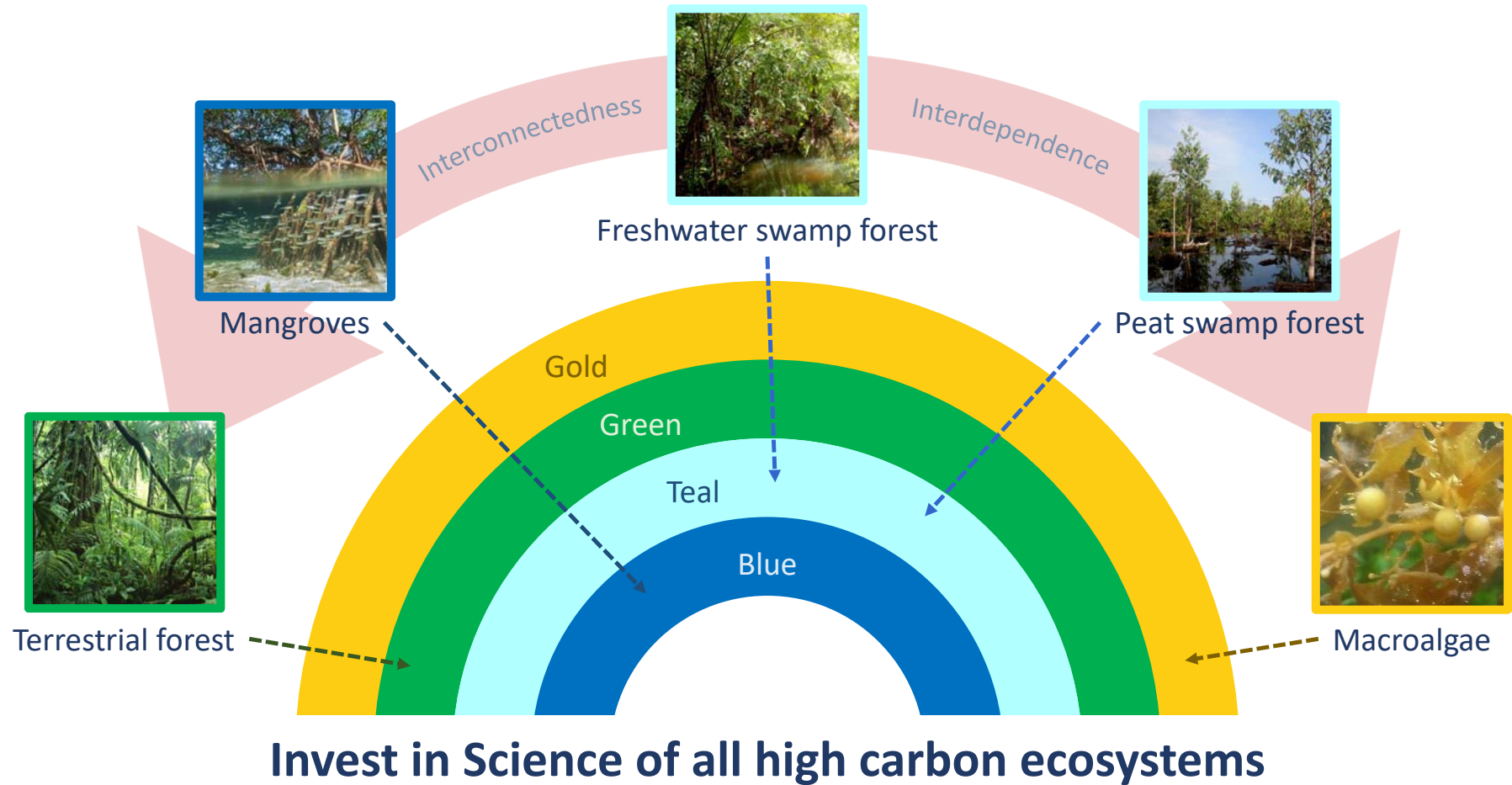
Develop approaches to quantify price premium of ‘beautiful carbon’



NUS
National University
of Singapore

Centre for Nature-based
Climate Solutions

Other Ecosystems in the Carbon Rainbow



Nature-based Carbon Offsets in High Demand

Table 1. Volumes, values and average prices of voluntary carbon offsets transacted in 2019.

	VOLUME MtCO ₂ e	AVERAGE PRICE	VALUE
RENEWABLE ENERGY	42.4	\$1.4	\$60.1 M
FORESTRY AND LAND USE	36.7	\$4.3	\$159.1 M
WASTE DISPOSAL	7.3	\$2.5	\$18.0 M
HOUSEHOLD DEVICES	6.4	\$3.8	\$24.8 M
CHEMICAL PROCESSES/ INDUSTRIAL MANUFACTURING	4.1	\$1.9	\$7.7 M
ENERGY EFFICIENCY/ FUEL SWITCHING	3.1	\$3.9	\$11.9 M
TRANSPORTATION	0.4	\$1.7	\$0.7 M

Nature-based offsets most highly sought after product in the voluntary carbon market

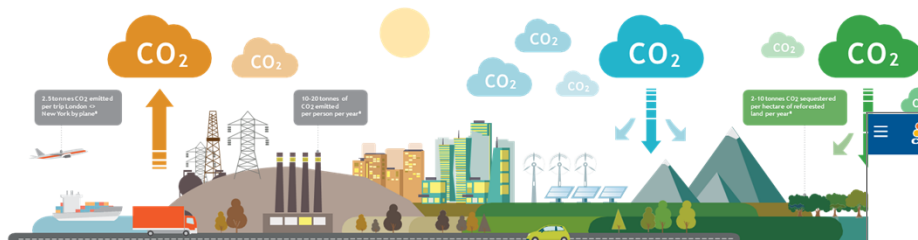
Nature-based credits command highest price



Nature-based Carbon Credits in High Demand

Why Carbon Credits?

A carbon credit is a certificate that represents a reduction of one metric ton of CO₂ emission. Carbon credits play a critical role in a holistic climate mitigation strategy and enable corporates to compensate and increasingly neutralise emissions on the path towards net zero.



01

CO₂ is emitted into the atmosphere due to human activities such as industrial output, transportation, power generation and travel

Companies, as one of the main sources of emissions, need to reduce their emissions by taking steps to measure, report and eliminate them

Some residual emissions are unavoidable since it may not be feasible for companies to reduce their carbon footprint entirely in the short-run

*Emissions estimates based on Gold Standard averages for select developed nations. Sequestration estimates based on UN Food and Agriculture Organisation research.

02

Companies purchase high-quality carbon credits via exchanges and marketplaces such as Climate Impact X (CIX)

CIX ensures carbon credits are generated from projects aligned with leading global standards (i.e. real, measurable, verified, additional, permanent and free from leakage, double claims, etc.) and achieve significant co-benefits

Companies compensate by retiring carbon credits equivalent to the emissions which they have not yet eliminated, supporting the transition to a zero-carbon future

03

Proceeds from the sale of fund climate mitigation and projects such as reforestation and renewable generation (e.g. solar, wind)

These projects also create benefits for local communities and biodiversity (e.g. livelihoods of endangered species)

Find out more at climateimpactx.com

A holistic, low-carbon transition requires companies to measure, reduce and neutralise unavoidable emissions. When done right, high-quality carbon credits provide a robust way for companies to support avoidance of further emissions and remove CO₂ from the atmosphere.

MARKETS BUSINESS INVESTING TECH POLITICS CNBC TV WATCHLIST PRO

INVESTMENT | RESPONSIBILITY | TECHNOLOGY | FUTURE POWER | INDUSTRY | CNBC ESG COUNCIL

SUSTAINABLE FUTURE

A new global carbon exchange will be launched in Singapore this year

PUBLISHED FRI, MAY 21 2021-5:13 AM EDT | UPDATED FRI, MAY 21 2021-5:25 AM EDT

Saheli Roy Choudhury
@SAHELIRBC

SHARE [f](#) [t](#) [in](#) [e](#)

KEY POINTS

- Climate Impact X is a joint venture from Asia's largest lender DBS Group, British bank Standard Chartered, Singapore state investor Temasek and market operator Singapore Exchange.
- It is expected to go live by the end of 2021 and will have two platforms catered to the needs of buyers and sellers of carbon credits.
- When is a company is unable to reduce its emissions, it can purchase a carbon credit as a way to offset the greenhouse gases its operations are releasing into the atmosphere.

