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INDUSTRIAL ECOLOGY AS A REGIONAL PLANNING TOOL

A New Potential for Economic / Environmental Regional Planning

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ABSTRACT

Industrial Ecology has thus far been presented and practiced as an approach towards material and energy balancing between industries located within singular industrial parks. Other than the circumstantial planning by industries that choose to utilize cooperative metabolic linkages, most efforts have not become fundamental tools for national or regional planning other than some theoretical proposals (see, for example, Koenig, Herman & John E. Cantlon, "Quantitative Industrial Ecology & Ecological Economics, Journal of Industrial Ecology, Vol. 3, No. 2 & 3). With the advent of Input/Output Life Cycle Assessment procedures and the combining of this methodology with Geographic Information Systems (GIS) there is now the potential to plan for the selection of industries at regional levels based on their industrial ecology attributes. There is, however, a need to provide interoperability linkages between key industrial data sets.

This paper presents a case where it is possible to apply the above procedure in the construction sector because of a breakthrough in the following data sets and specification procedures: a) construction and product specification categories; b) benchmarked techniques of economic input/output using regional and national data sets; and c) peer reviewed environmental impacts for greenhouse gases, criteria air pollutants and toxic releases utilizing the same industrial sectors as the input/output economic model.

The procedure was carried using two modeling tools, BaselineGreen™ and GreenBalance™, developed by the Center for Maximum Potential Building Systems and partners. The tools are designed to balance material flows within the building (or product) based on the quantity and type of feedstocks used and their associated upstream (source, manufacture, transport) impacts. CO2 and SO2 represent some of the easiest balancing examples, but others such as methane, water, O2 and certain toxins can also be balanced. Simply stated the built object itself, comprised of a specified bill of materials, can "balance" or "sequester" the upstream impacts.

1 INTRODUCTION

Optimizing the choice of regional products based on environmental and economic considerations guides planning decisions around a region's economic, environmental and resource attributes with the objective of improving the interrelationships between certain industries at a regional scale. There is a need for procedures that can be applied to optimize manufacturing choices resulting in reduced environmental impacts and increased employment, important issues anywhere, but key to Latin America sustainable development strategies.

As a planning policy for cities or regions, such procedures can be designed to address the flow of materials within that region and, in turn, evaluate environmental and economic impacts relative to the upstream and downstream flows of the life cycle. A regionalized industrial ecology can therefore be established that links the upstream and downstream life cycle phases.

Through a Cooperative Agreement with the U.S. Environmental Protection Agency, CMPBS successfully beta-tested an environmental and economic baselining method of a building's or product's specifications at each level of the CSI/Uniformat procedure. This method has evolved into two distinct but complementary procedures: 1) BaselineGreen™: a baselining procedure that represents hundreds of upstream inputs; and 2) GreenBalance™: a balancing procedure that uses a knowledge base of product and processing types to balance the impacts established in the baselining procedure.

The method encompasses the following:

a) provides a hierarchical breakdown of where the most important areas of environmental and employment impact exist and continues this hierarchy decision making procedure within all major and minor specification levels;

b) shows environmental and employment impacts and in dollars per dollar of purchased commodity;

c) establishes a range of choices of commodity or process types that offer improvements over the highest impact candidates in both environmental and economic terms.

The method first examines the upstream external environmental cost and regional employment impacts of the inputs to construction of a generic baseline building modeled after a proposed building design. The upstream external environmental costs are summarized in an "external environmental cost ratio" (EECR). The upstream employment impacts are summarized in an "employment impact ratio" (EIR). Both an EECR and an EIR are assigned to all high priority inputs to construction within major architectural Uniformat Building Group Element categories of the baseline building.

Second, it establishes a new "greener" baseline with reduced upstream environmental costs. This green baseline becomes the new benchmark for measuring the proposed building design and provides a framework to go beyond the present approach of simply minimizing environmental burdens. The approach attempts to neutralize or "balance" these conditions with the objective of mitigating and, in some cases, actually counteracting external environmental costs. Preliminary findings show that for those impacts that represent processes that can be chemically and materially balanced, a per unit carbon or SO_2 or even H20 intensity factor per weight can be established comparing upstream activity to the downstream sequestering or remediation actions be taken.

2 PROCEDURE STEPS

2.1 Environmental Prioritization of Uniformat Building Group Elements

The first step consists in identifying the high priority building group elements associated with upstream environmental burdens (in this report, negative environmental impacts are called environmental burdens since they impose health risks and economic costs to society). The method of analysis is environmental life cycle assessment (LCA) using U.S. Bureau of Economic Analysis (BEA) national data. The upstream (or "embodied") environmental consequences of the hundreds of inputs required to provide the bill of materials and products for the baseline building design are assessed using an economic input-output model of the entire construction sector of the U.S. economy. The input-output model is fully comprehensive and includes inputs of raw materials, energy, equipment, fabricated products, intermediate products, and services that can be correlated to various geographic locations and scales.

