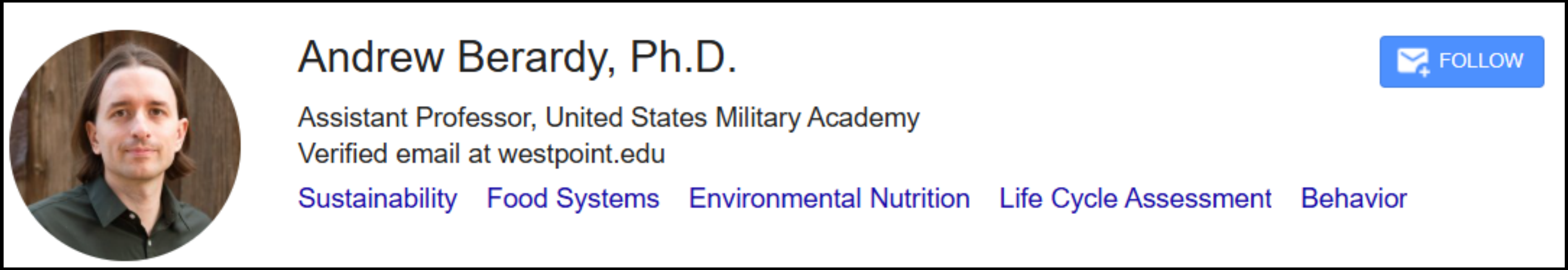
A Life Cycle Thinking Approach to Sustainable Food Systems

Dr. Andrew Berardy

Background & Disclaimer

- Dr. Andrew Berardy is an Assistant Professor at the United States Military Academy at West Point in the Department of Geography & Earth Sciences



- This presentation was prepared in my personal capacity and does not represent the official views of the U.S. Military Academy, the U.S. Army, or the Department of Defense

Overview / Research Agenda

- Food is necessary for life but can be detrimental to human & planetary health
- Sustainable food systems require holistic thinking to avoid burden shifting
- Life cycle assessment & epidemiological studies provide quantitative measures of environmental & health impacts
- Better choices can be made based on principles of environmental nutrition
- Behavior change is a key component, which can be better facilitated by artificial intelligence enabled assistance

Visual Outline

Humanity's Broken Relationship with Food

The Dilemma of Sustainable Food

Life Cycle of Food

Holistic View of Food Systems

Environmental Nutrition Model

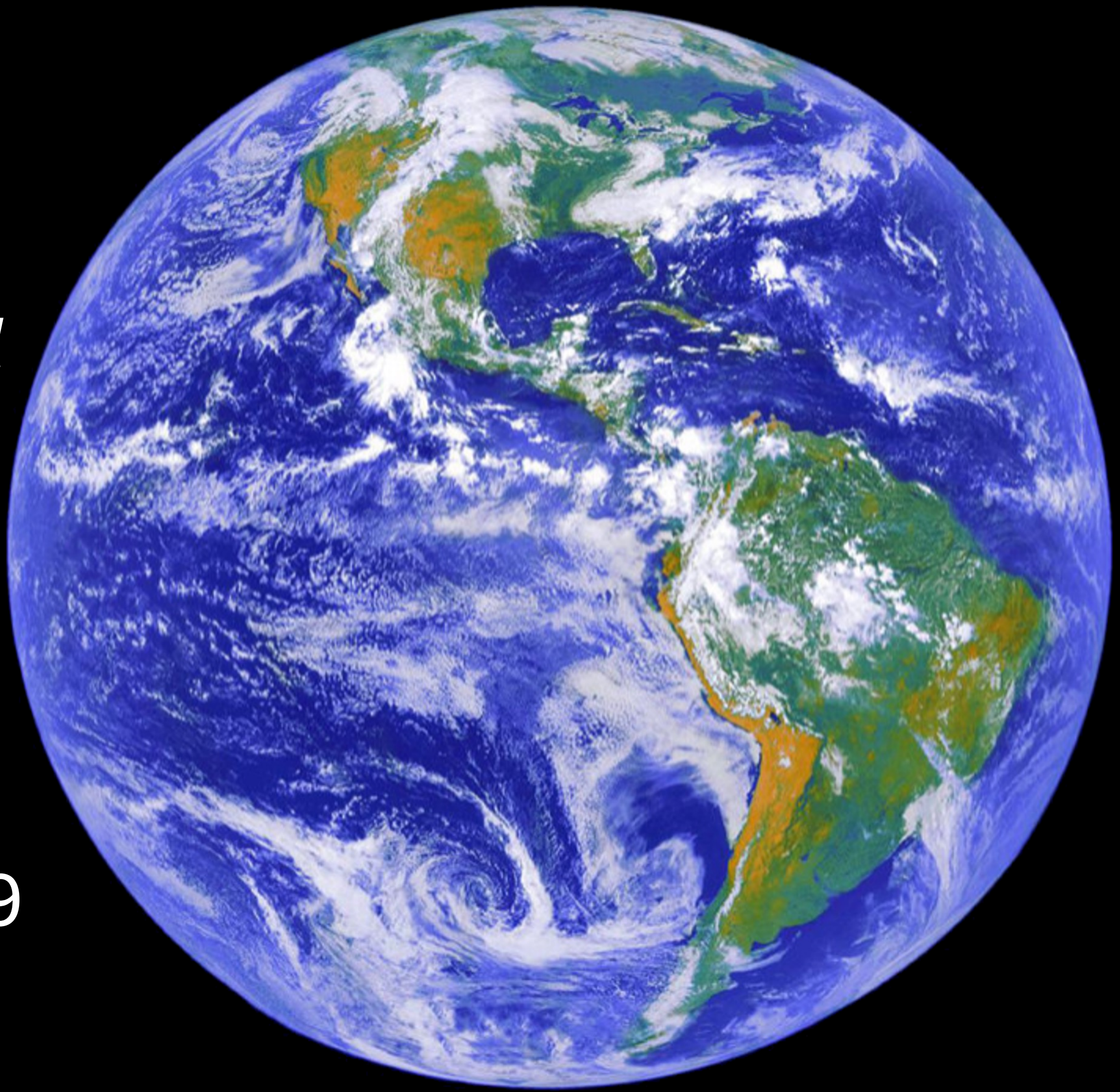
Behavior Change and Artificial Intelligence

Conclusions

Humanity’s Broken Relationship with Food

"Food systems have the potential to nurture human health and support environmental sustainability; however, they are currently threatening both."

-Willet, et al., 2019

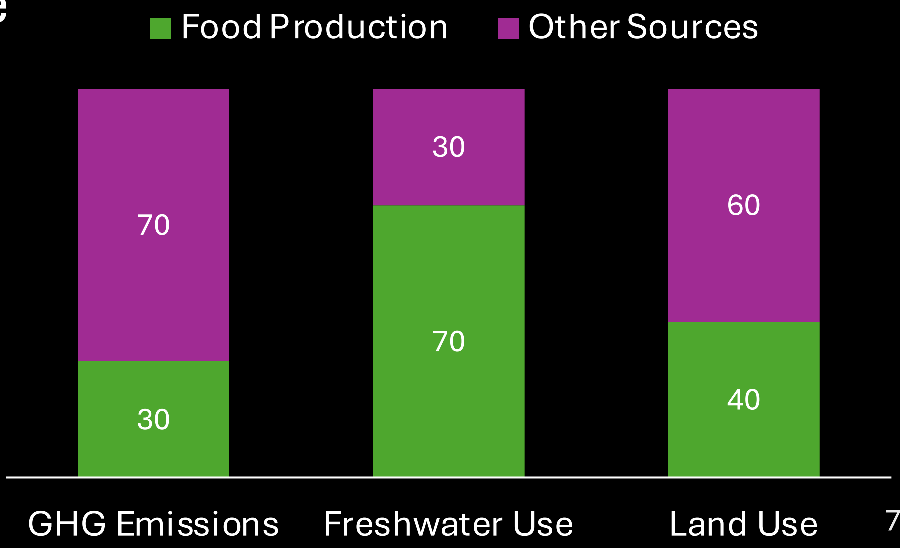


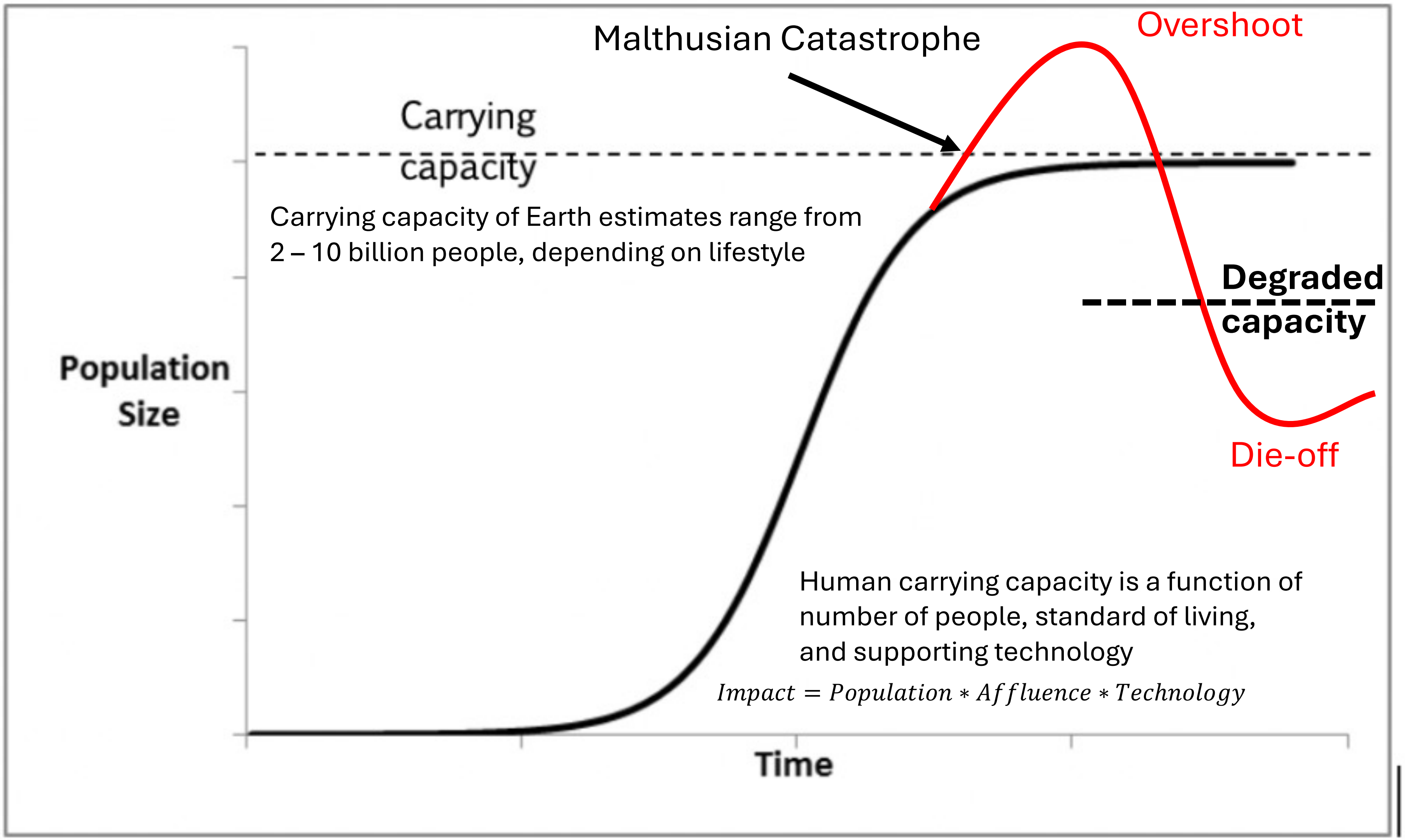
~8.2 billion people living on this planet