Risks of Nature-based Carbon

Bloomberg Green

A Top U.S. Seller of Carbon Offsets Starts Investigating Its Own Projects

The Nature Conservancy's review calls into question millions of dollars of credits sold to JPMorgan, BlackRock, and Disney.

By **Ben Elgin**

April 5, 2021, 7:00 PM GMT+8

[Search jobs](#) | [Sign in](#) | [Search](#) | [International edition](#) ▾

The Guardian
For 200 years

Carbon offsets used by major airlines based on flawed system, warn experts

Guardian investigation finds carbon credits generated by forest protection schemes are based on flawed system

- [What is carbon offsetting and how does it work?](#)

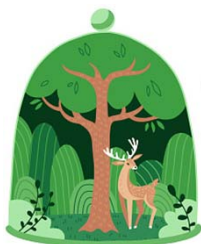


Risks of Nature-based Carbon



Carbon yield estimates

(Generic allometric models and assumptions, labor-intensive and costly methodologies)



Permanence

(Governance, operations, land use, tenure, carbon rights, funding, natural risks)



Additionality

(Challenges of benchmarking additional CO₂ emissions reduction and removal)



**Project
Credibility**



Leakage

(Shifts in location, commodity/market, from deforestation to degradation)



**Environmental
Integrity**



NUS
National University
of Singapore

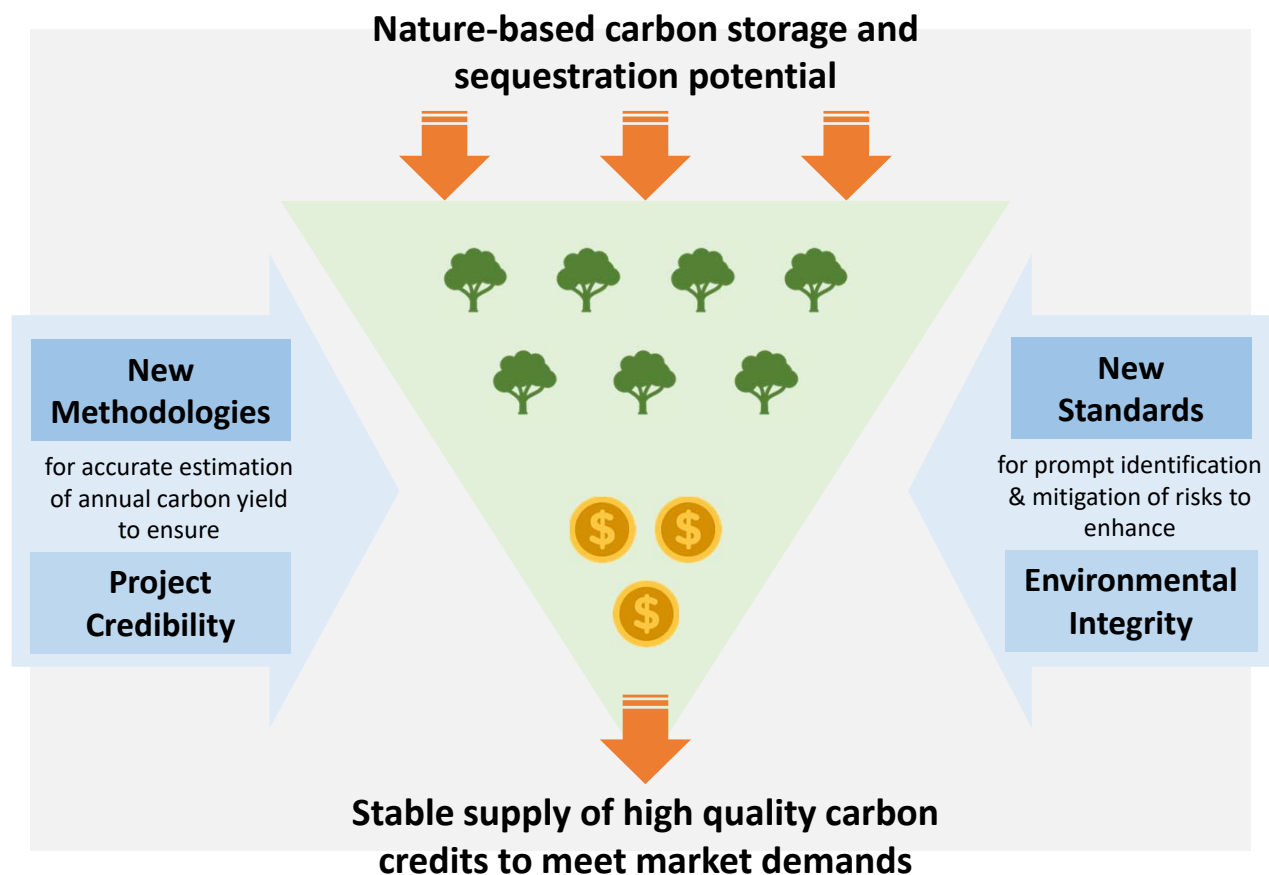
Centre for Nature-based
Climate Solutions

Risks of Nature-based Carbon



Let's not throw the baby out
with the bath water.

New Carbon Methodologies & Standards



Leverage opportunity...

Nature for Climate Research Programme (NCRP):

An innovative technology
and data driven research
programme led by NUS

...for desired outcome



nus.edu.sg/cncs

1. To produce *data-driven, policy-relevant & decision-supporting science* that informs climate strategies & actions in Singapore & the region
2. To *empower leadership* in public, private & people sectors by building capacity to respond to climate challenges & opportunities



Centre Research Interests & Expertise

Core Researchers:



Department of Biological Sciences
Faculty of Science

Department of
GeographySchool of Design
& Environment

Lee Kuan Yew
School of Public Policy

National University of Singapore



Engineering



| Law



National University of Singapore

Affiliate Researchers:



The Asian School of the Environment

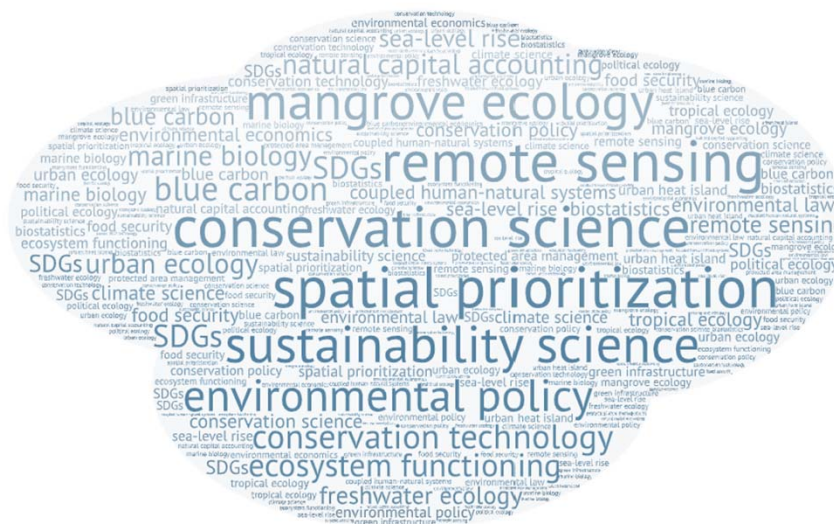


EARTH
OBSERVATORY
OF SINGAPORE



SMU
SINGAPORE MANAGEMENT
UNIVERSITY

**(SEC) SINGAPORE-ETH
CENTRE**



Scientific Advisory Board:

PRINCETON
UNIVERSITY

THE UNIVERSITY
OF QUEENSLAND
AUSTRALIA



UNIVERSITAS
INDONESIA
Veritas, Probitas, Iustitia
EST. 1940



Strategic Research on Nature-based Solutions



Understand Impacts

-  Economy
-  Environment
-  Society



Identify Solutions

-  Reduce emission
-  Remove GHG
-  Increase resilience




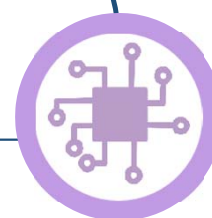
Overcome Barriers & Risks

-  Economy
-  Society
-  Policies & politics



Prioritise Actions

-  What?
-  Where?
-  How?



