An Extended Environmental-Input-Output Lifecycle Assessment Model to Study the Food-Energy-Water Nexus

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Introduction

The goal of this study is to:

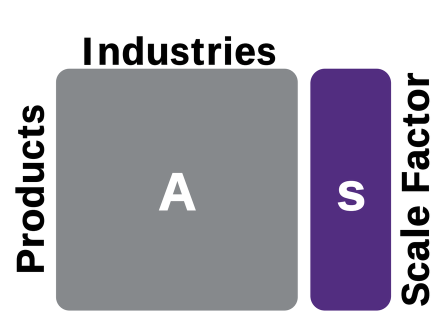
- Develop a physically based environmental account of U.S. food production systems and to integrate these data into the Environmental-Input-Output Lifecycle Assessment (EIO-LCA) model [1].
- Characterize and compare the food, energy, and water intensities of **every U.S. economic sector**.

The extended EIO-LCA model can determine the **food resource use** in units of mass (kg) or energy content (kcal), **water use** (kGal), and **energy use** (TJ) of any economic activity within the United States.

IO-LCA Methodology

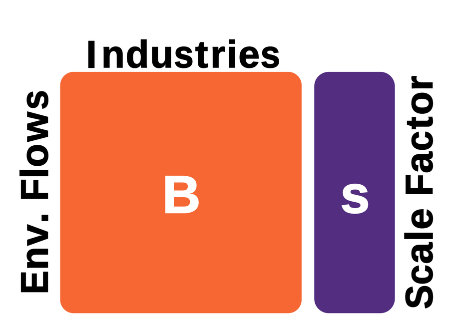
The major components of the model are two matrices (**A** and **B**) and three vectors (**f**, **s**, and **g**) [2].

The **A** matrix represents required monetary inputs of products (rows) for one dollar of output by an industry or process (columns). Typically, **A** is used with a functional unit vector, or final demand, **f** to find the scaling vector, **s**.



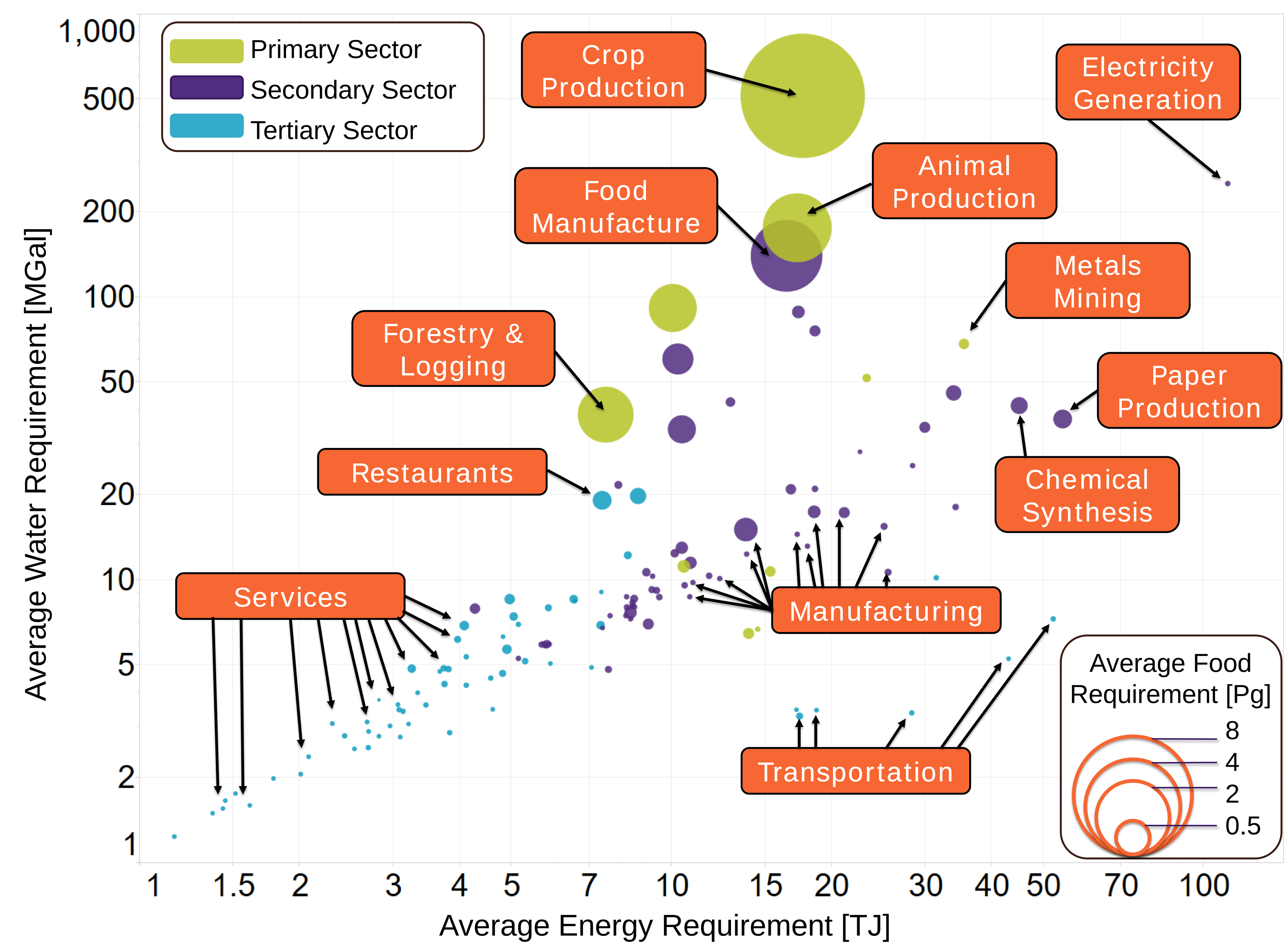
$$\mathbf{A}^{-1}\mathbf{f} = \mathbf{s}$$