- 3.1 billion can't afford a healthy diet
- 2.5 billion are overweight, 0.9 billion obese
- 2.3 billion are food insecure, ~1 billion severely insecure
- 11 million die per year because of diet

Food is the largest cause of global environmental change

- Major contributor to GHG, freshwater use, and land use
- 30% of world fish stocks are overfished
- Conversion to cropland is largest cause of extinction
- Overuse of fertilizer causes eutrophication
  - Eutrophication → hypoxia → dead zone

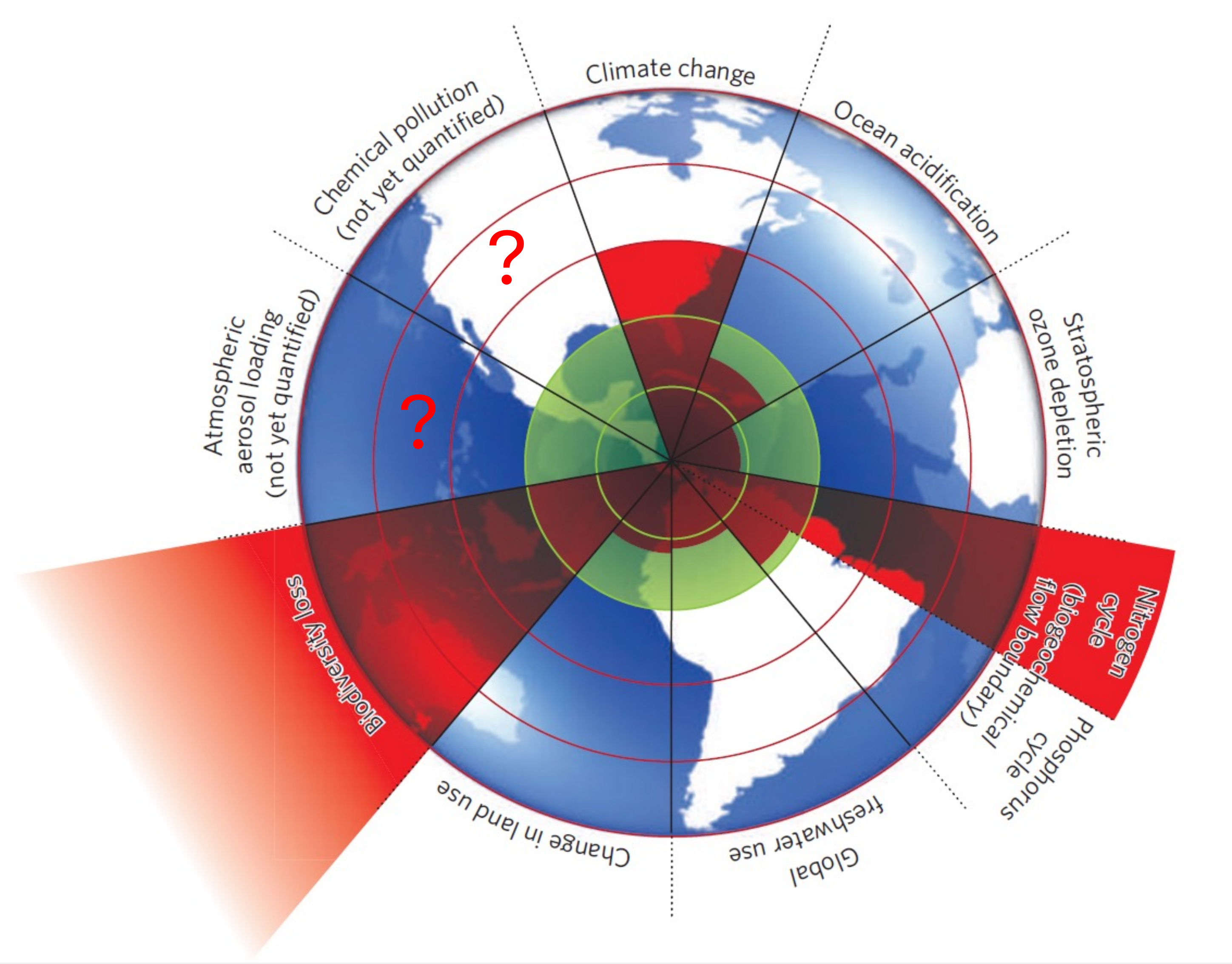


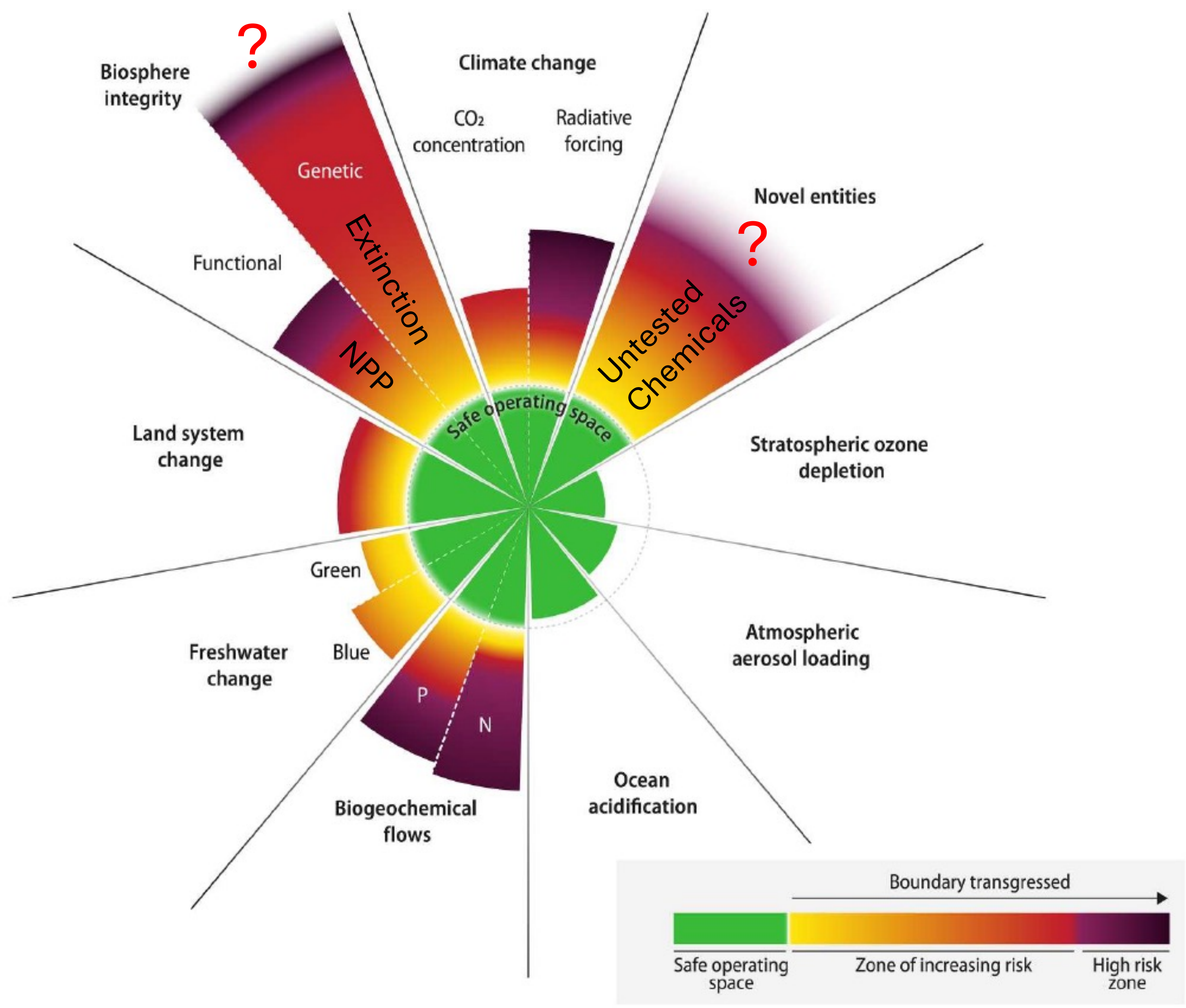

Malthusian Catastrophe
Overshoot
Carrying capacity
Carrying capacity of Earth estimates range from 2 – 10 billion people, depending on lifestyle
Degraded capacity
Population Size
Die-off
Human carrying capacity is a function of number of people, standard of living, and supporting technology
$Impact = Population * Affluence * Technology$
Time

A safe operating space for humanity
-Rockström et al., 2009

Exceeding safe planetary boundaries:

- Biodiversity
- Nitrogen cycle
- Climate change





Earth beyond six of nine planetary boundaries
-Richardson et al., 2023

Since 2009:

- ↑ Boundaries crossed
- Only "safe" in 3 areas
- Boundaries previously crossed now worse

Sustainability Challenges in the U.S. Food System Supply Chain

Production

Processing

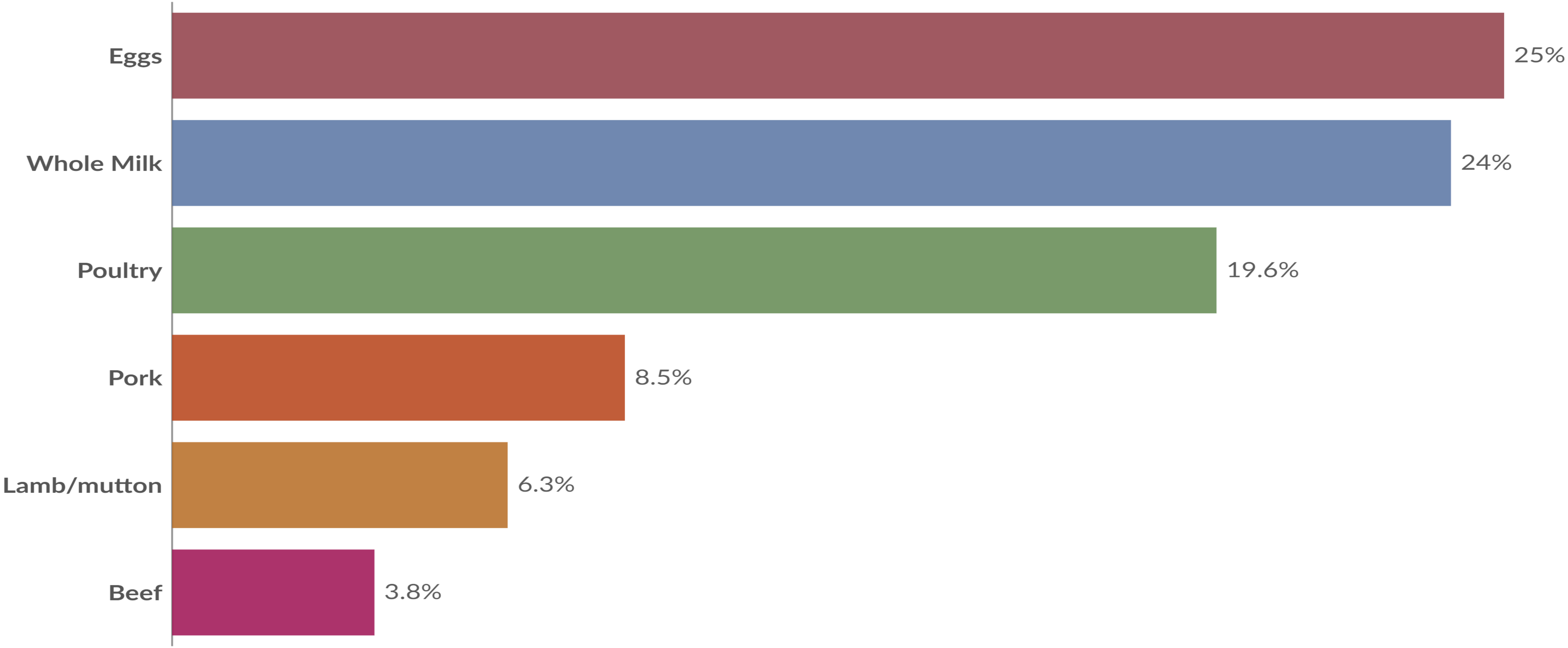
Distribution

Consumption

Disposal

Protein efficiency of meat and dairy production

The protein efficiency of meat and dairy production is defined as the percentage of protein inputs as feed effectively converted to animal product. An efficiency of 25% would mean 25% of protein in animal feed inputs were effectively converted to animal product; the remaining 75% would be lost during conversion.