Leverage Technology

-  Credibility & integrity
-  Reduce costs
-  Communications, education, outreach



Research Techniques



Scenario analyses
and prioritization



Spatial analyses
and mapping



Remote sensing



Fieldwork



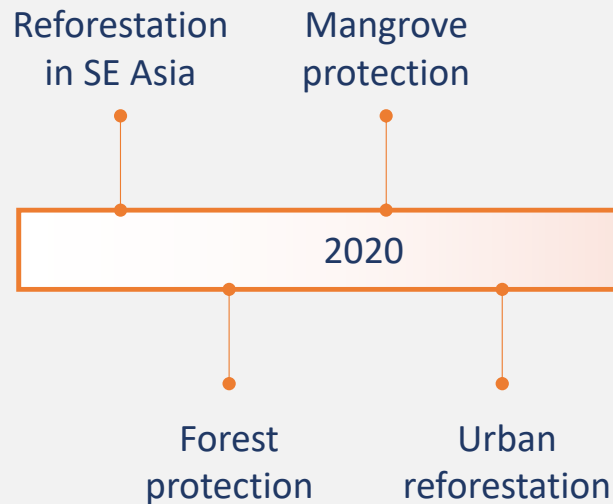
Lab experiments

Analytics

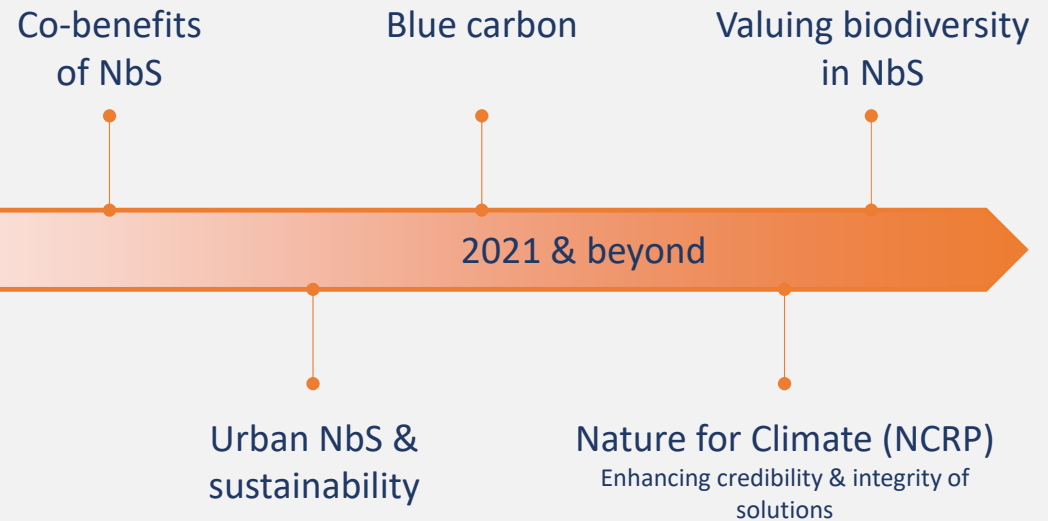
Data collection

Ongoing Research Programmes

Potential & limitations



Barriers & opportunities



Policy-relevant Research (2020/21)

- LP Koh, Y Zeng, TV Sarira, K Siman. 2021. **Carbon prospecting in tropical forests for climate change mitigation.** *Nature Communications* 12:1271
- L Mair, H Possingham, LP Koh, et al. 2021. **A metric for spatially-explicit contributions to science-based species targets.** *Nature Ecology and Evolution* 5:836-844
- LP Koh, Y Li, JSH Lee. 2021. **The value of China's ban on wildlife trade and consumption.** *Nature Sustainability* 4:2-4
- Y Zeng, TV Sarira, LR Carrasco, KY Chong, DA Friess, JSH Lee, P Taillardat, TA Worthington, Y Zhang, LP Koh. 2020. **Economic and social constraints on reforestation for climate mitigation in Southeast Asia.** *Nature Climate Change* 10:842-844
- E Meijaard, JSH Lee, LP Koh, et al. 2020. **The environmental impacts of palm oil in context.** *Nature Plants* 6:1418-1426
- A Goldstein, LP Koh, et al. 2020. **Protecting irrecoverable carbon in Earth's ecosystems.** *Nature Climate Change* 10:287-295
- Y Zeng, DA Friess, TV Sarira, K Siman, LP Koh. 2021. **Global potential and limits of mangrove blue carbon for climate change mitigation.** *Current Biology* in press
- HC Teo, Y Zeng, TV Sarira, TK Fung, Q Zheng, XP Song, KY Chong, LP Koh. 2021. **Global urban reforestation can be an important natural climate solution.** *Environmental Research Letters* 16:034059
- S Proches, S Ramdhani, AC Hughes, LP Koh. 2021. **Southeast Asia as one of world's primary sources of biotic recolonization following Anthropocene extinctions.** *Frontiers in Ecology and Evolution* 9:634711
- Q Zheng, HC Teo, LP Koh. 2021. **Artificial light at night advances spring phenology in the United States.** *Remote Sensing* 13:399.

Public Outreach



Signages to deliver content

Gardens by the Bay



Jurong Lake Gardens

Sentosa



Wildlife Reserves Singapore

Stakeholder Engagements



THE STRAITS TIMES

Singapore Parliament declares climate change a global emergency

PUBLISHED FEB 1, 2021, 10:56 PM SGT



The Singapore Green Plan 2030 is a national sustainability movement which seeks to rally bold and collective action to tackle climate change.

It is a living plan which will evolve as we work with Singaporeans and partners from all sectors to co-create solutions for sustainability. Let's work together to make Singapore a green and liveable home.

City in Nature

Green, Liveable and Sustainable Home for Singaporeans

- ✓ Plant 1 million more trees, and have every household within a 10-minute walk from a park by 2030
- ✓ Develop over 130 ha of new parks, and enhance around 170 ha of existing parks with more lush vegetation and natural landscapes by end-2026
- ✓ Add 1000ha of green spaces by 2035

Green Government

Public sector will lead on sustainability

- ✓ Be exemplary in taking sustainability action, including to peak public sector carbon emissions around 2025, ahead of national target
- ✓ Encourage and enable citizens and businesses to adopt sustainability practices, such as through green procurement

Sustainable Living

Strengthen Green Efforts in Schools

- ✓ Introduce an Eco Stewardship Programme to enhance environmental education in all schools
- ✓ Work towards two-thirds reduction of net carbon emissions from schools sector by 2030
- ✓ At least 20% of schools to be carbon neutral by 2030

Green Commutes

- ✓ 75% of trips during peak periods to be on mass public transport by 2030
- ✓ Triple cycling path network to 1,320km by 2030, from 460km in 2020
- ✓ Expand rail network to 360km by early 2030s, from around 230km today

Green Citizenry:

Reduce waste and consumption

- ✓ Reduce amount of waste to landfill per capita per day by 20% by 2026, and 30% by 2030
- ✓ Reduce household water consumption to 130 litres per capita per day

Energy Reset

Cleaner-energy Vehicles

- ✓ New diesel car and taxi registrations to cease from 2025, with all new car and taxi registrations to be of cleaner-energy models from 2030
- ✓ Further revise road tax structure to bring down road tax for mass-market electric cars
- ✓ Target 60,000 electric vehicle (EV) charging points by 2030, with 8 EV-Ready Towns by 2025

Greener Infrastructure & Buildings

- ✓ Green 80% of Singapore's buildings (by Gross Floor Area) by 2030
- ✓ 80% of new buildings (by Gross Floor Area) to be Super Low Energy buildings from 2030
- ✓ Best-in-class green buildings to see 80% improvement in energy efficiency (over 2005 levels) by 2030