The **B** matrix represents physical environmental flows (rows) for each industry (columns). **B** is multiplied by the scaling vector **s** to determine the total environmental impact, **g**. These flows include energy, food, and water use, and other flows of interest.



$$\mathbf{Bs} = \mathbf{g}$$

Resource Intensities (per $1M) of Economic Sectors



This graph contains **133** industry groups. The **primary sector** group directly uses natural resources. These resources are refined in the **secondary sector**. The **tertiary sector** contains all other activity.

Data Sources

Sources include the Bureau of Economic Analysis (BEA), the EIO-LCA model, and the United Nations Food and Agriculture Organization (UNFAO) [3].

BEA IO Tables	→	A Matrix
$1M per Industry (individually run)	→	Final Demand f vectors
EIO-LCA Data	→	B Matrix
UNFAO Data: Total Production, Price, Caloric Value	→	Food [kg/$] b vector; Food [kcal/$] b vector

Data Analysis

UNFAO data was aggregated into eight BEA farming sectors. These are the only sectors that directly produce food from the environment.

Mass Intensity [Kg/USD]	Calorie Intensity [kcal/USD]	BEA Industrial Sector
2.03	585	Vegetable and melon farming
1.56	8,626	Tree nut farming
3.75	11,945	Greenhouse, nursery, and floriculture production
5.20	24,373	Oilseed farming
10.39	37,300	Grain farming
5.45	1,660	Fruit farming
28.08	102,800	Sugarcane, sugar beet farming
6.42	4,300	All other crop farming

With the **B** matrix extended, $1M of final demand was queried for each BEA industry.

Interpretation

The results indicate that:

- The **primary sector** has the largest water and food intensity.
- The **secondary** and **tertiary** sectors usually have minimal food intensity, and have a strong correlation between water and energy intensity.
- **Electricity Generation** has the highest energy intensity, and second highest water intensity.
- **Transportation** is energy intensive, but not food or water intensive.

Note that this data excludes resources already embedded within an industry, such as in old machinery. However, new capital purchases are included.

All model data is from 2002, the most recent EIO-LCA model available.

Conclusion

The results of this study enable a more complete understanding of food, energy, and water as key ingredients to a functioning economy. With the food data added to the EIO-LCA framework, researchers will be able to better study the Food-Energy-Water Nexus and gain insight into how these three vital resources are interconnected. Any EIO-LCA study can now track embedded food as part of its impact assessment.

Acknowledgements & References

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[1] C. T. Hendrickson, L. B. Lave and H. S. Matthews, Environmental Life Cycle Assessment of Goods and Services: An Input-Output Approach, Washington, DC: Resources for the Future, 2006.

[2] R. Heijungs and S. Suh, The Computational Structure of Life Cycle Assessment, Dordrecht: Springer Science+Business Media, 2002.

[3] UNFAO Statistics Division, "FAOSTAT Download Production Data," Food and Agriculture Organization of the United Nations, [Online]. Available: http://faostat3.fao.org/download/Q/QC/E