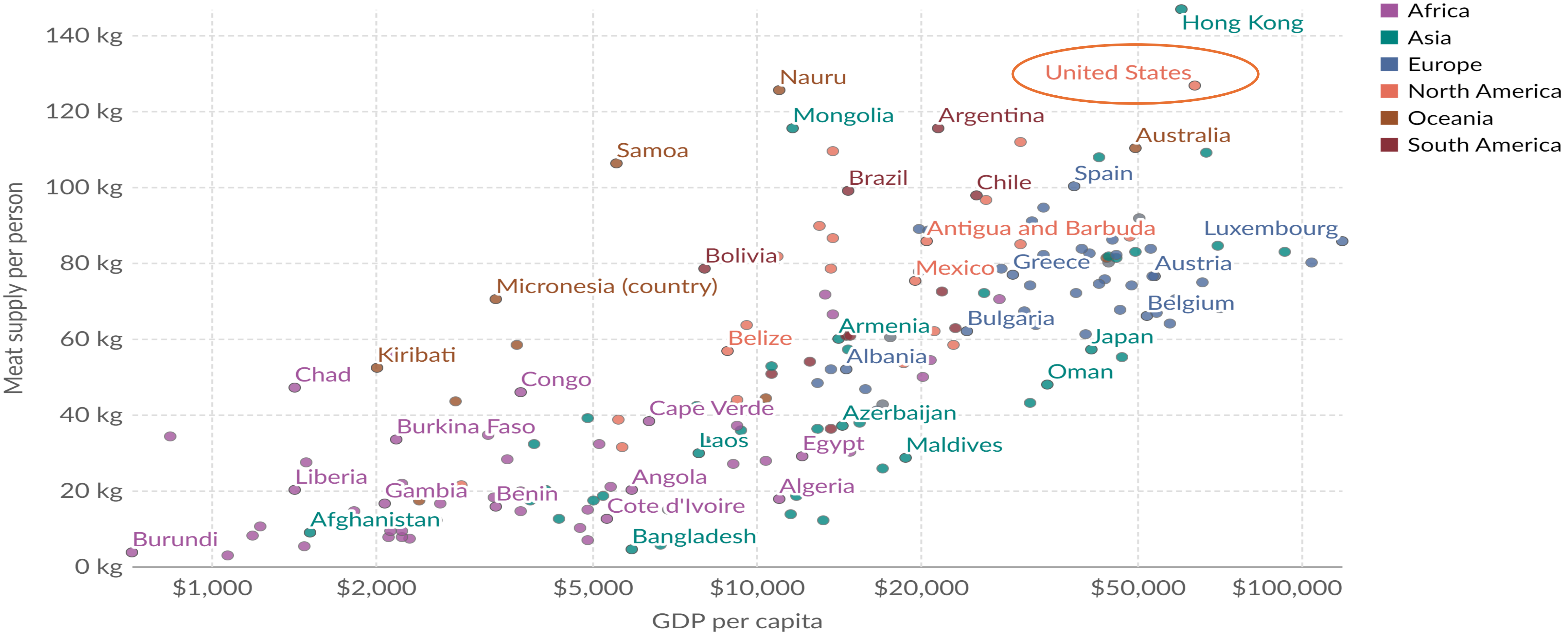


Data source: Alexander et al. (2016). Human appropriation of land for food: the role of diet. Global Environmental Change.

Meat supply vs. GDP per capita, 2021

Our World in Data

Average meat supply per capita, measured in kilograms per year versus gross domestic product (GDP) per capita measured in constant international-$. International-$ corrects for price differences across countries. Figures do not include fish or seafood.



Data source: Food and Agriculture Organization of the United Nations (2023); World Bank (2023)

The Dilemma of Sustainable Food

Sustainable

- Contested definition
- Balance environmental, social, and economic needs
- Meet present needs without compromising future needs

Food Systems

- Actors and activities across the life cycle of food
- Provide food security and nutrition for all
- Support health, pleasure, and culture

Food System Sustainability is a Wicked Problem

Wicked Problem Characteristic	Food System Examples
Essentially unique symptom of other problems	Root causes include poverty, production efficiency, ethics
Ill-defined	Sustainability is an essentially contested concept
No stopping rule and can't be proven true or false	Food system must continue for humanity's survival
Cannot be tested, because that changes the situation	Alterations to the food system may result in permanent changes (e.g., introduction of new genes to plants)
No right to be wrong	Potentially millions of lives and the environment are at stake
Problem explanation / framing determines nature of solutions	Framing as production problem encourages efficiency solution, framing as distribution problem encourages equity solutions

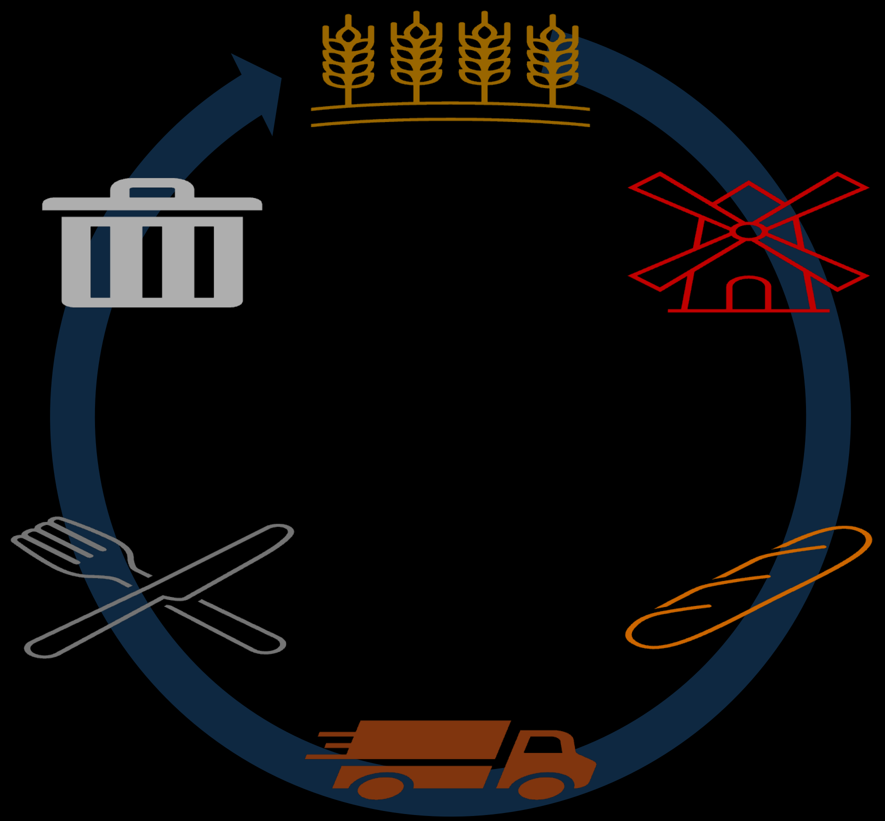
Finding the Future of Food – Berardy, 2015

Life Cycle of Food

Food System Life Cycle

Social Influences

Subsidies



Affordability

Availability

Tradeoffs exist across all phases of the life cycle of food: LCA can provide a quantitative comparison basis

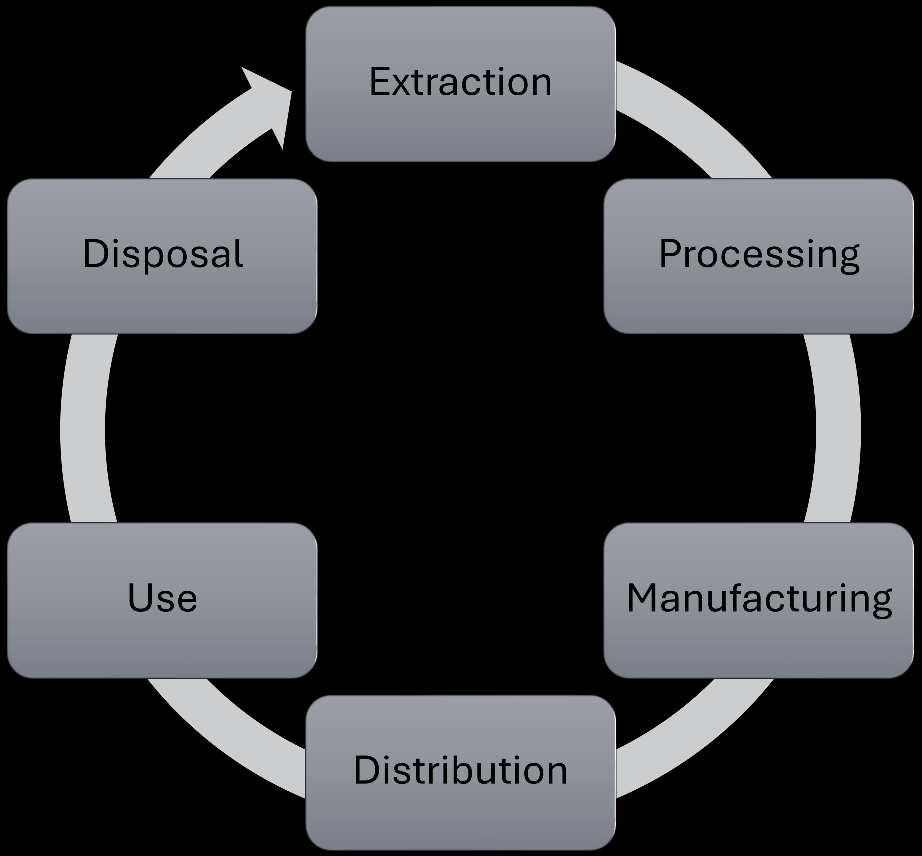
LCA can help people make the best food choices for reducing their environmental impacts

