THE COUNTY DIAGNOSTIC:
A REGIONAL ENVIRONMENTAL FOOTPRINT FRAMEWORK FOR THE USA

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Pre-Knowledge and Problems

Population Growth
- 6.6 to 8.8 Billion by 2030 (UNPD, 2011)

Rural to Urban Population Shift
- 50% global, 80% USA (UNPD, 2011; US Census 2010)
- USA has very high material, water, carbon fooprint compared to other nations (Wiedmann et al., 2015)

Peak Oil & Climate Change
- 2016-2026, Supply Unpredictable (Hirsch, 2006; Almeda and Silva 2008)
- Under current resources use, mean global temperatures will increase. This will result in redistribution of climate zones globally to correct for the additional warm energy in the global climate system. Climate changes are spatially heterogeneous, with a greater rate of change at northern latitudes than equitorial. (IPCC, 2014)

Well Studied, but Well Applied?
- Urban / Industrial Metabolism (Wolman, 1965, Ayres & Ayres, 2002)
- Systems Ecology (E.Odum, 1969; Vester, 1976; HT.Odum, 1983)
- Environmental Footprint (Rees & Wackernagel, 1996; Galli, 2015; Hoekstra 2012)

Regional Planning in the USA
- USA has robust federal regulations and local planning instruments, but lacks a contiguous regional spatially-based planning instrument focused on integration of human and natural systems
- Patchwork of Incorporated Places and Counties at regional level make inclusion of all actors and access to data challenging
- USA covers a diverse array of climate types and ecoregions, requiring a flexible regional planning approach.

Driving Research Question: How can the USA supply the basic resource and energy requirements for a growing urban population in the context of climate change, the energy transition, and competing global demand for basic resources?

Areas Expected to Experience Climate Change based on the SRES A1-F1 Scenario

A1-F1: Rapid fossil fuel-based economic and population growth peaks by 2050, followed by implementation of more efficient technologies and increased regional integration (Arnell, 2004). The scenario indicates that by 2100 the köppen Cfa climate region will expand northward into the colder Dfa and Dfb climate regions. The dryer Bsk and Bsh regions expand northward across the middle of the country and dry hot summers become the norm further northward from the Gulf region into the upper Midwest. On the West Coast, the wetter CSb and CSc climate types are replaced by the dry summer CSa climate type in much of the Sierra Nevada and Cascades and expand southward into the dryer B zone. Generally, the D climates in the Rockies are replaced by Cfa climates, likely resulting in reduced winter snowfall except at the higher elevations.

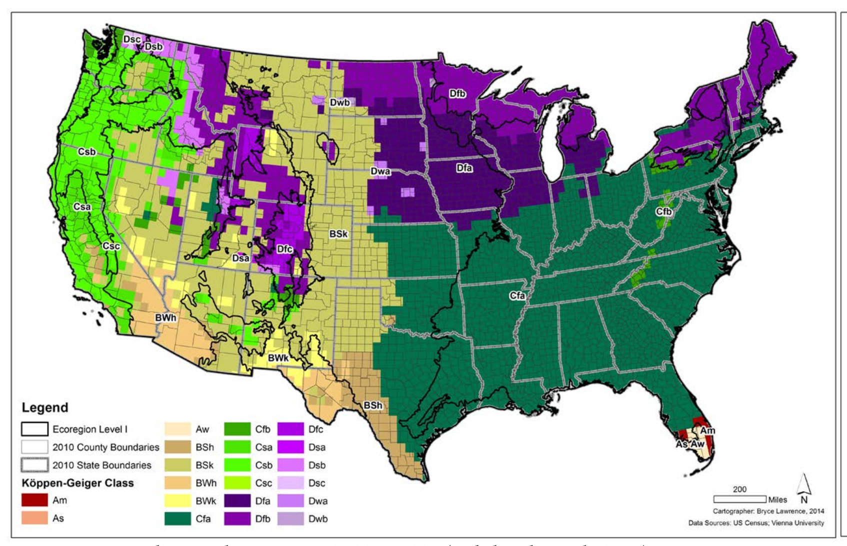

Figure 1: A1-F1 Climate Change Scenario 2001-2025 (Rubel and Kottek, 2010)

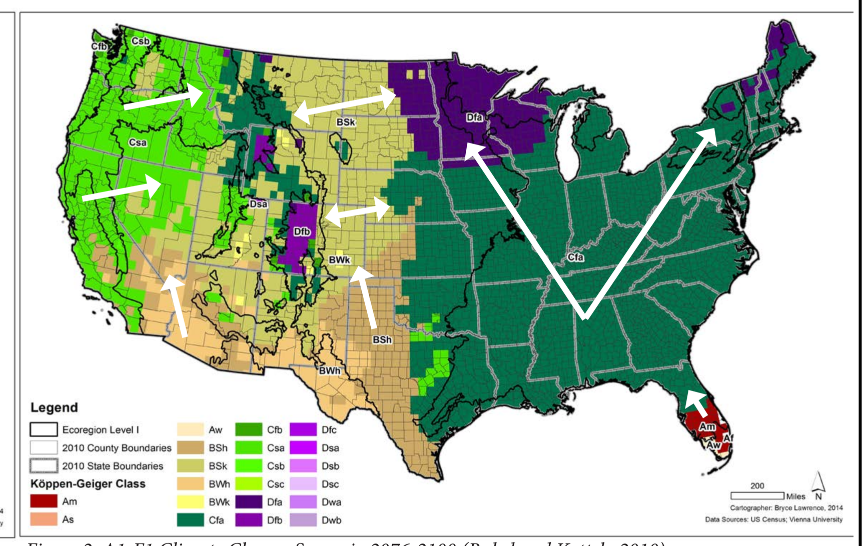

Figure 2: A1-F1 Climate Change Scenario 2076-2100 (Rubel and Kottek, 2010)