Sustainable Towns & Districts

- ✓ Reduce energy consumption in HDB towns by 15% by 2030

Green Energy

- ✓ Quadruple solar energy deployment to 1.5 gigawatt-peak by 2025
- ✓ Tap on cleaner electricity imports, and increase R&D on renewable energy and emerging low-carbon technologies

Green Economy

Sustainability as New Engine of Jobs and Growth

- ✓ New Enterprise Sustainability Programme to help local enterprises adopt sustainability practices
- ✓ Develop Singapore to be a carbon services hub, and a leading centre for green finance in Asia and globally
- ✓ Develop Jurong Island to be a sustainable energy and chemicals park
- ✓ Leverage opportunities in sustainable industries to create good jobs for Singaporeans

New Investments to be Carbon and Energy Efficient

- ✓ Seek new investments to be among the best-in-class in energy/carbon efficiency

Resilient Future

Safeguarding our Coastlines against Rising Sea Levels

- ✓ S\$5b dedicated to coastal and drainage flood protection measures
- ✓ Formulation of coastal protection plans for City-East Coast, North-West Coast (Lim Chu Kang and Sungei Kadut) and Jurong Island by 2030

Safeguarding Food Security

- ✓ Produce 30% of our nutritional needs locally and sustainably by 2030, through developing land and sea space and skilled workers, funding support, and promoting R&D

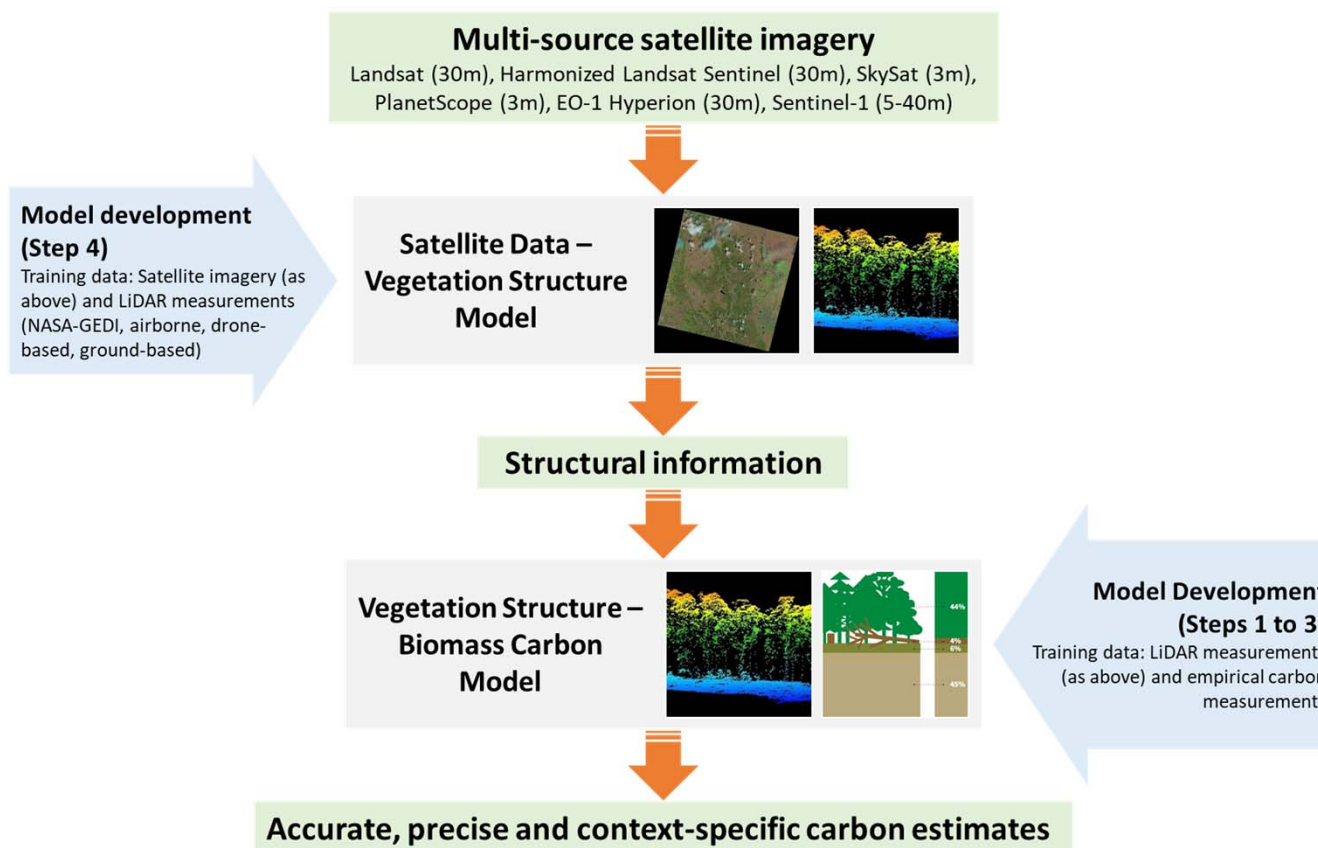
Keeping Singapore Cool

- ✓ Moderate the rise in urban heat, such as with cool paint and by increasing greenery

Jointly led by:



Nature for Climate (N4C) Programme



Compliance (binding targets; \$40-120b)

Kyoto Protocol (pre-2020)

Offsetting:

- Clean Development Mechanism (rich countries buy Certified Emission Reductions from poor)
- Joint Implementation (trade Emission Reduction Units between rich countries)

Cap and trade

- International Emissions Trading (trade Assigned Amount Units between rich countries)

Paris Agreement (post-2020)

Offsetting:

- Article 6.4 (Sustainable Development Mechanism)

Cap and trade

- Article 6.2 (bilateral agreements to trade Internationally Transferred Mitigation Outcomes, based on Nationally Determined Contributions)

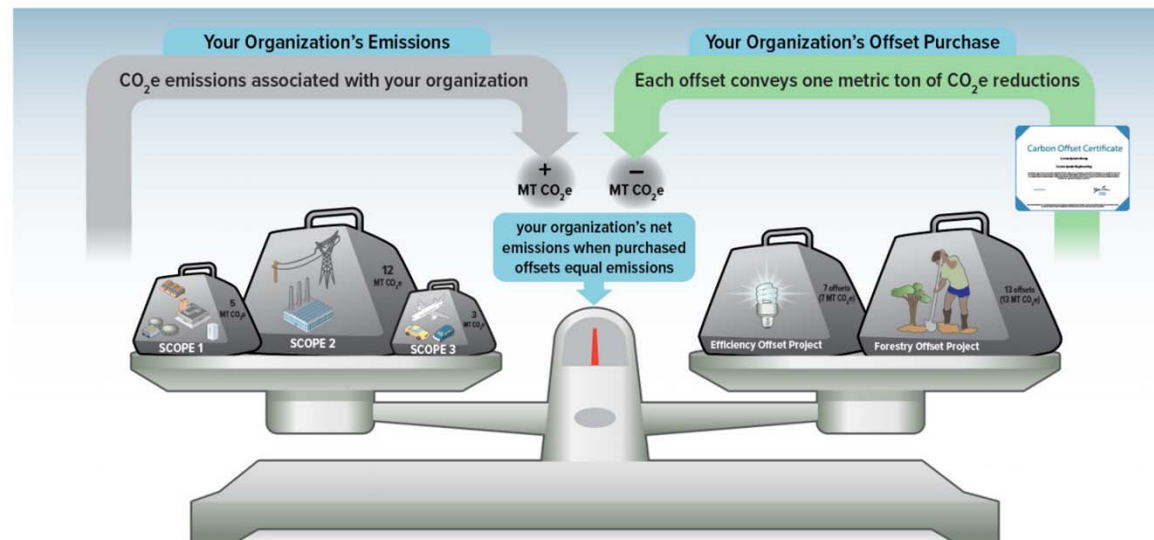
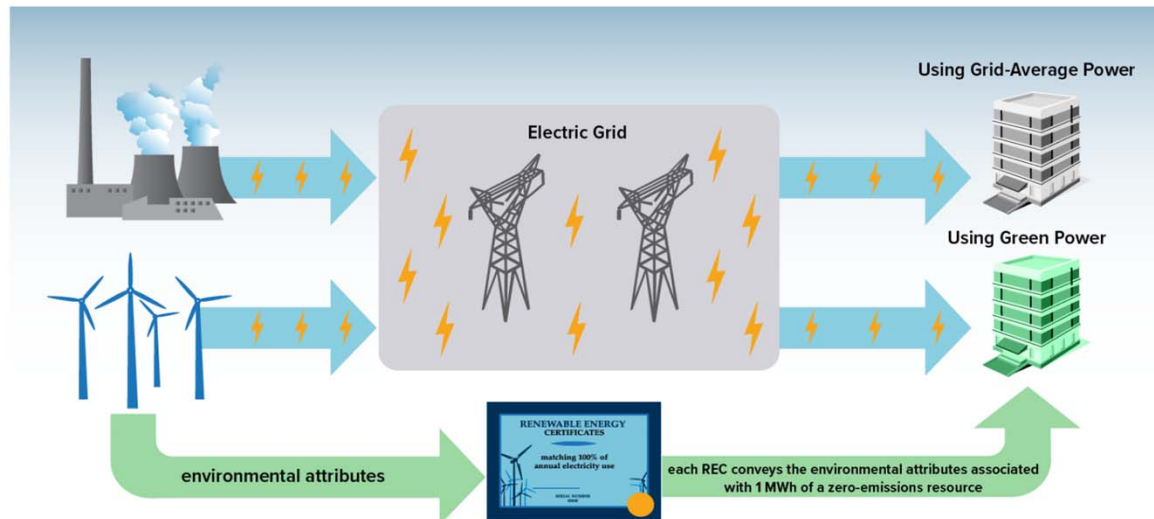