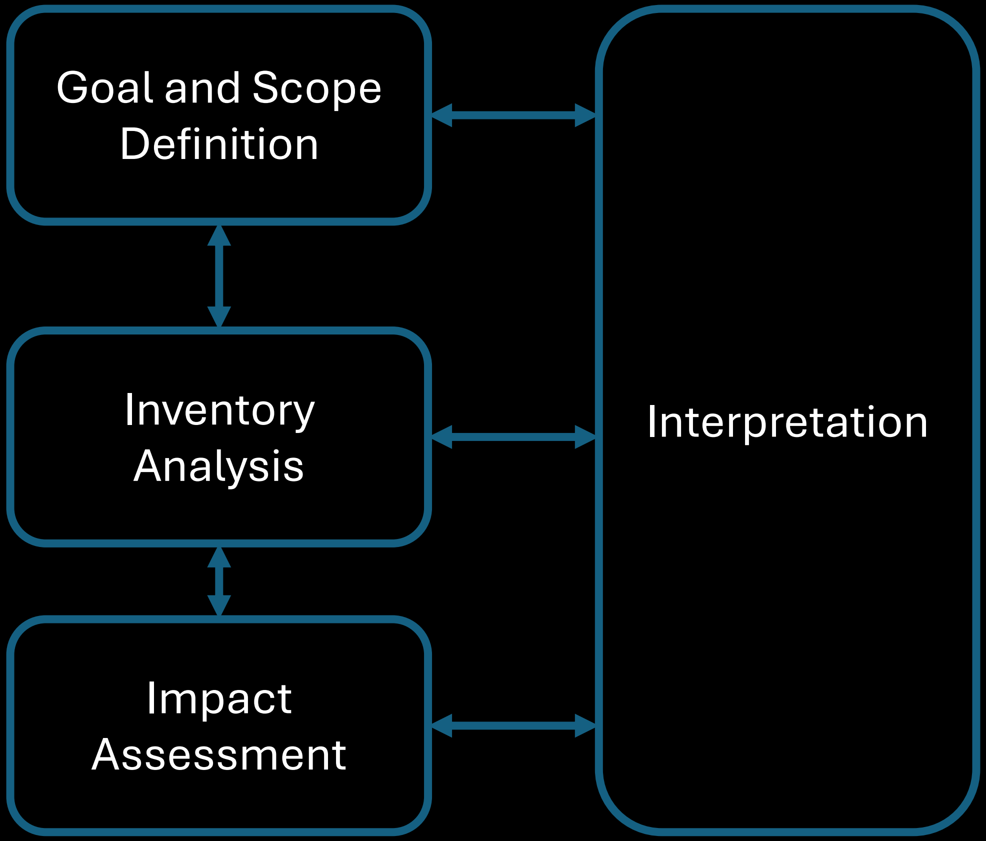
LCA can help identify improvements in growing, processing, and distributing food

Finding the Future of Food: Sustainable Consumption Lessons from and for Veganism – Berardy, 2015

The Role of Life Cycle Assessment

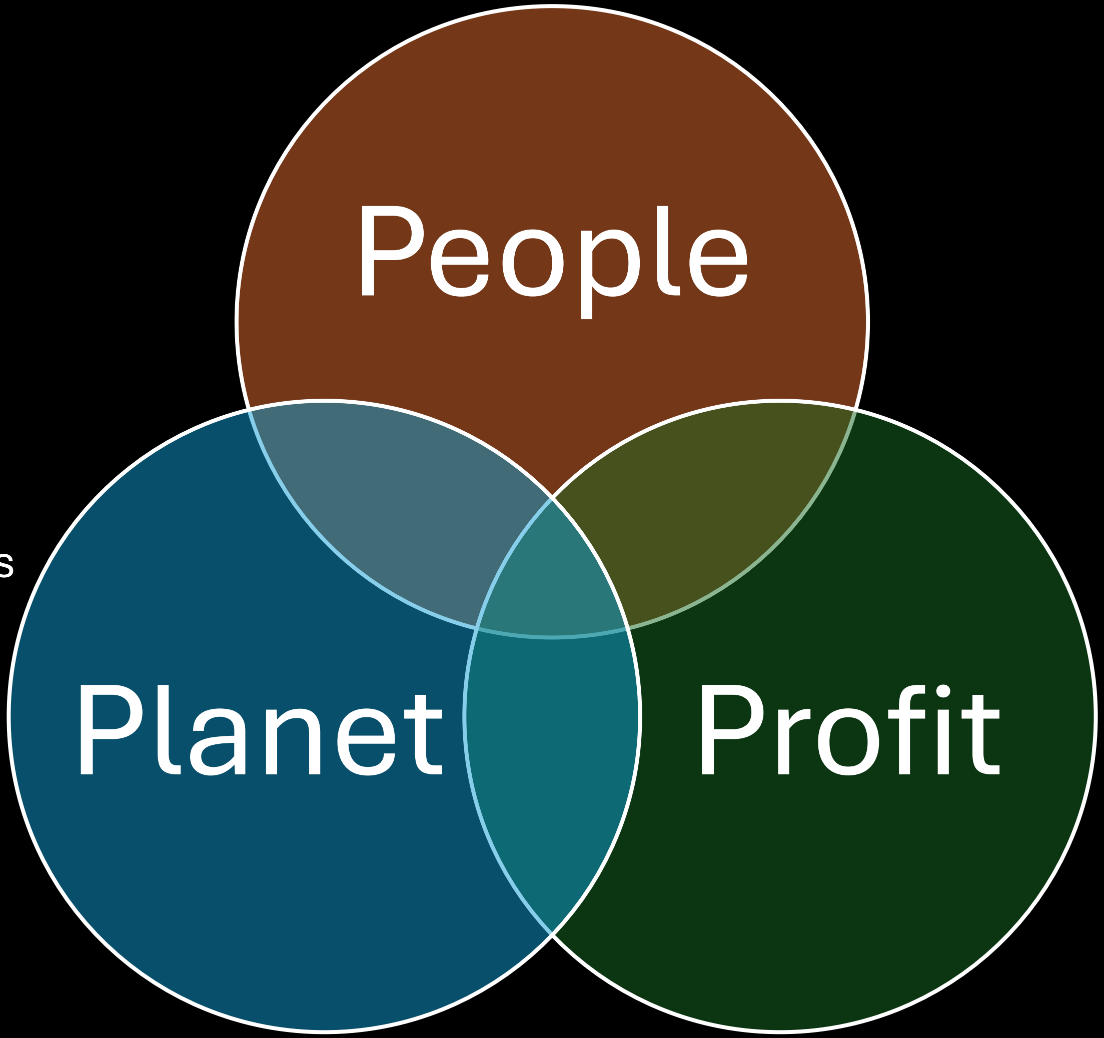
Life Cycle Assessment





LCA for Sustainability

- Quantify negative health impacts (e.g., DALYs)
- Policy & regulation support
- S-LCA: Working conditions, local effects, human rights



- Quantify environmental impacts
- Improve production efficiency
- Identify hotspots to address

- Reduce production costs
- Comply with regulations
- Market to customers

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https://www.foodsystemsjournal.org

Berardy, et al., 2020

Considering the role of life cycle analysis in holistic food systems research, policy, and practice

Challenges for LCA of Food	Potential Solutions
Blurred boundaries	Transparent methodology
Appropriate functional unit / LCA of diets	Multiple functional units
Geospatial variability	Geographic Information System enabled LCA, fate and transport models
LCA bias towards efficiency	Utilize mixed methods
Integrating qualitative methods	Food systems assessments, sustainable materialism, backcasting and scenario-building

LCA is better for

LCA is better for	LCA is worse for
Efficiency improvement	Increasing resilience
Quantitative evaluation	Systematic transformation
Comparison of similar alternatives	Ambiguity and variability

LCA is worse for

Why?

- Everything is relative to functional unit, i.e., efficient production
- Efficiency improvements reinforce status quo
- Some metrics, including resilience, are hard to quantify and evaluate

Maximizing Benefits from Using LCA

Holistic & iterative	• Take a holistic and iterative approach to problem-solving • Consider many perspectives, don’t be afraid to start over
Inform, don’t dictate	• Use LCA to inform, not dictate, decisions • Dispel myths, compare similar alternatives
Human behavior	• Account for human behavior • Irrational, emotional, habitual
Scenarios	• Model and build future scenarios, then identify improvements • Utilize other tools in combination with LCA

LCA Case Study

sustainability

MDPI

Article

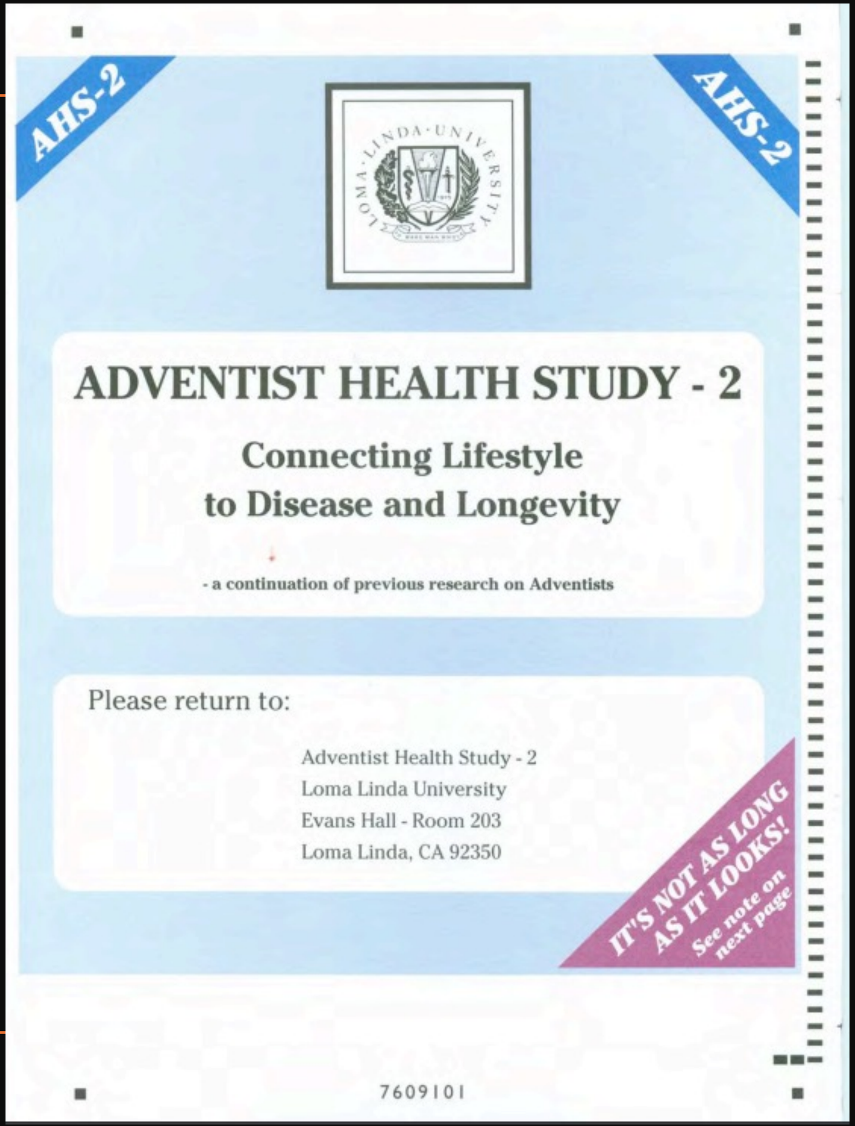
Environmental Impacts of Foods in the Adventist Health Study-2 Dietary Questionnaire

Andrew Berardy [1,*,†], Ujué Fresán [1,2,3,†], Rodrigo A. Matos [4], Abigail Clarke [1], Alfredo Mejia [1], Karen Jaceldo-Siegl [1] and Joan Sabaté [1]

LOMA LINDA UNIVERSITY

TO MAKE MAN WHOLE

198 items examined, impacts reported in GWP, LU, and WC



Goal and Scope Definition / Inventory Analysis

Cradle to gate (manufacturer or farm)