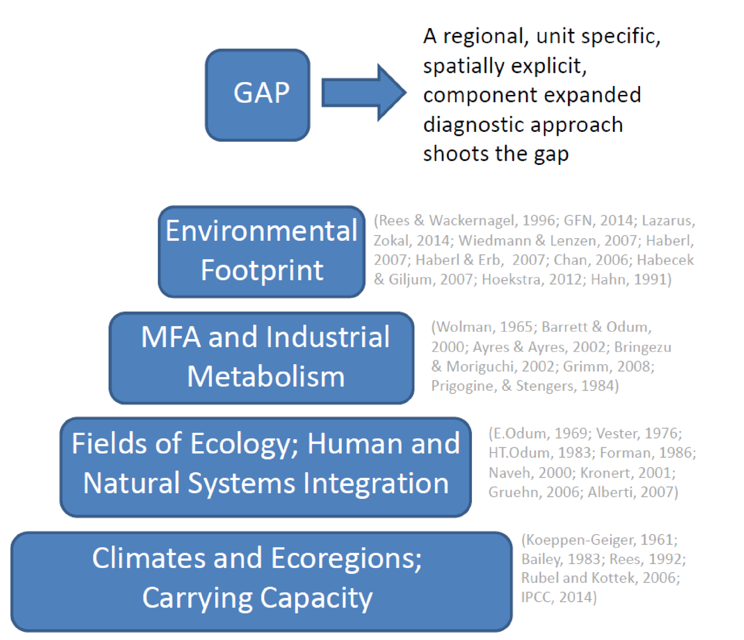

Figure 3: Research Pyramid, Author's own depiction

Primary Hypothesis and Null Hypothesis

H1 = It is possible for the USA to reduce material consumption and increase sub-regional level material balance if a method is developed to clearly diagnose the resource demands and availability at a sufficiently detailed scale so that inefficiencies and opportunities can be identified and improved at a manageable scale.

H1ø = The development of a consistent and spatially contiguous tool for the USA is not feasible or useful.

Two-Part Project Design

1. The development of a county wide spatial and material accounting system built on existing theories and frameworks and which addresses many of the previously perceived shortcomings of existing Footprint and material flow methods, tailored for application at the regional level in the USA.
2. The application of this method in a quantitative case study comparison across ecoregion units in the USA to test the variation in parameters and analysis outcomes when isolating ecoregions apart from population and scale. Answers questions regarding open and closed thermodynamic systems in regional material flow balance.

County Diagnostic Conceptual Framework

The Dissapative Ecological Unit (DEU): Described in detail by Odum (1969); Boiled down to the essence by Ripl and Hildmann (2000). In the DEU, the sun drives production, consumption, detritus creation and decomposition within the landscape. Materials are moved around by surface water, soil water, short cycles, and the global energy balance converts H2O from liquid (blue) to vapor (green). Energy is stored as NPP, and entropy is low.

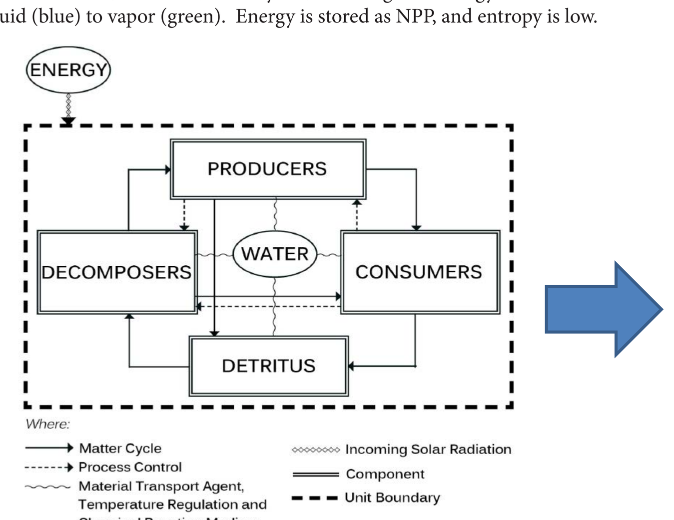

Figure 4: DEU concept framework, adapted from Ripl and Hildmann (2000)

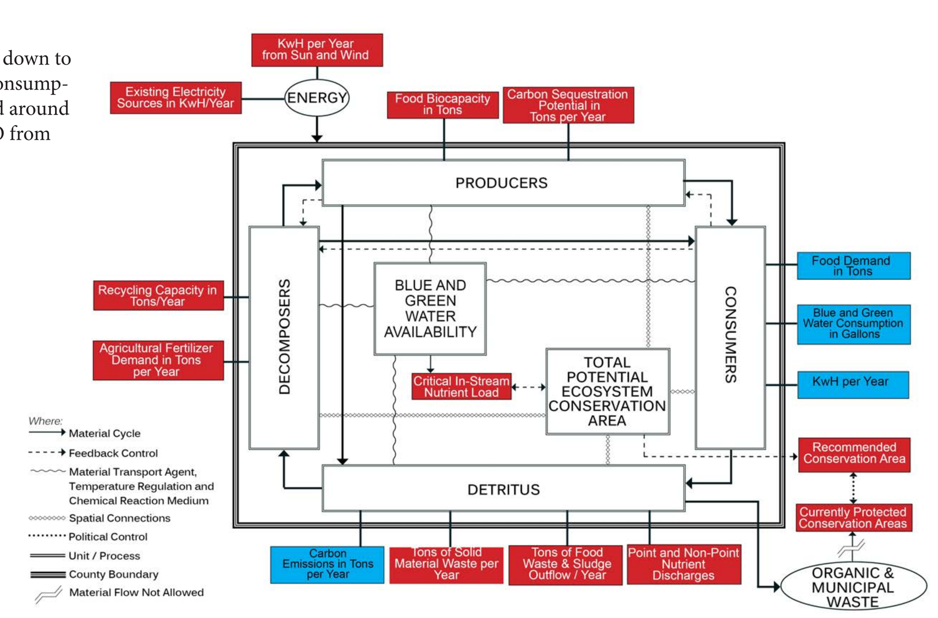

Figure 5: Integration of human and natural systems within the DEU Framework (Adapted from Ripl and Hildmann (2000) in Lawrence (2020)