Voluntary (CSR, PR; \$300m)

- Verified Carbon Standard
- Gold Standard

Industry specific

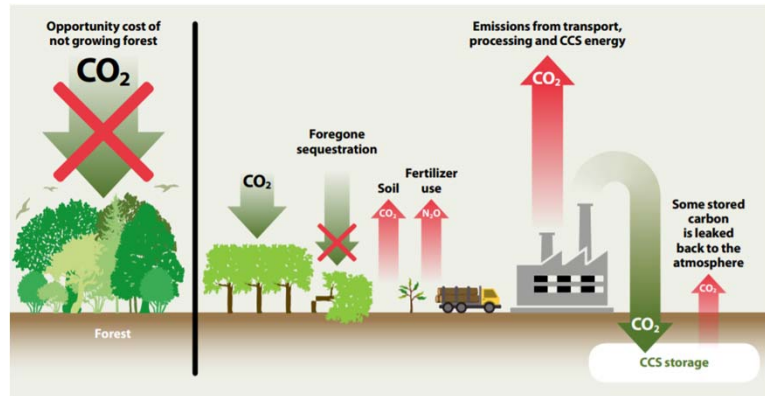
- Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)



RECs VS Offsets

Problems with BECCS

Opportunity costs

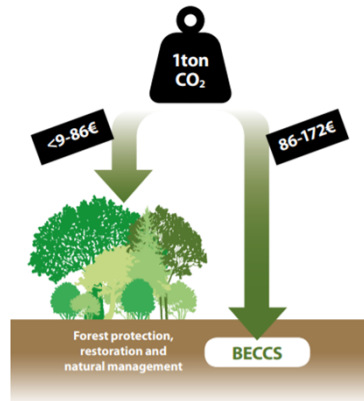


Biodiversity costs

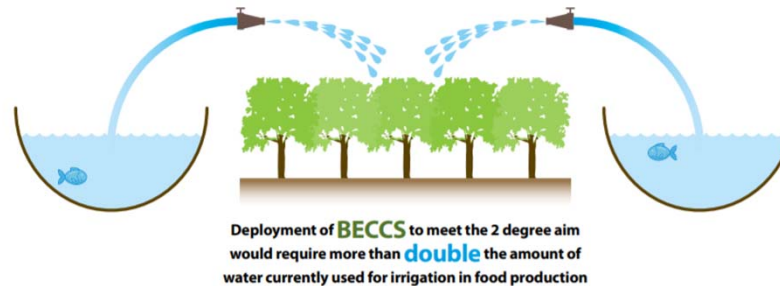
Large scale **BECCS** will almost certainly accelerate **biodiversity loss**