Including material and energy inputs

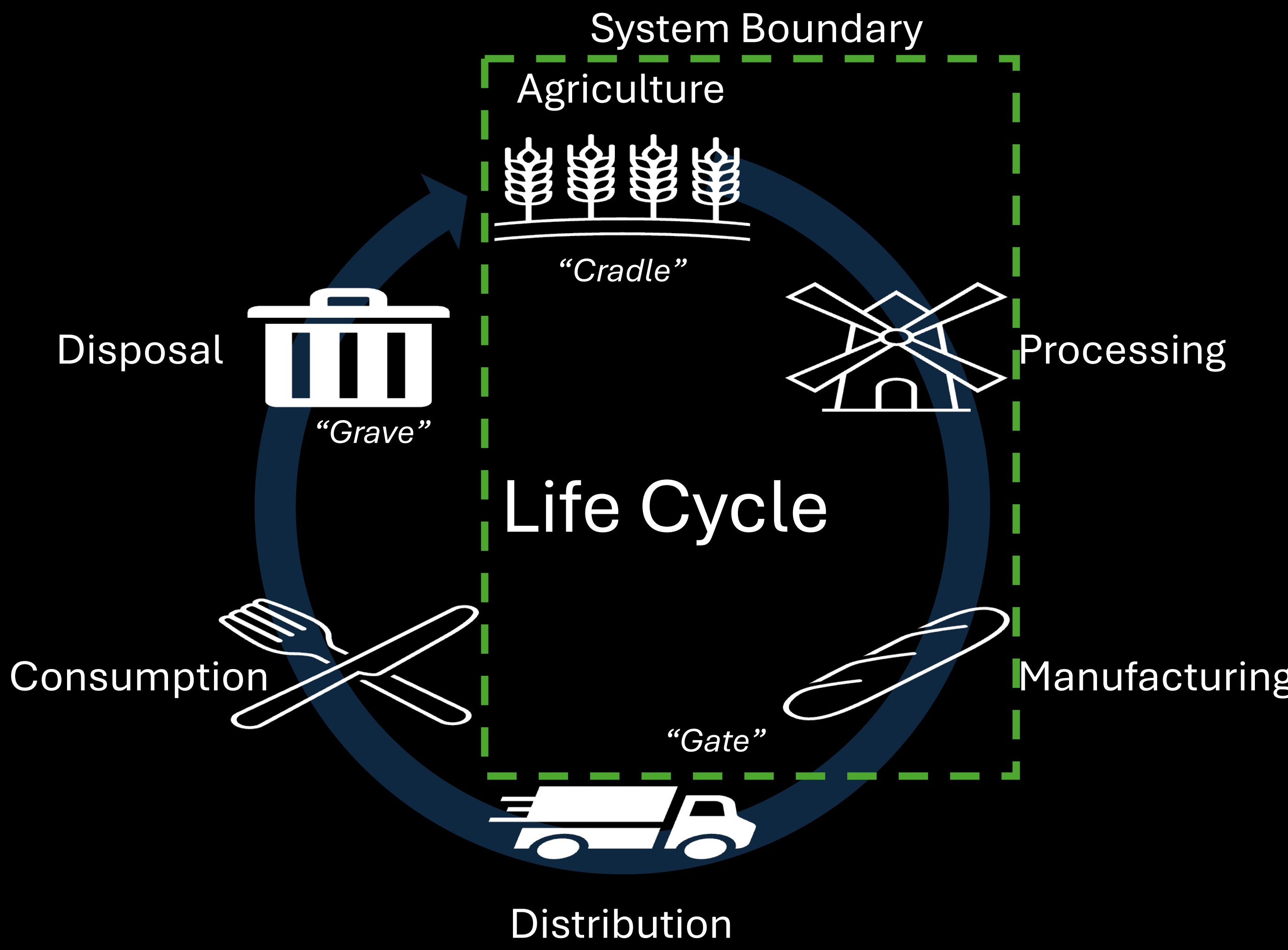
Excluding distribution through disposal

Primary and secondary data utilized

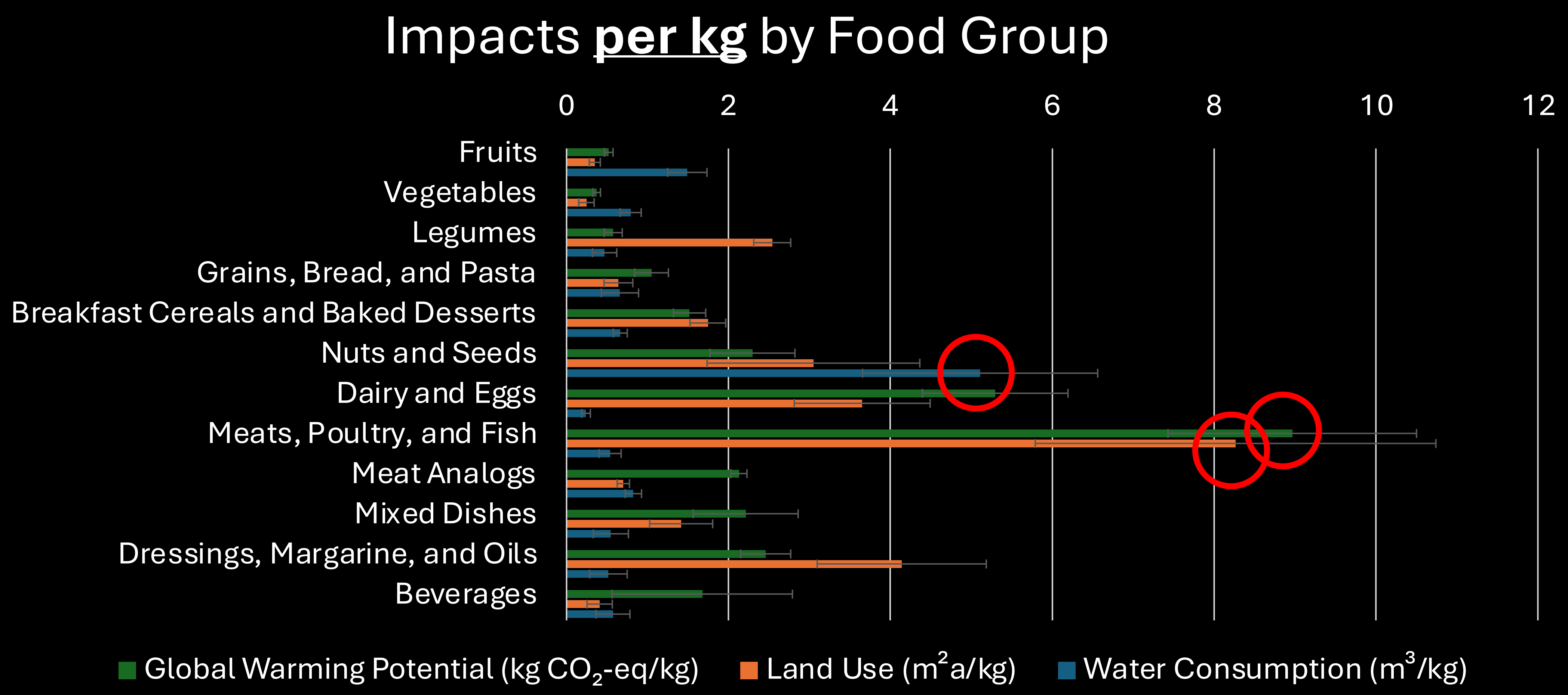
On-site measurements

Life cycle inventory databases

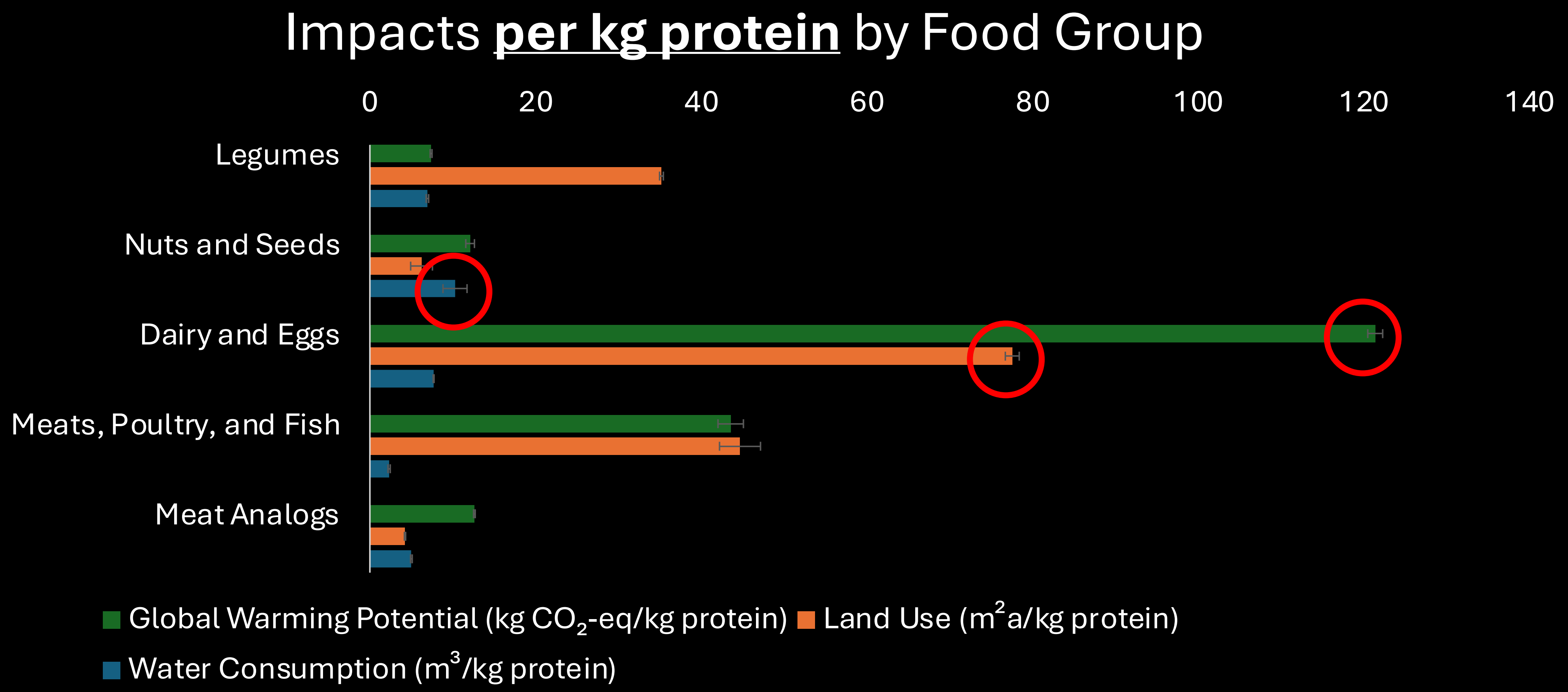
Calculations



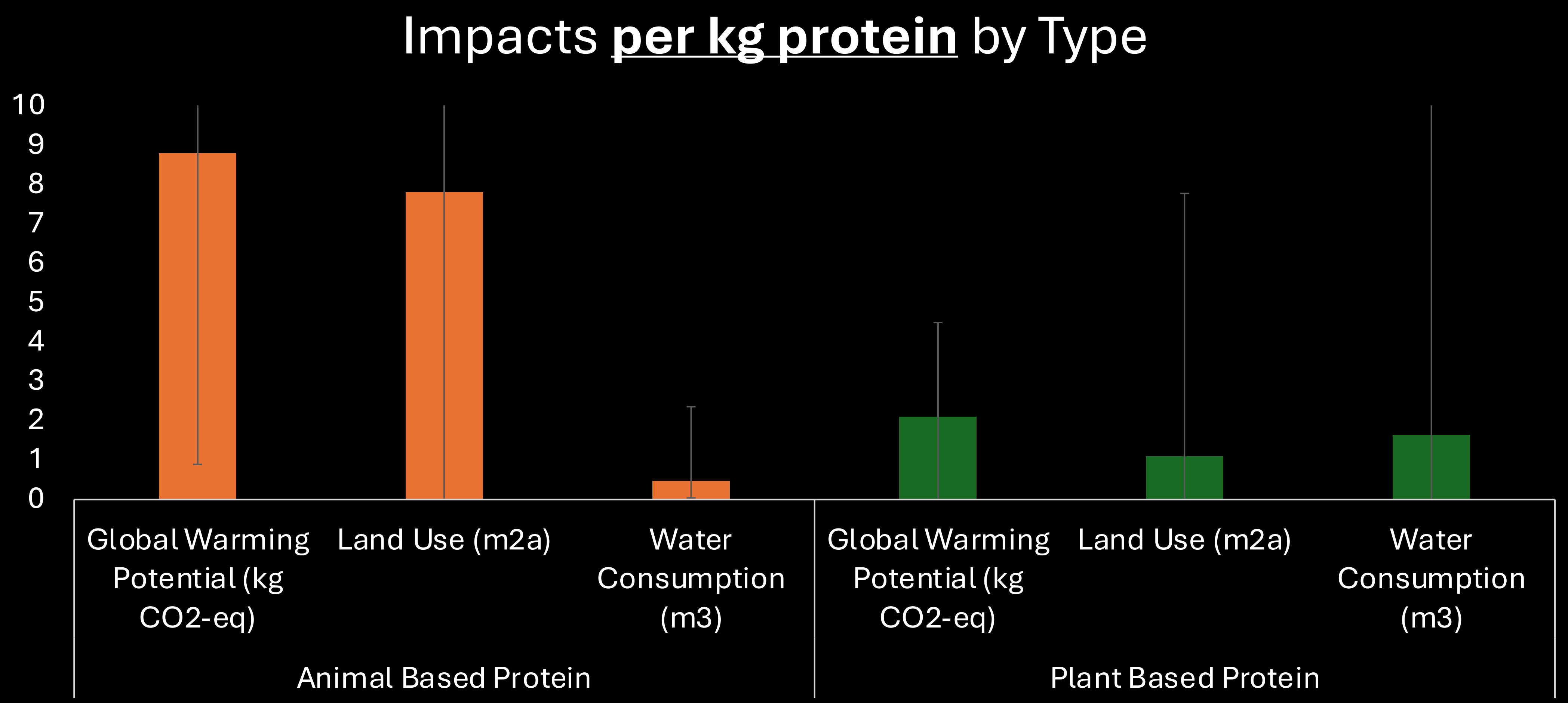
Impact Assessment



Impact Assessment

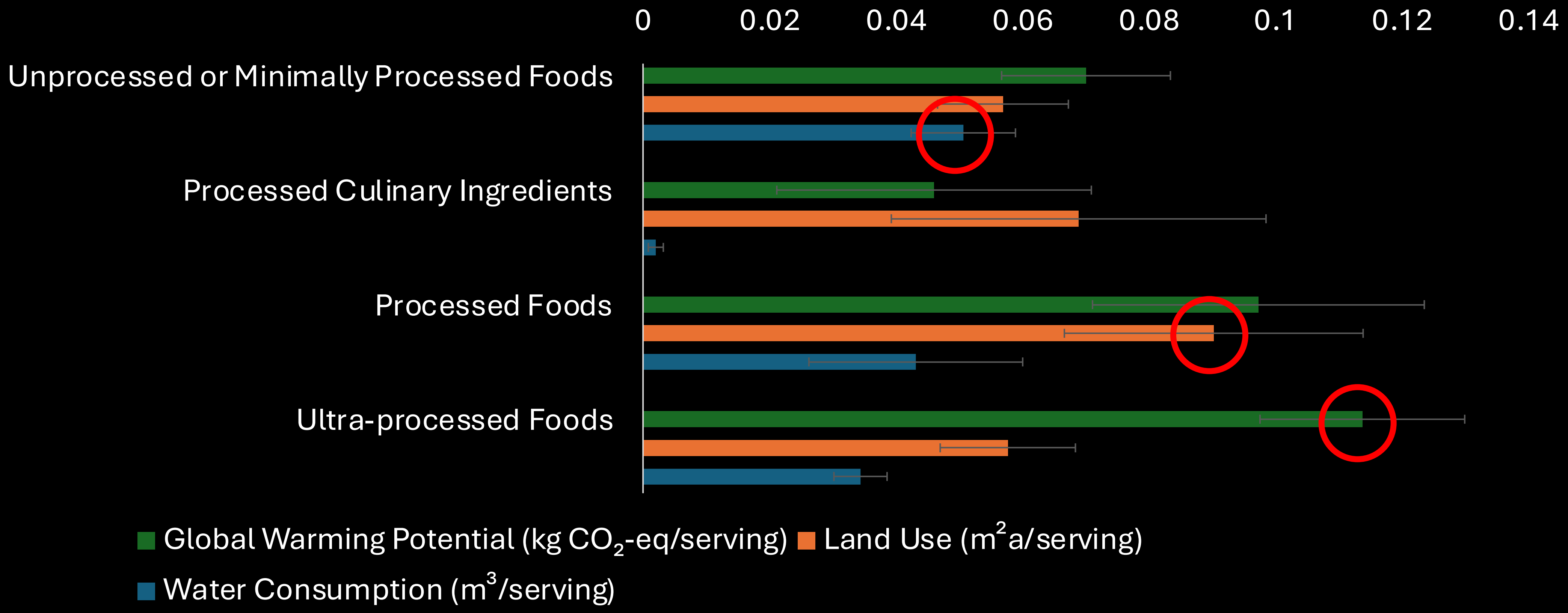


Impact Assessment



Impact Assessment

Impacts **per serving**, NOVA Classifications



Interpretation

Highest GWP and land use impacts from animal-based foods

Highest water consumption from nuts and seeds

Still true on a protein basis

Highest impacts varied across levels of processing

Overall, lowest impacts from minimally processed plant-based foods

Holistic View of Food Systems

Potential Technological Solutions
(Framing as production problem)

GENETIC MODIFICATION

VERTICAL FARMING

FOOD PRESERVATION

PRECISION AGRICULTURE

CULTURED MEAT

WASTE TO RESOURCE CONVERSION

NOVEL PROTEINS

INNOVATIVE PROCESSING TECHNIQUES

Climate Smart Agriculture – transform agri-food systems toward green and resilient practices

- Precision agriculture for efficient production