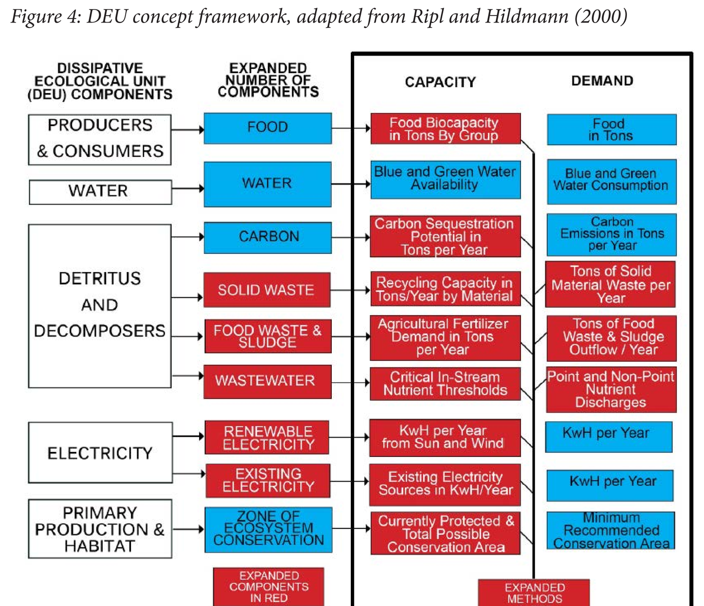

Figure 6: The County Diagnostic expands on current categories of the footprint family (Galli et al., 2012) with an expanded number of EF components in a human and natural systems integrated DEU model

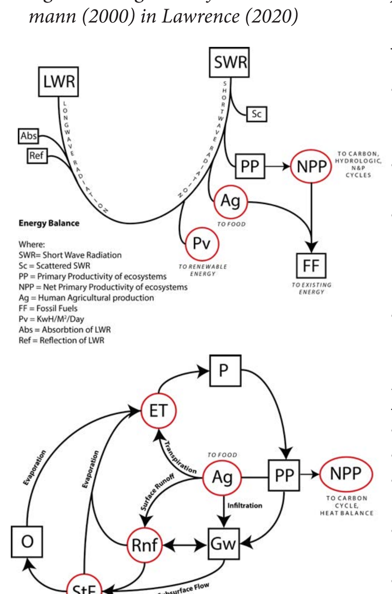

Figure 7: The hydrological cycle and energy balance are coupled systems that interface in the ecosystem service NPP and human agricultural production demand (Lawrence, 2020)

Why a County-wide Approach?

- The County as analysis unit allows for both sampling of individual units and regional aggregation for basin-wide assessment of coupled metabolic potentials.
- A wide range of spatial data is available for the USA at the county level.
- County administrations generally make periodic county-wide comprehensive plans where the county diagnostic may help illustrate the impacts of climate change scenarios on county metabolism.
- Fills a gap in regional spatial planning in the USA with a contiguous unit for regional spatial planning; follows the total area coverage principle from German spatial planning.

Expanded components include:

- A zone of conservation for landscape functions
- Inclusion of water demand and availability
- Inclusion of organic and municipal solid waste (MSW) and rate of organic material uptake and MSW recycling capacity
- Inclusion of current and potential renewable electricity generation and estimate of county-wide electricity demand.
- Accounting for the environmental water requirement (EWR)
- Integration of carbon emissions and natural carbon sequestration estimates
- Integration of food demand and capacity estimates based on USDA dietary guidelines
- Coupled assessment of human and natural systems as integrated water, energy and material cycles (see Fig. 7)

CALCULATION OVERVIEW WITH SELECTED EXAMPLES

Capacity Equations and Figures — *Demand Equations and Figures*

FOOD

F3c

$$NASS_{CEREALS} = \left\{ \sum_{p=1}^{n} (NASS_{CEREALCROPS}[p,x,t]) + \sum_{p=1}^{n} (NASS_{LEGUMES}[p,x,t]) \right\}$$

Where:
$NASS_{CEREALSCROPS}$ [p,x,t] = The sum of all cereal crop products [p] in tons by county [x] per year [t](United States Department of Agriculture 2012), definded in table 4-2
$NASS_{LEGUMES}$ [p,x,t] = The sum of all legume crop products [p] in tons by county [x] per year [t](United States Department of Agriculture 2012)
Equation 8: Cereal Crop Summation in Tons

Cereal Crops For Human Consumption	
Corn	Rye
Rice	Oats
Sweet Corn	Speltz
Pop or Orn Corn	Buckwheat
Barley	Hops
Durum Wheat	Triticale
Spring Wheat	Vetch
Winter Wheat	Other Small Grains

Table 4-2, list of cereal crops for human consumption. From (Lawrence, 2017)

Capacity Factor Description	NDI Calculation	Demand Factor Description
HAY	NDI-F1	HAY
FEED GRAINS	NDI-F2	FEED GRAINS
CEREAL GRAINS	NDI-F3	CEREAL GRAINS
DAIRY	NDI-F4	DAIRY
PROTEIN	NDI-F5	PROTEIN
FRUITS	NDI-F6	FRUITS
VEGETABLES	NDI-F7	VEGETABLES

$$NDI = \frac{(capacity - demand)}{(capacity + demand)}$$

Capacity Factor Calculation	Label	Value	Value	Label	Demand Factor Calculation
Tons of Hay	F1c	Integer	Integer	F1d	Tons of Hay
Tons of Feed Grains	F2c	Integer	Integer	F2d	Tons of Feed Grains
Tons of Cereal Grains	F3c	Integer	Integer	F3d	Tons of Cereal Grains
Tons of Dairy	F4c	Integer	Integer	F4d	Tons of Dairy
Tons of Protein	F5c	Integer	Integer	F5d	Tons of Protein
Tons of Fruit	F6c	Integer	Integer	F6d	Tons of Fruit
Tons of Vegetables	F7c	Integer	Integer	F7d	Tons of Vegetables