Direct costs



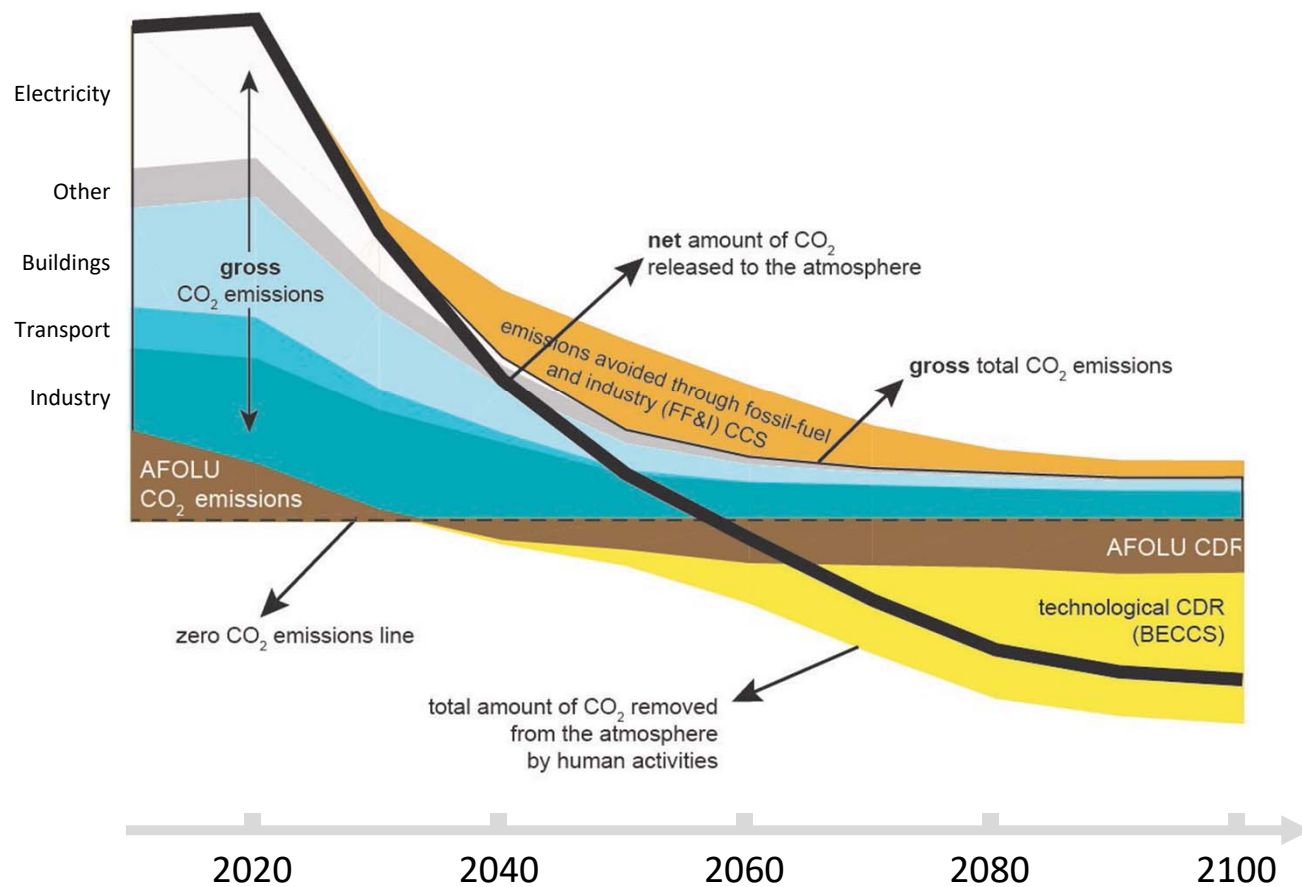
Water costs



Land costs



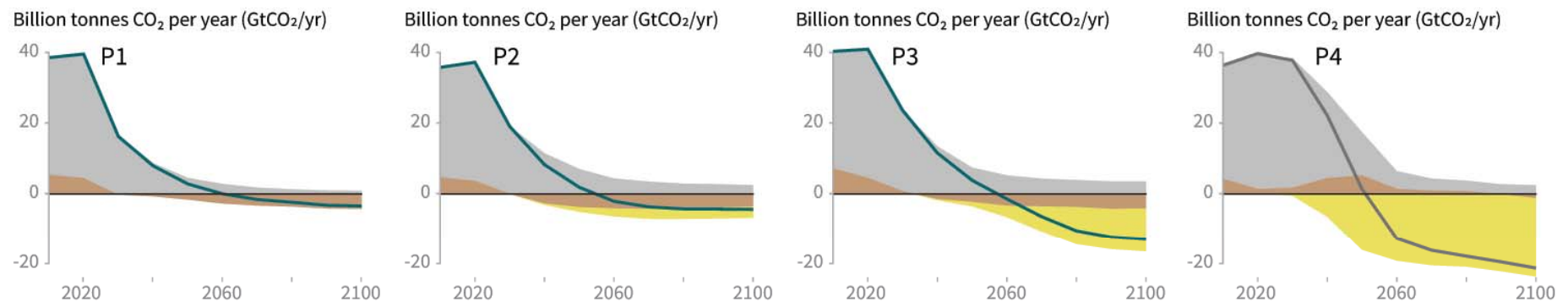
IPCC Pathway P3



IPCC Pathway narratives

Breakdown of contributions to global net CO₂ emissions in four illustrative model pathways

● Fossil fuel and industry ● AFOLU ● BECCS



P1: A scenario in which social, business and technological innovations result in lower energy demand up to 2050 while living standards rise, especially in the global South. A downsized energy system enables rapid decarbonization of energy supply. Afforestation is the only CDR option considered; neither fossil fuels with CCS nor BECCS are used.

P2: A scenario with a broad focus on sustainability including energy intensity, human development, economic convergence and international cooperation, as well as shifts towards sustainable and healthy consumption patterns, low-carbon technology innovation, and well-managed land systems with limited societal acceptability for BECCS.

P3: A middle-of-the-road scenario in which societal as well as technological development follows historical patterns. Emissions reductions are mainly achieved by changing the way in which energy and products are produced, and to a lesser degree by reductions in demand.

P4: A resource- and energy-intensive scenario in which economic growth and globalization lead to widespread adoption of greenhouse-gas-intensive lifestyles, including high demand for transportation fuels and livestock products. Emissions reductions are mainly achieved through technological means, making strong use of CDR through the deployment of BECCS.

Forest Protection ROIs

Region	Country	Investible carbon (tCO ₂ e yr ⁻¹)	Net present value (USD yr ⁻¹)
Global (Pantropic)		2,420,169,000 (±1,165,139,000)	77,540,431,000 (±25,606,498,000)
Americas		1,098,009,000 (±515,691,000)	33,414,594,000 (±12,152,680,000)
	Argentina	7,648,000 (±4,427,000)	308,061,000 (±126,780,000)
	Antigua and Barbuda	32,000 (±22,000)	1,072,000 (±614,000)
	Bonaire, Sint Eustatius and Saba	2,000 (±1,000)	17,000 (±7,000)
	Bahamas	320,000 (±165,000)	14,235,000 (±4,966,000)
	Belize	3,300,000 (±1,892,000)	101,234,000 (±38,320,000)
	Bolivia, Plurinational State of	130,305,000 (±61,355,000)	4,537,869,000 (±1,341,622,000)
	Brazil	578,524,000 (±255,050,000)	18,864,696,000 (±6,610,495,000)
	Barbados	0 (±0)	9,000 (±4,000)
	Chile	0 (±0)	0 (±0)
	Colombia	54,440,000 (±26,086,000)	1,200,642,000 (±497,545,000)
	Costa Rica	2,054,000 (±1,273,000)	18,084,000 (±6,581,000)
	Cuba	7,859,000 (±4,741,000)	196,755,000 (±65,477,000)
	Curaao	5,000 (±3,000)	54,000 (±7,000)
	Cayman Islands	33,000 (±19,000)	634,000 (±89,000)
	Dominica	0 (±0)	0 (±0)
	Dominican Republic	3,027,000 (±1,791,000)	100,782,000 (±42,249,000)
	Ecuador	17,422,000 (±8,539,000)	525,551,000 (±204,200,000)
	Guadeloupe	61,000 (±39,000)	1,264,000 (±508,000)
	Grenada	12,000 (±7,000)	64,000 (±8,000)
	Guatemala	7,411,000 (±4,265,000)	207,218,000 (±68,050,000)
	French Guiana	5,975,000 (±1,840,000)	37,584,000 (±6,334,000)
	Guyana	24,488,000 (±8,588,000)	332,155,000 (±76,627,000)
	Honduras	5,109,000 (±3,099,000)	99,320,000 (±38,976,000)
	Haiti	365,000 (±216,000)	9,016,000 (±3,222,000)
	Jamaica	622,000 (±347,000)	15,077,000 (±4,585,000)
	Saint Kitts and Nevis	9,000 (±6,000)	141,000 (±95,000)
	Saint Lucia	29,000 (±17,000)	594,000 (±162,000)
	Mexico	69,766,000 (±48,247,000)	2,257,596,000 (±1,395,082,000)
	Montserrat	4,000 (±3,000)	52,000 (±33,000)
	Martinique	18,000 (±12,000)	351,000 (±193,000)
	Nicaragua	5,919,000 (±3,818,000)	109,885,000 (±52,511,000)
	Panama	3,950,000 (±2,232,000)	57,901,000 (±14,633,000)
	Peru	68,857,000 (±25,910,000)	1,338,466,000 (±196,156,000)
	Puerto Rico	47,000 (±28,000)	1,692,000 (±731,000)
	Paraguay	34,064,000 (±21,378,000)	1,441,391,000 (±711,074,000)
	El Salvador	980,000 (±663,000)	25,265,000 (±14,035,000)
	Suriname	16,530,000 (±6,305,000)	223,935,000 (±67,681,000)
	Turks and Caicos Islands	32,000 (±17,000)	1,162,000 (±335,000)
	Trinidad and Tobago	406,000 (±239,000)	9,626,000 (±3,136,000)
	Saint Vincent and the Grenadines	5,000 (±3,000)	15,000 (±3,000)
	Venezuela, Bolivarian Republic of	48,373,000 (±23,045,000)	1,375,029,000 (±559,519,000)
	Virgin Islands, British	1,000 (±0)	19,000 (±4,000)
	Virgin Islands, U.S.	2,000 (±1,000)	83,000 (±31,000)
Africa		533,210,000 (±318,678,000)	5,700,130,000 (±1,508,084,000)
	Angola	69,419,000 (±44,298,000)	873,398,000 (±239,173,000)
	Burundi	183,000 (±159,000)	918,000 (±1,055,000)
	Benin	2,014,000 (±1,811,000)	16,598,000 (±15,248,000)
	Burkina Faso	304,000 (±298,000)	642,000 (±1,174,000)
	Botswana	484,000 (±465,000)	3,928,000 (±4,870,000)
	Central African Republic	38,320,000 (±25,241,000)	134,132,000 (±10,382,000)
	Côte d'Ivoire	69,419,000 (±44,298,000)	873,398,000 (±239,173,000)
	Cameroon	27,841,000 (±12,154,000)	468,304,000 (±73,405,000)
	DR Congo	115,691,000 (±48,676,000)	829,881,000 (±62,382,000)