Three summary environmental burden indicators associated with each upstream input to construction of the baseline building - total air pollution, global warming (greenhouse gases), and toxic releases – are identified and quantified. After all upstream inputs to construction are categorized according to Uniformat Level 2 Building Group Elements, the Building Group Elements are subsequently ranked according to each of the three environmental burdens and then an overall "final ranking" is given that combines rankings for all three burdens. The rankings for one example municipal building project in Seattle, Washington are presented in Table 1 below.

The "final ranking" column indicates that the Interior Finishes Uniformat Level 2 Building Group Element is the most significant in terms of all three types of environmental burdens combined. Superstructure is the second most significant, Exterior Closure is third, and so on. (Note that this simplified ranking method does not prioritize the three summary environmental burden indicators. Some toxic releases for example, although regulated, may be a greater environmental burden per unit than the other two indicators.)

TABLE 1: RANKING OF UNIFORMAT LEVEL 2 BUILDING GROUP ELEMENTS
BY UPSTREAM ENVIRONMENTAL BURDENS

UNIFORMAT LEVEL 2 BUILDING GROUP ELEMENTS	ENVIRONMENTAL BURDEN RANKING			COMBINED RANKING	FINAL RANKING
	AIR POLLUTION	GLOBAL WARMING	TOXIC RELEASES		
C30 INTERIOR FINISHES	2	2	1	5	1
B10 SUPERSTRUCTURE	1	1	4	6	2
B20 EXTERIOR CLOSURE	4*	3*	3	10	3
D50 ELECTRICAL	4*	5	2	11	4
A10 FOUNDATIONS	3	3*	8	14	5
D30 HVAC	7	6	5	18	6
C10 INTERIOR CONSTRUCTION	6	7	6	19	7
D20 PLUMBING	8	8	7	23	8

NOTES:
1.) * Denotes equal contribution to environmental burden indicator.
2.) The Miscellaneous and Service Sector categories have been omitted.

2.2 Environmental Prioritization of Inputs to Construction

In the second part of the upstream environmental burdens analysis, the high priority individual inputs to construction within each Uniformat Level 2 Building Group Element were identified that contributed most to the upstream environmental burdens within each Uniformat category. The purpose of this more detailed analysis is to provide environmental burden indicator data for a more specific building material and/or product type.

For example, according to Table 1 above, Superstructure was ranked the number one Building Group Element in terms of total upstream air pollution. Within this Uniformat Building Group Element, the inputs to construction are ranked from largest to smallest contribution for the air pollution environmental burden indicator as indicated in Table 2 below. (Note that the first four inputs to construction account for more than 80% of cumulative contribution and the top seven account for more than 90% of cumulative contribution.)

TABLE 2: RANKING OF INPUTS TO CONSTRUCTION BY UPSTREAM AIR POLLUTANTS WITHIN SUPERSTRUCTURE UNIFORMAT LEVEL 2 BUILDING GROUP ELEMENT

B10 SUPERSTRUCURE Inputs to Construction	% CONTRIBUTION	CUMULATIVE %
1. Ready mixed concrete	39.8%	39.8%
2. Fabricated structural iron, steel, and aluminum for buildings	19.0%	58.8%
3. Cement, hydraulic	17.4%	76.2%
4. Fabricated structural metal, not elsewhere classified	4.4%	80.6%
5. Hardwood & softwood lumber, rough & dressed, except siding	4.3%	84.9%
6. Fabricated bar joists and conc. reinforcing bars	3.7%	88.6%
7. Structural wood products	2.8%	91.4%
8. Structural shapes, sheet piling, & conc. Reinforcing bars	2.4%	93.8%
9. Other fabricated structural metal, not elsewhere classified	2.3%	96.1%
10. Rough & dressed lumber – treated, not edged	1.6%	97.7%

2.3 External Environmental Cost Ratio

Based on a literature review of societal costs of air pollution, monetary values were calculated for upstream environmental burdens associated with each input to construction in the Uniformat Building Group Element categories. This monetary value can be expressed as a ratio. The units of the ratio are external cost of upstream environmental burden in dollars per dollar (or thousand, hundred, etc. dollars) of the market cost of the input to construction. We have called this ratio the "external environmental cost ratio" (EECR) for each input to construction within the Uniformat categories.

In Table 3 below, the EECR for the state of Washington for each of the high priority (80-90% cumulative contribution) inputs to construction within each of five major architectural Uniformat categories is indicated. Table 3 can be used to determine which inputs to construction within Uniformat categories have the highest per dollar upstream external environmental cost. For example, in the Uniformat category Interior Finishes, "tufted carpets" has an EECR of 0.24 meaning that for every $1.00 of market cost, $0.24 is generated in upstream external environmental cost. Compare that with "ceramic wall and floor tile" which has an EECR of 0.17 meaning that $0.17 of upstream external environmental cost is generated for each $1.00 of market cost. Dollar for dollar, tufted carpets have 40% greater upstream external environmental cost than ceramic tile.

Of course, the total upstream external environmental costs for any input to construction have to be adjusted according to the unit cost of that input to construction. In the example above, if the unit cost of ceramic tile is higher than that of tufted carpet, then the cost difference must be accounted for in determining the upstream external environmental cost in providing a floor finish for a particular area.