Figure 8: Food Factors Overview
11 Capacity Equations & 7 Demand Equations
33 Data Sources (Secondary Data; Peer-Reviewed)

F3d

$$CEREALS_{DEM} = ((6 \text{ ounces per day} * 365 \text{ days}) / 32000 \text{ ounces per ton})$$

Equation 20: 2000 Calorie Food Demand by Food Group per Year

$$CEREALS_{HUMAN} = \sum_{p=2}^{n} CEREALS_{DEM}[P,x,t]$$

Where:
P = population, from (US Census, 2012)
x = County area
t = Time, by year
Equation 21: Food Demand Summary by Food Group for Human Supply

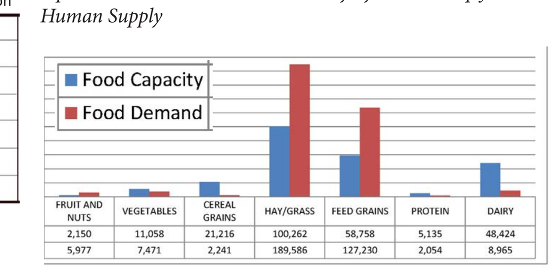

Figure 9: Schoharie Countz, New York Food Balance (Lawrence, 2017)

WATER

W2c

Available Annual M^3 Green Water (W2c)

$$= \sum_{t_m=12}^{n} \left\{ \left(\frac{ET_{green}[x,t_m]}{1000} \right) \langle ERASE \rangle ZOC[x] \right\} * (858782)$$

Where:
W2c = Total Adjusted Green Water Availability in cubic meters (M3)
ET_{green}[x,tm] = Monthly [tm] estimated evapotranspiration (ET_{green}) for a ~1km ($858,872 m^2$) raster cell within county [x] in mm(The University of Montana 2010), converted to meters[tm] via division by 1000
ZOC [x] = The total spatial extent [x] of the final Zone of Conservation (ZOC) (Equation 48)
<ERASE> = The defined spatial extent to the right of the <ERASE> symbol is erased from the spatial extent on the left of the symbol, performed in ArcGIS.
858782 = The area of each raster cell for which an ET point value is representative
Equation 32: Total Available Atmospheric Moiosture (Green Water Availability); adapted from (Hoekstra et al. 2011, p. 79)

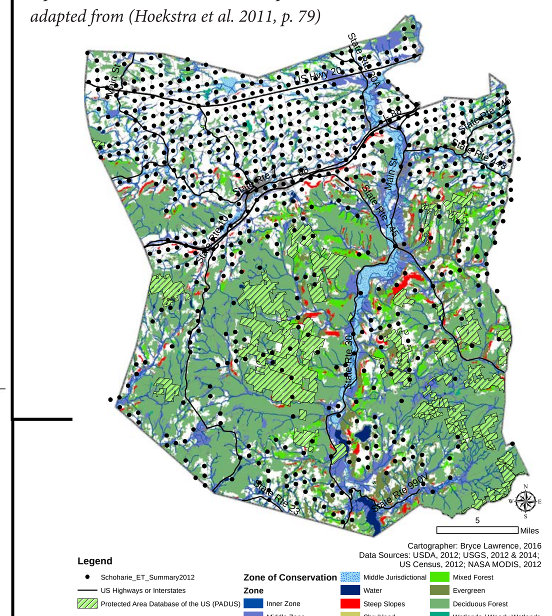

Figure 10: Carroll County EWR adjusted ET and ZOC (Lawrence, 2017)

Capacity Factor Description	NDI Calculation	Demand Factor Description
AVAILABLE STREAM FLOW	NDI-W1	SURFACE & GROUND ABSTRACTIONS
EVAPOTRANSPIRATION (GREEN WATER)	NDI-W2	ATMOSPHERIC MOISTURE CONSUMPTION (GREEN)
TOTAL RUNOFF (BLUE WATER)	NDI-W3	SURFACE WATER CONSUMPTION (BLUE)
CRITICAL NITROGEN LOAD	NDI-W4	NITROGEN (N) LOAD
CRITICAL PHOSPHORUS LOAD	NDI-W5	PHOSPHORUS (P) LOAD

$$NDI = \frac{(capacity - demand)}{(capacity + demand)}$$

Capacity Factor Calculation	Label	Value	Value	Label	Demand Factor Calculation
Total Available M^3 of Stream Flow	W1c	Interger	Interger	W1d	Total M^3 of Adjusted Abstraction
Total M^3 of Available Atmospheric Moisture (Green)	W2c	Interger	Interger	W2d	Total M^3 of Consumed Atmospheric Moisture (Green)
Total Available M^3 of Surface Runoff (Blue)	W3c	Interger	Interger	W3d	Total M^3 of Consumed Surface Water (Blue)
Critical Annual Nitrogen Load in Tons (Grey)	W4c	Interger	Interger	W4d	Total Annual Nitrogen Load in Tons (Grey)
Critical Annual Phosphorus Load in Tons (Grey)	W5c	Interger	Interger	W5d	Total Annual Phosphorus Load in Tons (Grey)

Figure 11: Water Calculations Overview
5 Capacity Equations & 6 Demand Equations
16 Data Sources (Secondary; Remotely Sensed Data; Peer Reviewed Data)

W2d

Annual Green Water Demand in M^3 (W2d)

$$= \sum_{t_m=12}^{n} \left\{ \sum_{p=1}^{n} (CROP_{type}[p,x,t_{m(t,f)}] * GWF_{cons}[p]) + \sum_{p=1}^{n} (FEED_{type}[p,x,t_{m(t,f)}] * GWF_{cons}[p]) \right\}$$