Congo	30,412,000 (±11,592,000)	449,714,000 (±48,969,000)
Comoros	8,000 (±5,000)	18,000 (±0)
Djibouti	0 (±0)	0 (±0)
Eritrea	0 (±0)	0 (±0)
Ethiopia	13,996,000 (±10,672,000)	158,458,000 (±66,874,000)
Gabon	25,706,000 (±7,887,000)	358,117,000 (±47,273,000)
Ghana	5,347,000 (±4,178,000)	57,627,000 (±20,244,000)
Guinea	6,070,000 (±5,020,000)	55,691,000 (±25,736,000)
Gambia	116,000 (±109,000)	2,255,000 (±2,580,000)
Guinea-Bissau	1,225,000 (±1,007,000)	13,313,000 (±7,477,000)
Equatorial Guinea	2,282,000 (±671,000)	58,857,000 (±7,488,000)
Kenya	3,205,000 (±2,253,000)	53,284,000 (±22,251,000)
Liberia	4,661,000 (±1,304,000)	127,526,000 (±12,587,000)
Madagascar	8,630,000 (±6,428,000)	77,596,000 (±30,107,000)
Mali	1,305,000 (±1,211,000)	7,397,000 (±10,068,000)
Mozambique	37,632,000 (±27,570,000)	475,324,000 (±165,761,000)
Mauritania	0 (±0)	0 (±0)
Malawi	2,111,000 (±1,521,000)	23,087,000 (±8,883,000)
Mayotte	8,000 (±4,000)	53,000 (±6,000)
Namibia	289,000 (±278,000)	262,000 (±310,000)
Niger	0 (±0)	0 (±0)
Nigeria	11,270,000 (±8,431,000)	123,691,000 (±49,010,000)
Rwanda	71,000 (±58,000)	623,000 (±685,000)
Sudan	1,236,000 (±1,223,000)	749,000 (±2,151,000)
Senegal	2,634,000 (±2,400,000)	16,832,000 (±17,041,000)
Sierra Leone	901,000 (±479,000)	17,800,000 (±1,879,000)
Somalia	273,000 (±249,000)	226,000 (±26,000)
South Sudan	15,719,000 (±14,012,000)	22,681,000 (±26,038,000)
Sao Tome and Principe	49,000 (±22,000)	1,323,000 (±338,000)
Chad	2,324,000 (±2,040,000)	21,501,000 (±14,532,000)
Togo	1,109,000 (±1,018,000)	3,271,000 (±3,679,000)
Tanzania, United Republic of	45,807,000 (±33,473,000)	667,900,000 (±285,635,000)
Uganda	2,325,000 (±1,840,000)	7,888,000 (±1,431,000)
South Africa	344,000 (±246,000)	3,287,000 (±1,017,000)
Zambia	40,476,000 (±28,510,000)	503,656,000 (±179,552,000)
Zimbabwe	5,650,000 (±5,338,000)	13,153,000 (±18,217,000)
Asia-Pacific	788,950,000 (±330,770,000)	38,425,706,000 (±11,945,734,000)
Bangladesh	5,640,000 (±3,017,000)	316,162,000 (±144,884,000)
Brunei Darussalam	1,491,000 (±644,000)	68,868,000 (±22,812,000)
China	38,407,000 (±16,379,000)	2,039,668,000 (±643,915,000)
Indonesia	312,145,000 (±124,176,000)	15,437,841,000 (±4,787,115,000)
India	67,688,000 (±35,388,000)	2,983,599,000 (±1,115,359,000)
Cambodia	38,444,000 (±16,975,000)	2,225,685,000 (±785,231,000)
Lao People's Democratic Republic	30,022,000 (±11,939,000)	1,463,878,000 (±399,438,000)
Sri Lanka	5,650,000 (±2,963,000)	299,090,000 (±128,053,000)
Myanmar	47,762,000 (±20,663,000)	2,056,144,000 (±563,612,000)
Malaysia	72,657,000 (±25,893,000)	3,942,487,000 (±1,012,462,000)
Philippines	13,750,000 (±5,772,000)	575,079,000 (±158,503,000)
Singapore	0 (±0)	0 (±0)
Thailand	2,000 (±1,000)	92,000 (±44,000)
Timor-Leste	53,025,000 (±22,738,000)	2,724,504,000 (±850,265,000)
Taiwan	640,000 (±294,000)	30,380,000 (±10,023,000)
Viet Nam	812,000 (±346,000)	29,316,000 (±7,407,000)
Australia	32,619,000 (±13,519,000)	1,713,860,000 (±518,748,000)
Papua New Guinea	0 (±0)	0 (±0)

Mangrove blue carbon ROIs

Countries	Extent (ha)	Climate mitigation potential (tCO ₂ e yr ⁻¹)	Net present value (\$ yr ⁻¹)
World	1,054,900 (± 78,000)	26,164,000 (± 4,664,000)	1,188,889,000 (± 241,216,000)
Americas	58,800 (± 17,800)	1,871,000 (± 718,000)	47,749,000 (± 21,718,000)
Brazil	17,300 (± 4,900)	678,000 (± 217,000)	15,645,000 (± 6,071,000)
Cuba	10,000 (± 5,400)	332,000 (± 224,000)	6,704,000 (± 6,548,000)
Colombia	5,700 (± 1,500)	196,000 (± 60,000)	5,416,000 (± 1,993,000)
French Guyana	4,800 (± 400)	96,000 (± 16,000)	3,932,000 (± 813,000)
Guyana	1,300 (± 100)	96,000 (± 16,000)	3,932,000 (± 815,000)
Venezuela	3,000 (± 700)	131,000 (± 37,000)	2,962,000 (± 1,037,000)
Nicaragua	3,900 (± 600)	51,000 (± 14,000)	1,760,000 (± 645,000)
Suriname	2,800 (± 1,200)	61,000 (± 31,000)	1,369,000 (± 905,000)
Ecuador	2,100 (± 600)	51,000 (± 18,000)	1,322,000 (± 576,000)
Honduras	2,600 (± 500)	38,000 (± 11,000)	1,286,000 (± 452,000)
Haiti	1,900 (± 400)	23,000 (± 10,000)	1,056,000 (± 537,000)
Panama	1,000 (± 300)	45,000 (± 15,000)	796,000 (± 346,000)
El Salvador	1,000 (± 300)	16,000 (± 5,000)	561,000 (± 167,000)
Costa Rica	200 (± 100)	10,000 (± 5,000)	211,000 (± 106,000)
Jamaica	200 (± 100)	10,000 (± 5,000)	196,000 (± 154,000)
Mexico	400 (± 400)	14,000 (± 16,000)	188,000 (± 242,000)
Belize	300 (± 100)	7,000 (± 3,000)	128,000 (± 86,000)
Cayman Islands	200 (± 100)	6,000 (± 6,000)	106,000 (± 138,000)
Dominican Republic	200 (± 100)	6,000 (± 4,000)	100,000 (± 114,000)
Guatemala	100 (± 0)	2,000 (± 0)	48,000 (± 17,000)
Africa	240,500 (± 14,900)	3,940,000 (± 597,000)	211,323,000 (± 35,007,000)
Madagascar	71,600 (± 1,600)	1,557,000 (± 158,000)	92,629,000 (± 9,997,000)
Nigeria	73,100 (± 8,300)	1,056,000 (± 250,000)	48,202,000 (± 13,821,000)
Cameroon	33,500 (± 1,100)	524,000 (± 76,000)	29,597,000 (± 4,707,000)
Tanzania	13,500 (± 400)	391,000 (± 38,000)	22,035,000 (± 2,348,000)
Guinea Bissau	15,800 (± 1,200)	107,000 (± 19,000)	4,867,000 (± 1,089,000)
Mozambique	7,500 (± 300)	63,000 (± 9,000)	3,326,000 (± 540,000)
Sierra Leone	8,900 (± 500)	60,000 (± 12,000)	3,153,000 (± 711,000)
Gabon	1,400 (± 300)	52,000 (± 13,000)	1,611,000 (± 427,000)
Angola	900 (± 100)	29,000 (± 4,000)	1,294,000 (± 214,000)
Kenya	2,000 (± 300)	29,000 (± 6,000)	1,239,000 (± 316,000)
Equatorial Guinea	500 (± 0)	19,000 (± 2,000)	1,093,000 (± 116,000)
Guinea	9,300 (± 300)	19,000 (± 2,000)	1,093,000 (± 117,000)
Ghana	800 (± 100)	16,000 (± 4,000)	580,000 (± 182,000)
Gambia	900 (± 100)	5,000 (± 1,000)	181,000 (± 67,000)
Senegal	500 (± 200)	4,000 (± 2,000)	107,000 (± 64,000)
Liberia	100 (± 0)	2,000 (± 0)	96,000 (± 14,000)
Somalia	100 (± 0)	1,000 (± 0)	33,000 (± 11,000)
Asia	703,600 (± 42,600)	19,153,000 (± 3,183,000)	874,468,000 (± 175,033,000)
Indonesia	325,400 (± 21,100)	11,262,000 (± 1,889,000)	513,327,000 (± 106,538,000)
Myanmar	124,500 (± 3,100)	2,946,000 (± 404,000)	157,135,000 (± 24,841,000)
Vietnam	75,900 (± 3,200)	1,635,000 (± 272,000)	75,208,000 (± 16,171,000)
Bangladesh	98,900 (± 2,800)	808,000 (± 75,000)	42,079,000 (± 4,484,000)
Malaysia	23,500 (± 5,000)	940,000 (± 256,000)	24,854,000 (± 9,019,000)
Andaman And Nicobar	6,100 (± 100)	444,000 (± 47,000)	24,284,000 (± 2,966,000)
Philippines	12,000 (± 1,500)	511,000 (± 105,000)	17,600,000 (± 4,836,000)
Thailand	8,800 (± 1,700)	262,000 (± 66,000)	6,623,000 (± 2,312,000)
India	18,900 (± 2,800)	192,000 (± 43,000)	6,553,000 (± 1,918,000)
Cambodia	7,200 (± 300)	116,000 (± 16,000)	5,722,000 (± 991,000)
Pakistan	2,300 (± 700)	24,000 (± 10,000)	715,000 (± 394,000)
Sri Lanka	200 (± 100)	10,000 (± 4,000)	239,000 (± 139,000)
Oceania	51,900 (± 2,700)	1,199,000 (± 156,000)	55,349,000 (± 8,833,000)
Papua New Guinea	48,600 (± 2,500)	1,009,000 (± 134,000)	47,240,000 (± 7,706,000)
Solomon Islands	3,200 (± 100)	189,000 (± 22,000)	8,091,000 (± 1,235,000)