- Improve resilience of food systems and livelihoods
- Can be any type or size of farm

Utilize GIS and AI to identify unhealthy areas of fields and automatically apply amendments

Burden Shifting

Vertical farm reduces land and water use, but increases energy use and pollution emissions
Local production reduces food miles but decreases efficiency, especially out of season

Jevon's Paradox
(Rebound Effect)

More efficient technology can increase resource usage

Resource Scarcity
- Limited coal supply

Technology Improvement
- More efficient coal-fired engine

Lower Cost
- Less coal needed for same function

Increased Use
- Utilized in more industries

Increased Resource Usage
- More coal used than before

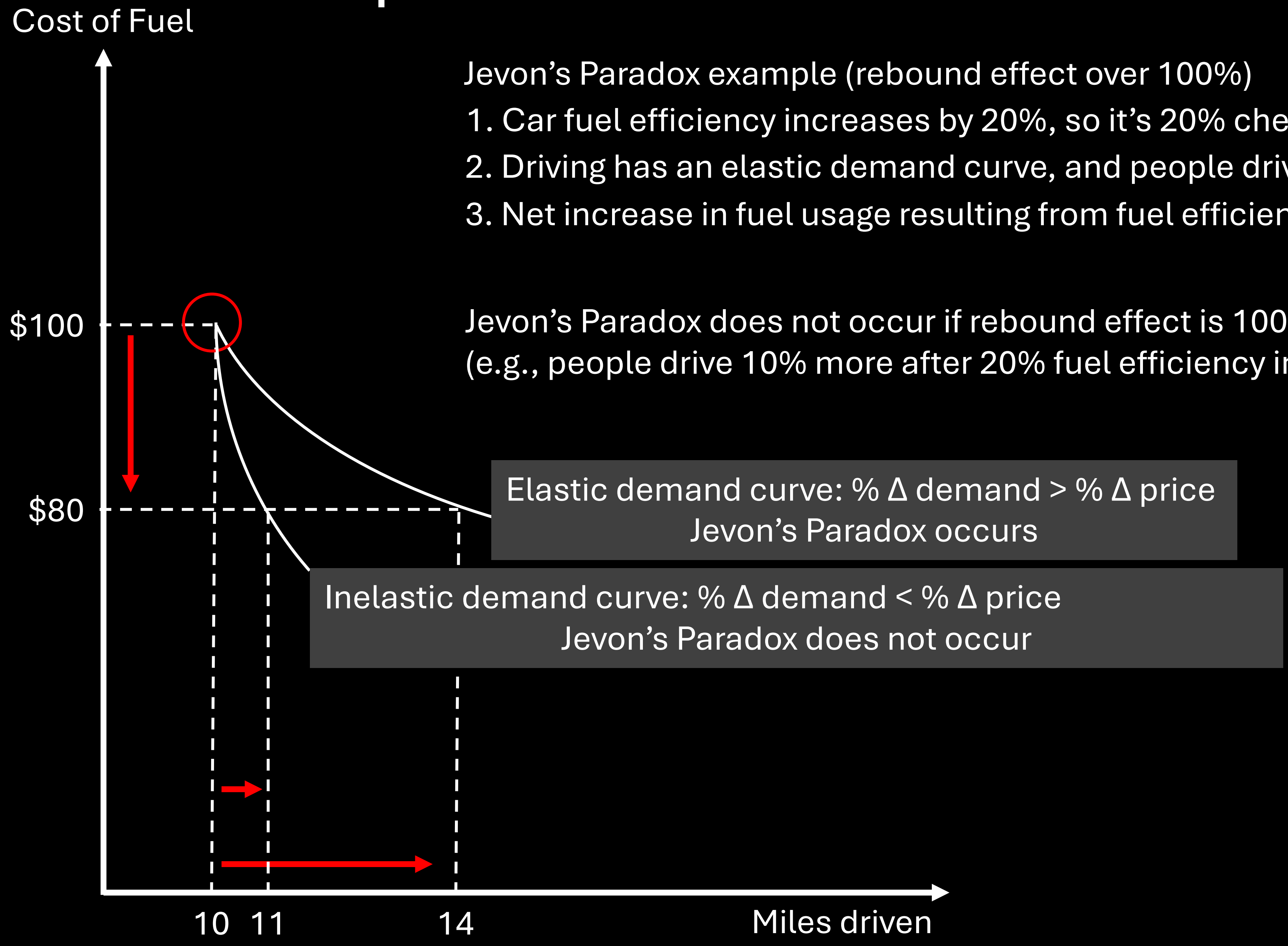
Time

People with Fuel Efficient Cars Tend to Travel More

Jevon's Paradox example (rebound effect over 100%)

1. Car fuel efficiency increases by 20%, so it's 20% cheaper to drive
2. Driving has an elastic demand curve, and people drive 40% more
3. Net increase in fuel usage resulting from fuel efficiency increase

Jevon's Paradox does not occur if rebound effect is 100% or less (e.g., people drive 10% more after 20% fuel efficiency increase)