Where:
$CROP_{type}$ [p,x,$t_{m(t,f)}$] = Tons of crop type [p] per county [x] (USDA 1994) per month $t_{m(t,f)}$ with active [tm(t)] or inactive [tm(f)] growing season of crop type [p] (USDA 1997)
FEEDtype [p,x, t_m] = Tons of feed type [p] demanded per county [x], derived from 4.1.3.2 (F2d) per month [t_m] (USDA 1997)
GWFcons [p] = The green water consumption of crop type [p] in M3 (Mekonnen, Hoekstra 2010a, 2010c)
Equation 37: Green Water Consumption of Crop and Livestock Products in Mgal / Year

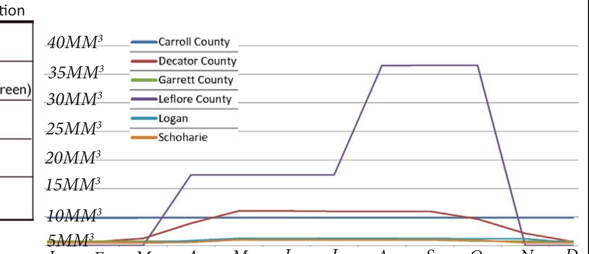

Figure 12: Total surface (Blue) water demand (W3d) by county (Lawrence, 2017)

ZONE OF CONSERVATION (ZOC)

EC2c

$$ZOC = \partial \left\{ \sum_{p}^{n} VEGTYPE_p < INTERSECT > \partial ZO_{100} \right\} + \partial ZO$$

$\sum_p^n$ $VEGTYPE_p$ =All dissolved vegetation types intersecting vegetation layers listed in section 4.3.1.2, the "outer zone"
∂ZO =The total overlay summation of zones 1 through 4 with a 100-meter buffer
∂= The total spatial extent of a layer, union or overlay
<INTERSECT>= The symbol for spatial intersect, where layer A spatially intersects layer B
Equation 47: Summarization of the 5th (Outer) Zone of the ZOC

Capacity Factor Description	NDI Calculation	Demand Factor Description
EXISTING CONSERVATION	NDI-EC1	17% LAND/WATER AREA
ZONE OF CONSERVATION	NDI-EC2	17% LAND/WATER AREA

$$NDI = \frac{(capacity - demand)}{(capacity + demand)}$$

Capacity Factor Calculation	Label	Value	Value	Label	Demand Factor Calculation
Total Existing Area of Conservation in Acres	EC1c	Integer	Integer	EC1d	Minimum Area for Biodiversity Conservation in Acres
Total Existing Area of Conservation in Acres	EC2c	Integer	Integer	EC2d	Minimum Area for Biodiversity Conservation in Acres

Figure 13: ZOC Overview
2 Capacity Equations & 1 Demand Value
14 Data Sources (Secondary Data; Remotely Sensed Data; Peer Reviewed Data; GIS Models)

EC1&2d

Area-Based Conservation Targets
- Current terrestrial biodiversity targets for developed nations is estimated at of 17% land area and 10% of marine areas based on recommendations from the International Convention on Biodiversity (United Nations 2010), although Hoekstra settles on a recommendation of 30% area preserved for biodiversity and ecosystem function (Hoekstra et al. 2011, p.81).
- **For this terrestrial study 17% land and water area is used.**
- US Protected Area Database (PAD-US) provides nation-wide conservation area data (USGS 2012)

CARBON

C1c

$$CARBON_{SEQ} = \left\{ \sum \frac{MODIS17_{NPP}[px,x,t] * 691129.8}{1000000} \right\}$$

Where:
$MODIS17_{NPP}$ [px,x,t]= The summary of all pixel values [px] per county [x] per year [t], representing total NPP in gC/m²/year (Zhao et al. 2005)
691129.8 = The area in meters of each raster pixel
1000000 = The conversion from grams to metric tons
Equation 59: Carbon Sequestration Calculation

Capacity Factor Description	NDI Calculation	Demand Factor Description
CARBON SEQUESTRATION	NDI-C1	CARBON EMISSIONS

$$NDI = \frac{(capacity - demand)}{(capacity + demand)}$$

Capacity Factor Calculation	Label	Value	Value	Label	Demand Factor Calculation
Total Carbon Sequestration Potential in Tons	C1c	Integer	Integer	C1d	Total Carbon Dioxide Emissions in Tons

Figure 14: Carbon Overview
1 Capacity Equation & 1 Demand Equation
2 Data Sources (Remotely Sensed Data; Peer Reviewed Data; GIS Model)

C1d

$$CARBON_{EMISS} = \sum \left[\sum_{s=5}^{n} (CARBON_{TONS}[s,x,t]) * (POP_{[\Delta_{12}/\Delta_{02}]}) \right]$$

Where:
$CARBON_{TONS}$ [s,x,t]= Tons of Carbon emissions per sector [s] per county [x] per year [t] (Gurney et al. 2009)
$POP_{[t12/t02]}$ = The difference in per capita population between 2012 [t12] and 2002 [t02] as a percentage of growth or reduction.
Equation 60: Calculation of Adjusted Carbon Emissions per County

ELECTRICITY

E1c (solar)

Annual Solar Energy Production in MWh

$$= \sum_{t_m=12}^{n} \left\{ \frac{((R[b] * 0.667) * 1.5) + ((NR[b] * 0.667) * 6) * (P_{\alpha R})}{1000} \right\} * D_{m[x]}$$

Where:
R[b]= Residential Buildings (United States Census Bureau 2012)
NR[b]= Non-Residential Establishments (US Census Bureau 2012)
$P_{\alpha R}$= Photovoltaic Resource in kWh/m2/day) (Roberts 2012)
$D_{m[x]}$= Days per Month [x]
Equation 62: Annual Solar Electricity Production Potential in MWh