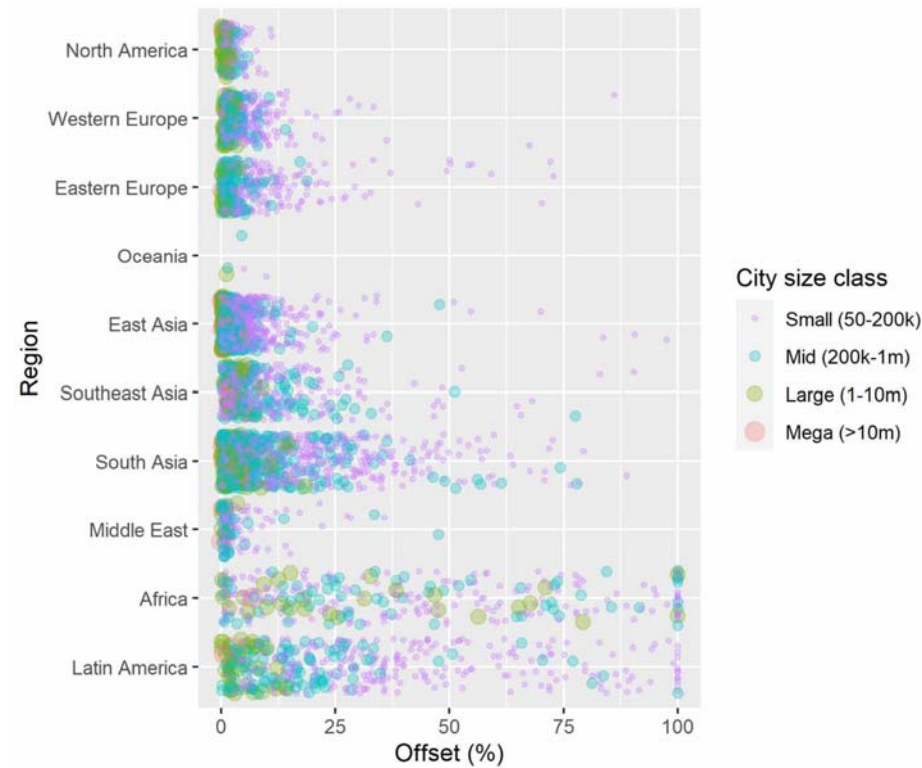


Figure 2. Percentage of city carbon emissions that can be offset by urban reforestation for each world region. Only biophysically reforestable areas were considered. Unsuitable types of land uses were excluded.

Table 1. Urban reforestation potential by world regions and city size class, for the year 2015.

		Cities			Existing urban forest		Reforestation potential			
		<i>n</i>	Area (Mha)	2015 emissions MtCO ₂ e	Area (Mha)	%	Area (Mha)	%	Mitigation potential (MtCO ₂ e yr ⁻¹)	% offset
Region	Global North	1406	20.4	2410	3.24 ± 0.83	15.9	4.06 ± 1.04	19.9	18.33 ± 6.29	0.8
	North America	283	8.66	842	1.67 ± 0.43	19.3	1.49 ± 0.38	17.2	5.74 ± 2.00	0.7
	Western Europe	472	4.86	542	0.86 ± 0.22	17.7	1.24 ± 0.32	25.5	6.78 ± 2.25	1.3
	Eastern Europe	529	3.88	592	0.43 ± 0.11	11.2	0.84 ± 0.22	21.8	2.97 ± 1.06	0.5
	Oceania	28	0.758	59	0.05 ± 0.01	6.9	0.13 ± 0.03	16.7	0.67 ± 0.24	1.1
	Japan (East Asia)	94	2.20	375	0.23 ± 0.06	9.7	0.36 ± 0.09	16.2	2.17 ± 0.74	0.6
	Global South	6189	41.5	4868	2.75 ± 0.71	6.7	6.82 ± 1.75	16.4	64.06 ± 19.36	1.3
	East Asia (minus Japan)	1640	12.07	2945	0.80 ± 0.21	6.6	1.88 ± 0.48	15.5	12.23 ± 3.97	0.4
	Southeast Asia	487	5.75	351	0.43 ± 0.11	7.5	0.64 ± 0.16	11.1	9.63 ± 2.70	2.7
	South Asia	1701	8.15	509	0.64 ± 0.16	7.9	0.92 ± 0.24	11.2	6.62 ± 2.14	1.3
	Middle East	394	2.69	439	0.05 ± 0.01	1.9	0.22 ± 0.06	8.1	0.70 ± 0.27	0.2
	Africa	1189	7.11	272	0.26 ± 0.07	3.7	1.87 ± 0.48	26.3	20.06 ± 5.95	7.4
	Latin America	778	5.73	351	0.58 ± 0.15	10.0	1.30 ± 0.33	22.7	14.82 ± 4.34	4.2
Size class	Small (50–200k)	5023	11.9	555	1.09 ± 0.28	9.1	2.27 ± 0.58	19.0	16.63 ± 5.23	3.0
	Mid (200k–1 m)	2123	18.1	1712	1.67 ± 0.43	9.2	3.22 ± 0.83	17.8	23.51 ± 7.37	1.4
	Large (1–10 m)	419	22.4	2831	2.39 ± 0.61	10.7	4.12 ± 1.06	18.4	32.14 ± 9.93	1.1
	Mega (>10 m)	30	9.5	2178	0.86 ± 0.22	9.0	1.26 ± 0.32	13.2	10.12 ± 3.12	0.5
	Total world	7595	61.87	7277	6.01 ± 1.54	9.7	10.88 ± 2.80	17.6	82.40 ± 25.65	1.1