Jevon’s Paradox in Agriculture

MORE EFFICIENT FARMING EQUIPMENT

LOWER COST OF PRODUCTION AND FOOD PRICES

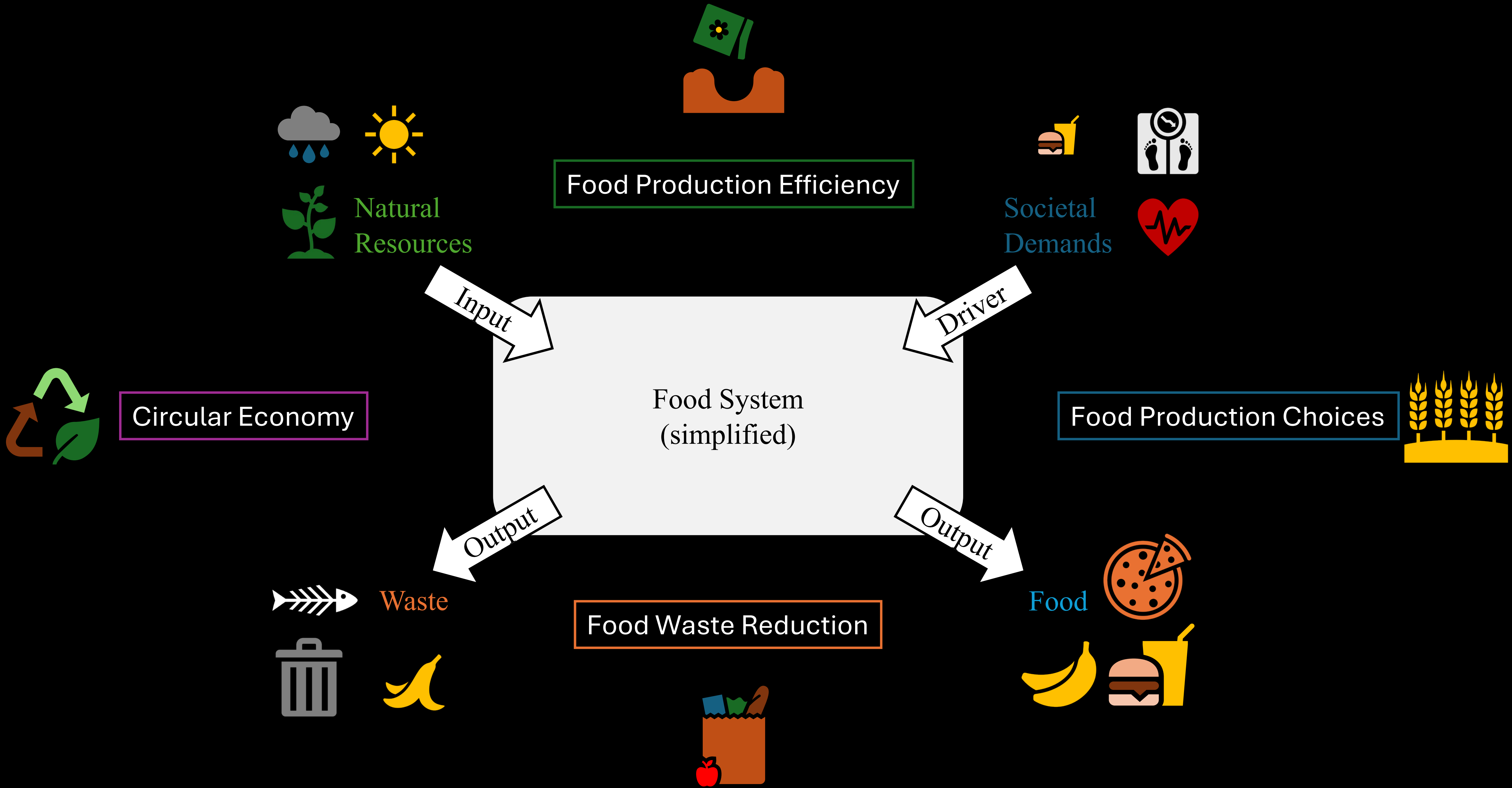
INCREASED DEMAND, PRODUCTION, AND CONSUMPTION

MORE INTENSIVE FARMING PRACTICES

INCREASED RESOURCE CONSUMPTION

Time

Environmental Nutrition Model



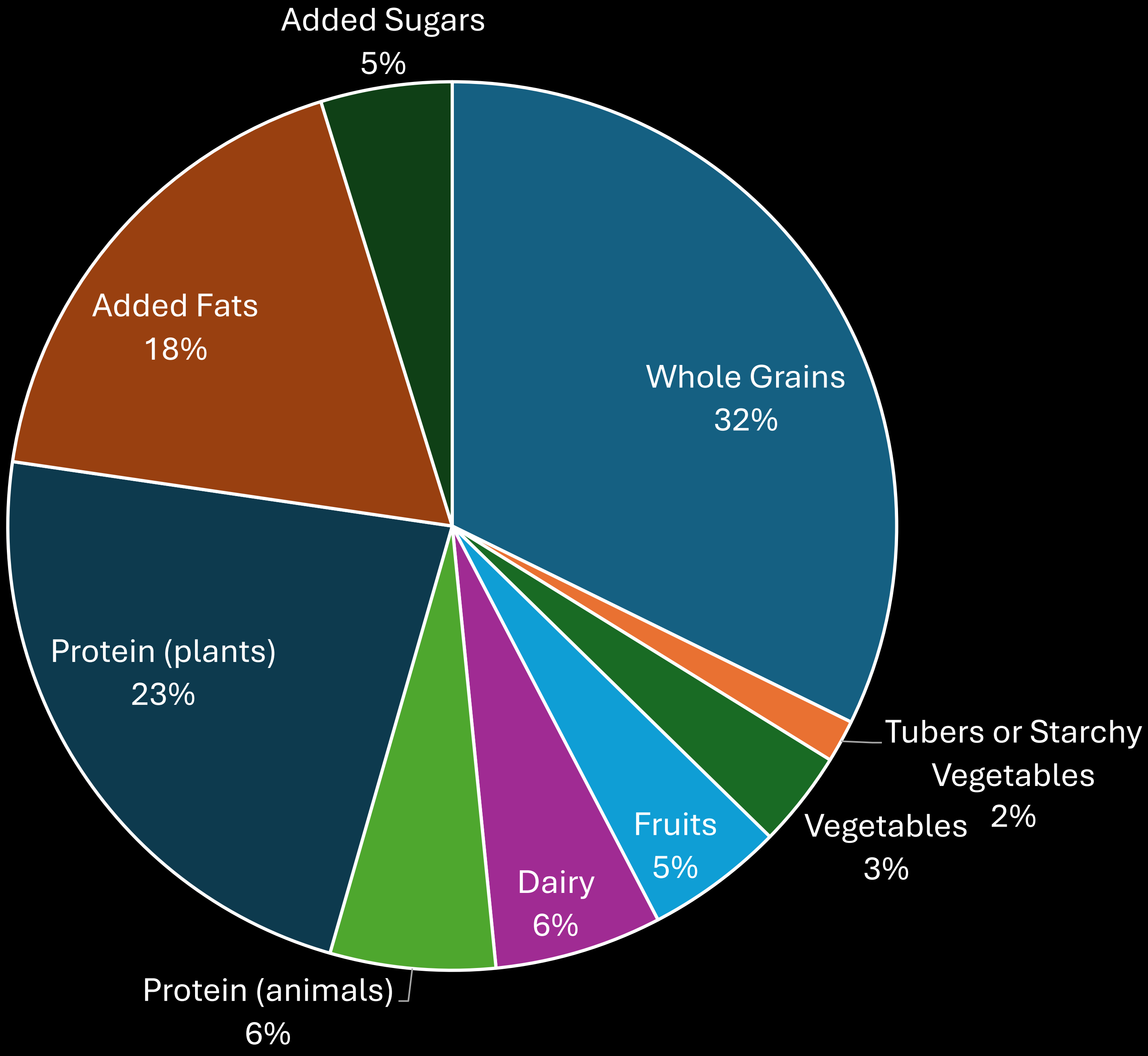
Food Production Efficiency
Natural Resources
Societal Demands
Input
Driver
Circular Economy
Food System (simplified)
Food Production Choices
Output
Output
Waste
Food Waste Reduction
Food

Behavior Change and Artificial Intelligence

Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems
-Willet, et al., 2019

Environmental Impact	Control Variable	Boundary	Uncertainty Range
Climate Change	Greenhouse Gas Emissions	5 Gt CO_2-eq per year	4.7-5.4
Nitrogen Cycling	Nitrogen Application	90 Teragrams per year	65-130
Phosphorus Cycling	Phosphorus Application	8 Teragrams per year	6-16
Freshwater Use	Consumptive Water Use	2500 m^3 per year	1000-4000
Biodiversity Loss	Extinction Rate	10 extinctions per million species per year	1-80
Land-system Change	Cropland Use	13 million km^2	11-15 million