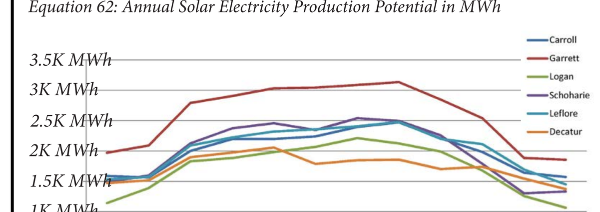

Figure 15: Solar Production Potential for All Cases (Lawrence, 2017)

Capacity Factor Description	NDI Calculation	Demand Factor Description
RENEWABLE POTENTIAL	NDI-E1	ELECTRICITY DEMAND
EXISTING PRODUCTION	NDI-E2	ELECTRICITY DEMAND

$$NDI = \frac{(capacity - demand)}{(capacity + demand)}$$

Capacity Factor Calculation	Label	Value	Value	Label	Demand Factor Calculation
Total Renewable Potential Electricity in Megawatt Hours	E1c	Integer	Integer	E1d	Total Electricity Demand in Megawatt Hours
Total Existing Electricity Production in Megawatt Hours	E2c	Integer	Integer	E2d	Total Electricity Demand in Megawatt Hours

Figure 16: Electricity Overview
9 Capacity Equations & 1 Demand Equation
13 Data Sources (Peer Reviewed Data; GIS Model; Spreadsheet Models)

E1&2d *Electricity Demand in MWh*

$$= \left[\sum \left(\left(R_{TBTU}[x_{state},t] * \frac{R[b]_{county}}{R[b]_{state}} \right) + \left(C_{TBTU}[x_{state},t] * \frac{C[b]_{county}}{C[b]_{state}} \right) + \left(I_{TBTU}[x_{state},t] * \frac{I[b]_{county}}{I[b]_{state}} \right) + \left(T_{TBTU}[x_{state},t] * \frac{POP_{county}}{POP_{state}} \right) + \left(\frac{\sum_{p=1}^{n} MMbtu[pm,t,x]}{1000000} \right) \right) / 0.000000000001 \right) / 3412 \right] / 1000$$

Where:
R,C,I,& T_{TBTU} = Annual State-Wide Estimates of Energy use in Trillion British Thermal Units (TBtu) by End-Use sector (US Energy Information Administration 2012, Table C1).
3412 = A Constant, where 1 kWh of Electricity Equals Approximately 3,412 BTU (United States Energy Information Administration (US EIA) 2014)
x_{state}= County-Wide Boundary
t = Per Year
$R[b]_{county}$ = The Number of Residential Buildings in a County (USCB 2012)
$R[b]_{state}$ = The Number of Residential Buildings in a State (USCB 2012)
$C[b]_{county}$ = The Number of Non-Residential Buildings in a County (USCB 2012)
$C[b]_{state}$ = The Number of Non-Residential Buildings in a State (USCB 2012)
POP_{county} = US Census Population of the County (USCB 2010)
POP_{state} = US Census Population of the State (USCB 2010)
MMBtu[pm,t,x]= Summary of Reported in Million Btu's for all Prime Movers (United States Energy Information Administration 2012)
Equation 70: Annual Electricity Demand in MWH for Residential [R], Commercial [C], Industrial [I] and Transportation [T] Sectors

ORGANIC & MUNICIPAL SOLID WASTE (MSW)

M2c

$$RMSW_{dem} = \sum_{p}^{n} PPD_{msw}[mswtrp] * POP[x,t]$$

Where:
$RMSW_{dem}$ [mswtrp] = The PPD of MSW Multiplied by the Municipal Solid Waste Type Recycling Percentage [mswtrp] from (US EPA 2012).
POP[x,t]= The Reported Population per County for the Study Year from the 2012 US
American Community Survey Adjusted DP1 Table.
Equation 77: Total Tons of Recycling Capacity by Material Type

Capacity Factor Description	NDI Calculation	Demand Factor Description
MAXIMUM COMPOST APPLICATION RATE	NDI-M1	COMPOSTED ORGANIC WASTE OUTFLOWS
RECYCLING CAPACITY BY MATERIAL TYPE	NDI-M2	MUNICIPAL SOLID WASTE (MSW) OUTFLOWS

$$NDI = \frac{(capacity - demand)}{(capacity + demand)}$$

Capacity Factor Calculation	Label	Value	Value	Label	Demand Factor Calculation
Total Potential Compost Application Load in Tons	M1c	Integer	Integer	M1d	Total Composted Organic Waste in Tons
Recycling Capacity by Material Type	M2c	Integer	Integer	M2d	Total Tons of Material Outflow by Type (MSW)

Figure 17: Organic and MSW Overview
3 Capacity Equations & 3 Demand Equation
9 Data Sources (Rem. Sens.; Existing Model; Peer Reviewed)

M2d

$$MSW_{dem} = \sum_{p}^{n} PPD_{msw}[mswtgp] * POP[x,t]$$

Where:
PPD_{msw} [mswtgp] = The PPD of MSW as Reported from State, Regional or County MSW Planning Reports, Multiplied by the Municipal Solid Waste Type Production Percentage [mswtgp] from (US EPA 2012) or from County Reports when Available.
POP[x,t]= The Reported Population per County for the Study Year (US Census)
Equation 74: MSW Demand Calculation, to be Split by Material Type

*Full references from the methods section are not listed on this poster for brevity, they can be found in full in Lawrence (2017)

A comparative case study application of the County Diagnostic within the US Eastern Temperate Forest Ecoregion

Secondary Research Questions

Part 2: Case Study Application

2. Do Ecoregions Influence the Potential for Footprint Reduction?

H2 = The natural variation of bioproductivity and resource availability between ecoregions will have a varied effect on the county to provide the basic minimum human demands from within their jurisdictions.