Recommended Caloric Intake per day for 2500 Calorie Diet



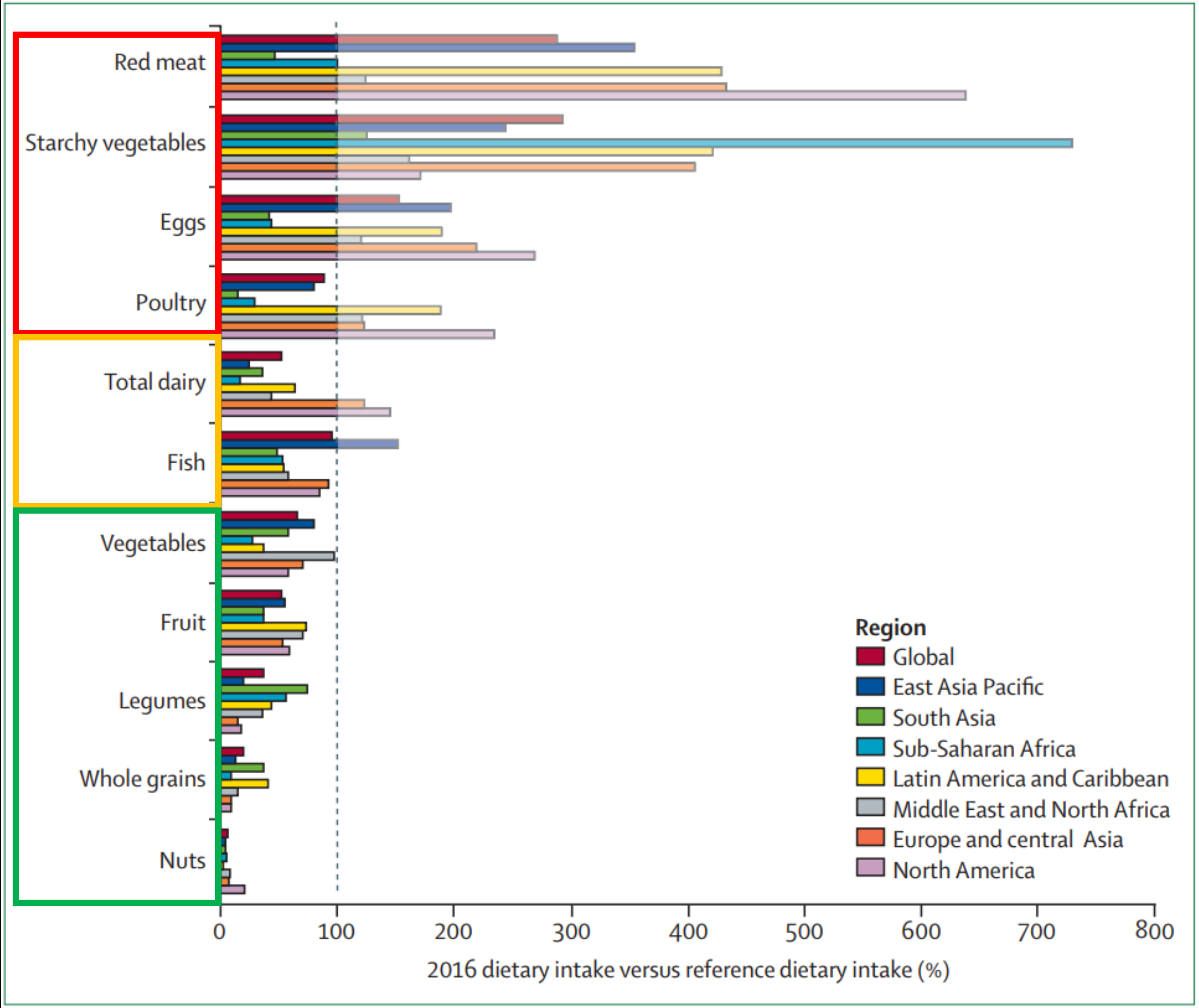
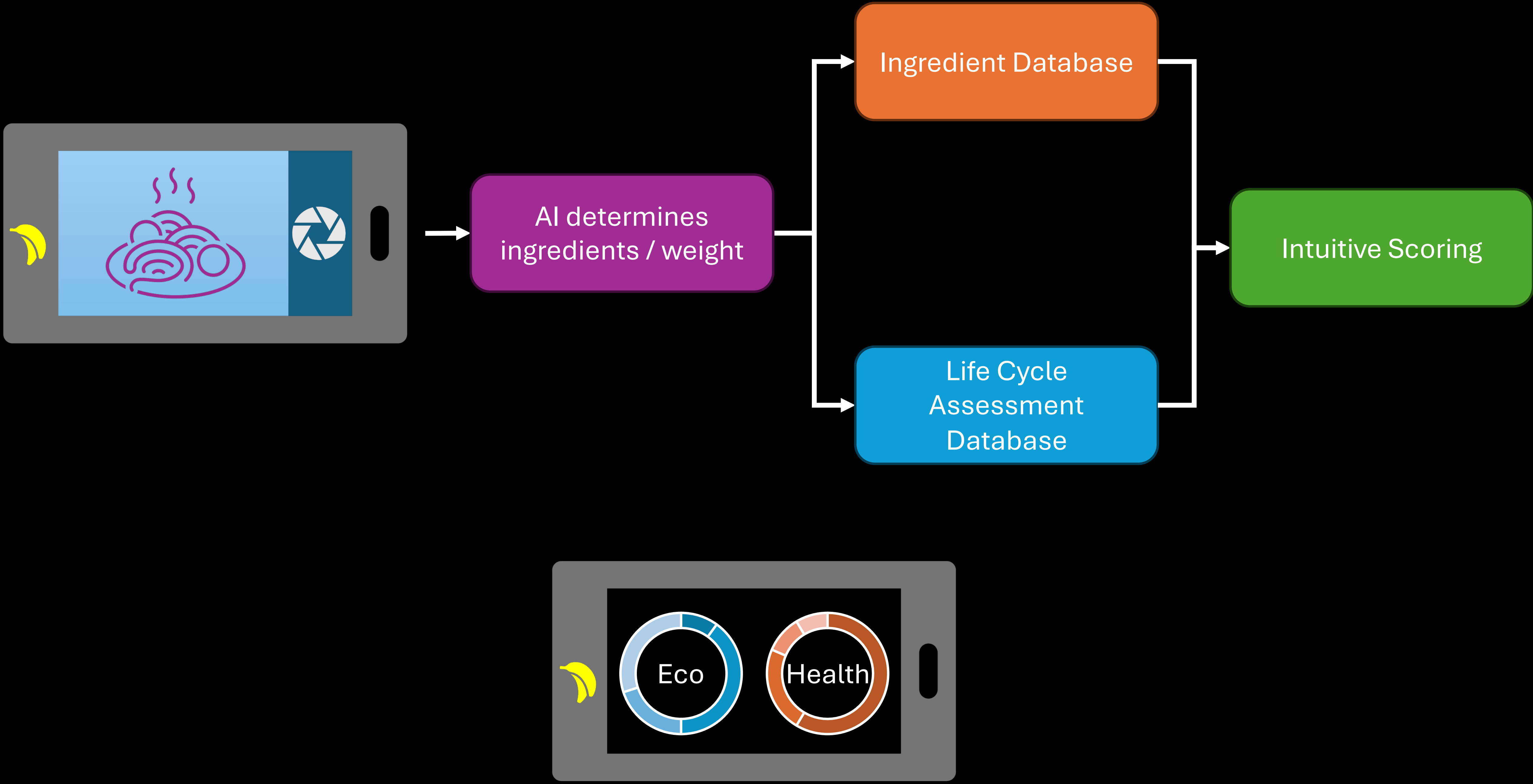


***Figure 1:* Diet gap between dietary patterns in 2016 and reference diet intakes of food**
Data on 2016 intakes are from the Global Burden of Disease database.[130] The dotted line represents intakes in reference diet (table 1).

Challenges Influencing Better Food Choices

- Overwhelming amount of information, with many authoritative sources providing conflicting viewpoints
- Quantitative measurements can provide counterintuitive results
- One study found consumers overestimate impact of processing and underestimate impact of water-intensive foods
- Participants in another study guessed calorie content from photos of food within 20% of the correct value only 25% of the time


AI determines ingredients / weight
Ingredient Database
Life Cycle Assessment Database
Intuitive Scoring
Eco
Health


Lay's
wavy
Original
Wavy potato chips
23
Nutrition Value
58
Eco Value


SARAH'S SINGLE MEAL MANIFEST
Grilled Chicken with Quinoa
Health
Calories
Eco
Protein
Minerals
Fats
Vitamins
Fiber
Meal
Day
Week
Month
Year
Life
Out of Recommended Range
FATS
VITAMINS
Low
DEFICIENT
EXCESSIVE
In Recommended Range
CALORIES
925
PROTEIN
48
FIBER
32

A matrix approach to visually communicate simultaneously the environmental and health impacts of foods

Andrew Berardy, Ujué Fresán, Nazanin Abbaspour, Joan Sabaté

Goal: Simplified visual representation of environmental and health impacts from 30 commonly consumed food groups

Methods: Data aggregated from meta-analyses and reviews using weighted averages

Results: Color-coded 3x3 matrix classification of foods based on carbon footprint and relative risk of ACM and diseases

Carbon Footprint

$$CFP = \frac{(sv * CF_{MA}) + \frac{(sv * \sum_{i=1}^{n} CF_F)}{n}}{2}$$

Low	<100
Medium	100-300
High	>300

g CO2-eq/serving

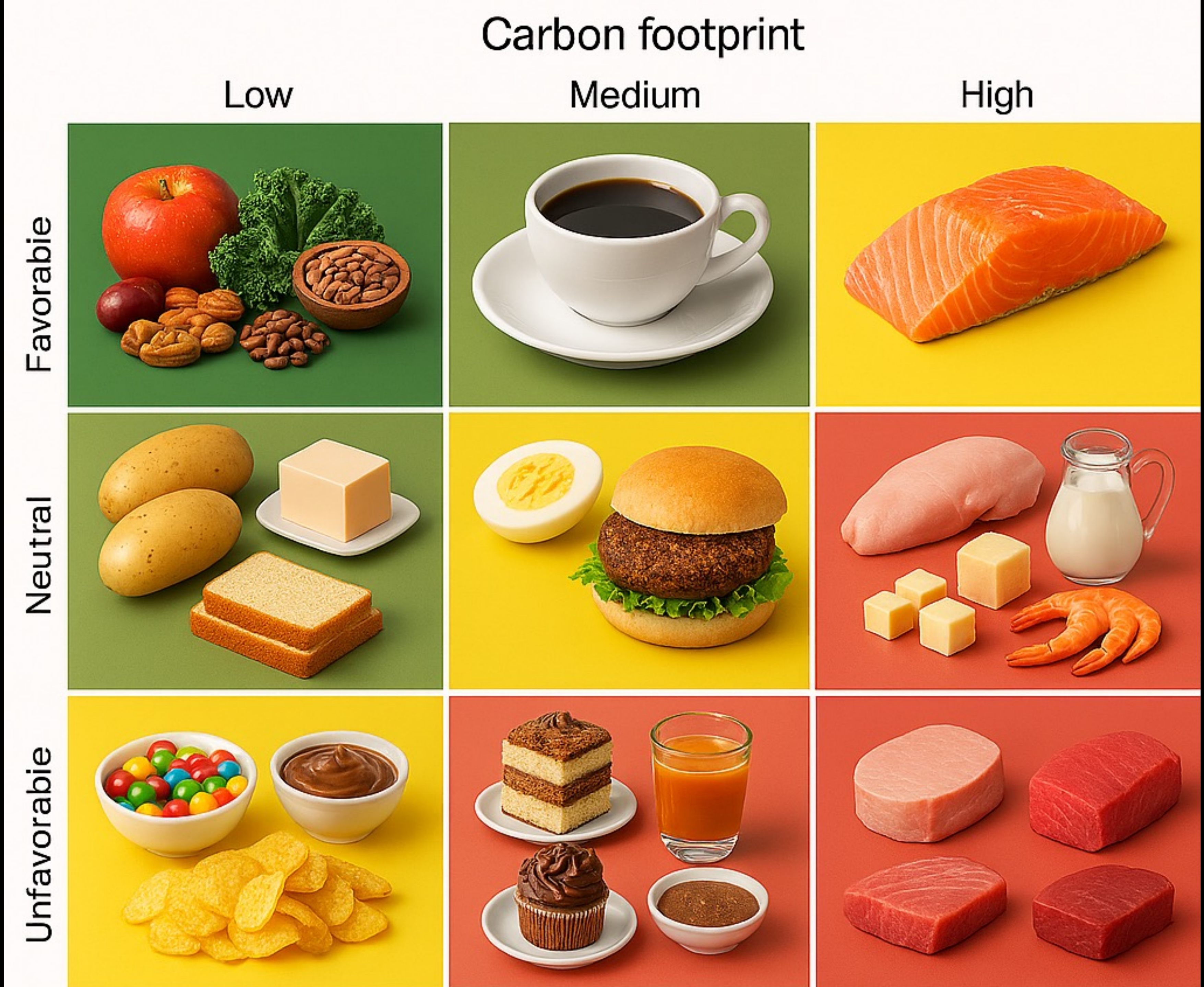
Health Effect

$$HIS = \frac{RR_{ACM} + \frac{\sum_{i=1}^{m} RR_i}{n}}{2}$$

Favorable	<0.96
Neutral	.96-1.07
Unfavorable	>1.07

Carbon footprint

Health effect	Low	Medium	High
Favorable	Fruits Vegetables Beans & Peas Nuts & Seeds Whole grains Water	Coffee & Tea	Fish
Neutral	Potatoes Margarine Refined grains Vegetable oils	Eggs Butter Dairy substitutes Meat substitutes Fruit & Veg. Juices	Poultry Dairy products Shellfish
Unfavorable	Candy & Sugars Savory snacks Dressings & Sauces	Ready-to-eat cereals Pastries & Desserts Alcoholic drinks Sodas	Processed meats Pork Beef


Carbon footprint
Low
Medium
High
Favorabie
Neutral
Unfavorabie

Conclusions

Summary and Lessons

- Humanity's Broken Relationship with Food → We're Far from Sustainable
- The Dilemma of Sustainable Food → Balance the Triple Bottom Line
- Holistic View of Food Systems → Consider the Whole Life Cycle
- Environmental Nutrition Model → Support Nutrition and Health
- Life Cycle of Food → Plant-based Foods Perform Best
- Behavior Change and Artificial Intelligence → LCA is Useful in Limited Contexts

Thank you!

QUESTIONS?

ANDREW.BERARDY@WESTPOINT.EDU