H2ø = Ecoregion divisions will make no differences on the availability and type of biocapacity or the potential carrying capacity

3. Does Equilibrium or Non-Equilibrium Thermodynamics Explain Regional Footprint or Metabolism?

H3 = The thermodynamic paradigm of closed-loop cycling, or a thermodynamic equilibrium, may have a limited applicability regarding planning of regional and supra-regional material flows.

H3ø = Closed loop systems, completely balanced demand and capacity in terms of the County Diagnostic model, are the ecological norm at the county level.

Six County Case Study

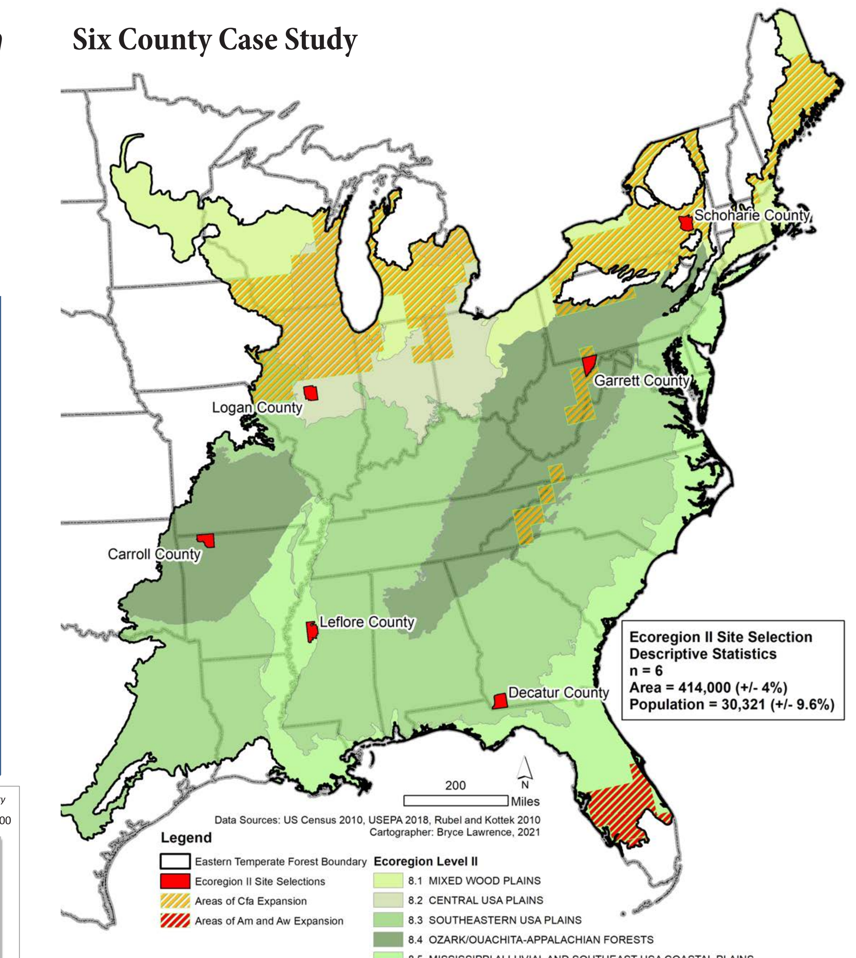

Figure 18: Six county case study in the Eastern Temperate Forest (ETF) Ecoregion Level II, and the expected climate changes (Author's own work, based on Rubel and Kottek (2010))

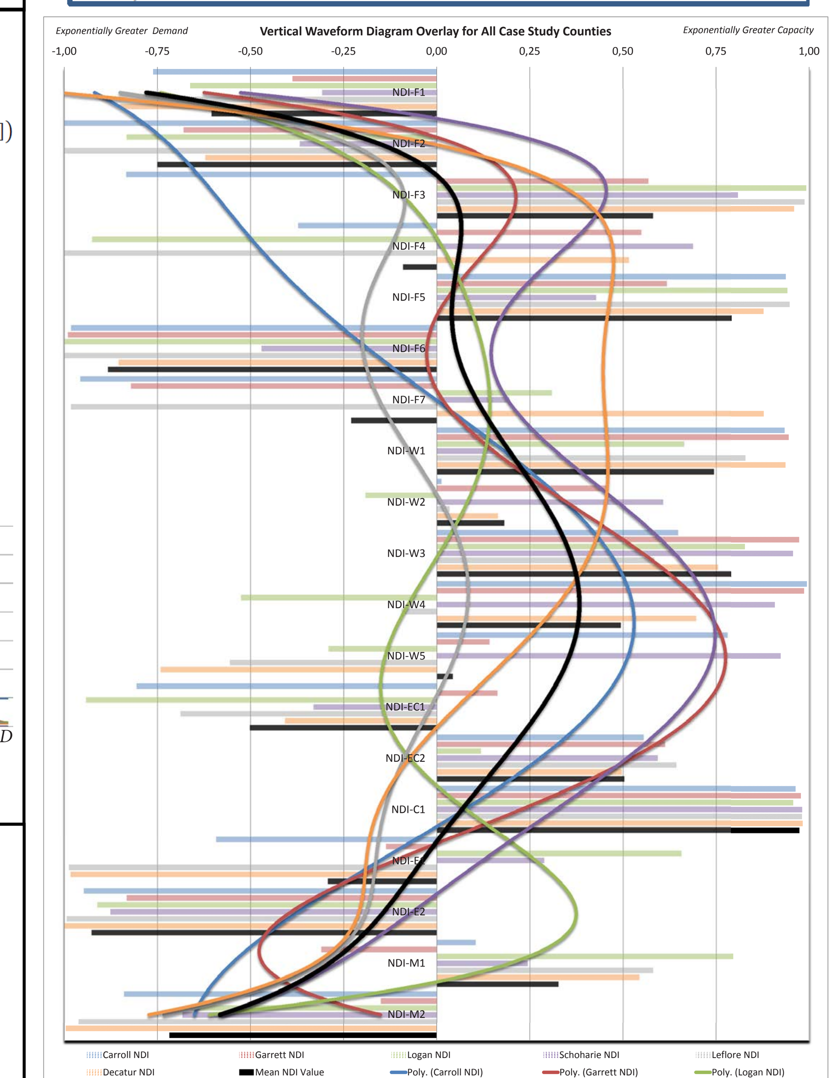

Figure 19: Vertical waveform diagrams (VWDs) for all six case study counties. Graphical VWD underpinned by normalized difference index (NDI) interger values (Lawrence, 2020)

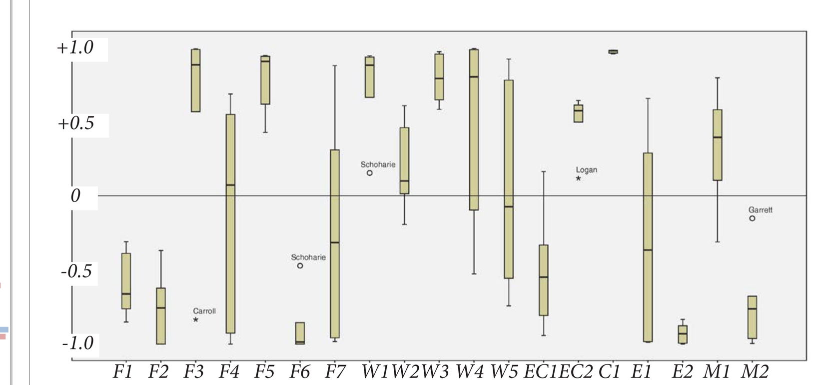

Figure 20: Boxplots of mean NDI values across all factors (Lawrence, 2020)

Dimension	Cronbach's Alpha	Variance Accounted For: Total (Eigenvalue)	Variance Accounted For: % of Variance
1	.905	6.997	36.827
2	.833	4.742	24.958
3	.811	4.311	22.688
4	.696	2.931	15.428
Total	1.000[a]	18.981	99.902

a. Total Cronbach's Alpha is based on the total Eigenvalue.

Figure 21: Summary of NDI values with the Categorical Principal Component Analysis, expressed as Cronbach's Alpha, total eigenvalue, and total variance accounted for (Lawrence, 2020)

Conclusions Regarding Climate Change in the Case Counties

- Expansion of the warm Cfa climate zone northward replacing snow climte zone Dfa will affect Schoharie County, NY. Resulting change translates to mean temperature of the coldest month increasing from under 26.6 degrees (F) to between 26.6 and 64.4 degrees (F). Sufficient precipitation in all months is still predicted (f), but the temperature of the warmest month will increase from a mean of under 71.6 degrees F to a mean over 71.6 degrees F. Increases in warm months could increase evaporative losses from plants and surfaces, potentially resulting in water scarcity or increased need for agricultural irrigation. The balance of available streamflow (159,744,805m3) to abstraction (117,132,427m3) in Schoharie indicates there is available blue water for irrigation, but the quantity of surplus is much lower than in other counties further south, such as Logan or Garrett, where streamflow is exponentially greater than demand.
- Increase in temperatures in Schoharie could also increase sun hours and crop yields, potentially a net positive effect for food production where hay, grain and fruit yields, which have negative NDI values on the vertical waveform diagram (Figure 19), could be increased.
- Loss of Cfb climate zone in the Appalachian Mountains will affect Garrett County, where Cfa will replace Cfb. Temperatures in the warmest month will increase from under 71.6 to over 71.6 degrees F. This will likely increase evaporative losses and potentially alter snowfall or snowmelt patterns.
- The encroachment of the tropical Aw or Am climate into Cfa areas in Florida will increase mean monthly temperatures to 64.4 degrees F or above and the loss of the coldest month between 26.6 and 64.6 degrees F in the central region of the penninsula. The rainfall regime will change from sufficient in all months (f) to either desert (w) or monsoon with significant dry season (m). Certainly, this change will cause increased evaporative losses in the dry season. Coupled with salt water encroachment in coastal aquifers related to sea level rise (Karl et al., 2009) occuring in Florida (Abd-Elaty et al., 2019), water abstraction could outstrip water availability for at least some months of the year in major population centers, such as Tampa.

Four Dimensions Affecting Net Positive or Negative NDI Outcome According to CatPCA Analysis

Dimension 1: Human and Livestock Population
Dimension 2: Areas with High Precipitation or Surface Water
Dimension 3: Affluence and Application of Technology
Dimension 4: Area Devoted to or Available for Ecosystems

Can the Environmental Footprint be Improved Upon or Adapted for the USA?

- ANOVA results found statistically significant variation in NDI values by County, thus, sub-regional analysis may increase sensitivity of EF.
- Correlation indicated that food, water, ZOC and energy are the primary components of the analysis.
- Interplay between factors indicate a paradigm of 'trade-offs'.

Do Ecoregions Influence the Potential for Footprint Reduction?

- K-S test indicated a difference in distribution of NDI values amongst only six counties, could be effect of ecoregion….or something else. More cases are needed to confirm results about Ecoregion influence.
- Statistically significant variation in NDI values via ANOVA could indicate an influence of Ecoregions.

Should Regional Footprint or Metabolism Aim for Equilibrium or Non-Equilibrium Thermodynamics ?

- Non-equilibrium thermodynamic paradigm appears to be predominant, required for urbanism. Materials, water and energy flow between county boundaries in coupled open metabolism that can also be described as a non-equilibrium thermodynamic state, or open system.
- Closed loop could be possible with governance strategies and technology applications, but is it desirable? Regional strategies to cooperate on technological solutions for organic and MSW cycling, energy generation, and food production are reasonable considerations to support the integrated flows between counties, share infrastructure costs, and ensure supply of critical materials, water and energy in urban sinks.

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