2.4 Employment Impact Ratio

Finally, the analysis can estimate the employment impact for major Uniformat categories as well as each input to construction for local, regional, or national geographic regions. Summaries by county and by state of employment associated with each input to construction within the Uniformat categories can be provided. The total number of jobs associated with the input to construction for the baseline building alongside the market cost of that input to construction in the baseline building can be indicated. The "employment impact ratio" (EIR) is the ratio between these two numbers. For the same project in Seattle, for example, in the Uniformat category Superstructure, the job total associated with "ready mix concrete" input to construction is 11.52 and the regional market cost is $744,800. The ratio between these two numbers is 15.47 meaning that this is the number of jobs per $1 million dollars of market cost. This is the employment impact ratio (EIR) for ready mix concrete within the Uniformat category Superstructure. These figures represent employment in King County and Washington only and not the rest of the U.S.

3 BaselineGreenä Benchmark

The second combined procedure indicates which material and product types of the baseline building have the lowest EECR and should therefore replace types with higher EECR values. For example, under Interior Finishes, ceramic floor tile has a lower EECR than hardwood flooring, hard surface floor coverings, and tufted carpets. Thus, depending on unit cost, it should be considered as an environmentally preferred product type.

Once the EECR and EIR values have been determined for the baseline building, ways to improve the environmental performance (i.e., reduce the external environmental costs) of the inputs to construction are considered. This "greener" baseline building is the BaselineGreen™ Benchmark. The upstream environmental burdens of material and product types are evaluated and low-embodied energy, recycled content/by-product, and locally/regionally available materials are substituted for high-embodied energy, high environmental impact raw materials. Three examples are:

- fly ash may be substituted for cement (e.g., 50%) in hydraulic cement and ready mix concrete,
- high-recycled content structural steel (90%) may be substituted for average recycled content steel (65%), and
- synthetic (flue gas desulphurization) gypsum may be substituted for mined gypsum (up to 100%).

In each of these examples, the upstream (or "embodied") environmental consequences of the materials and products comprising a particular input to construction has been significantly reduced by the selection of appropriate environmentally preferred substitutes.

TABLE 3: EECR AND EIR DATA FOR HIGH PRIORITY INPUTS TO CONSTRUCTION

	UNIFORMAT LEVEL AND CATEGORY	EECR COST/$	EIR JOBS/$M
LEVEL 1	A SUBSTRUCTURE		
LEVEL 2	A10 FOUNDATIONS & A20 BASEMENT CONSTRUCTION		
INPUTS	Cement, hydraulic	2.22	51.01
	Structural shapes, sheet piling, and concrete reinforcing bars	0.61	18.01
	Ready mix concrete	0.49	15.49
	Fabricated bar joists and concrete reinforcing bars	0.34	11.70
	Wood poles, piles, & posts	0.16	22.89
LEVEL 1	B SHELL		
LEVEL 2	B10 SUPERSTRUCTURE		
INPUTS	Cement, hydraulic	2.22	51.01
	Structural shapes, sheet pilings, & concrete reinforcing bars	0.61	17.81
	Ready mix concrete	0.49	15.47
	Fabricated bar joists and concrete reinforcing bars	0.34	11.78
	Fabricated structural iron, steel, aluminum for buildings	0.23	13.84
	Fabricated structural metal, nec	0.23	13.85
	Other fabricated structural metal	0.23	13.85
	Hardwood & softwood lumber, rough & dressed, exc. siding	0.20	16.34
	Rough & dressed lumber, treated	0.16	23.04
	Structural wood products	0.12	17.68
LEVEL 2	B20 EXTERIOR CLOSURE		
INPUTS	Gypsum building materials	0.63	12.70
	Brick and structural clay tile	0.41	18.27
	Concrete block and brick	0.38	15.32
	Other glass products including tempered, multiple glazed, & stained	0.26	27.83
	Interior and exterior architectural solvents and paints	0.25	#N/D
	Commercial and industrial metal doors and frames	0.24	14.59
	Residential metal doors and frames	0.24	14.60
	Building and construction plastic foam products	0.24	109.86
	Other granite products including building stone	0.23	61.45
	Marble building stone, monument tone, & other marble products	0.23	113.88
LEVEL1	C INTERIORS		
LEVEL 2	C10 INTERIOR CONSTRUCTION		
INPUTS	Concrete block and brick	0.38	15.21
	Softwood plywood products, rough, sanded, and specialties	0.23	16.65
	Commercial and industrial metal doors and frames	0.24	14.63
	Hardwood and softwood lumber, rough and dressed exc. siding	0.20	10.20
	Partitions and fixtures, except wood	0.18	17.09
	Movable partitions except freestanding	0.18	17.03
LEVEL 2	C30 INTERIOR FINISHES		
INPUTS	Gypsum building materials	0.63	12.70
	Wallcoverings	0.28	14.05
	Interior and exterior architectural solvents, paints, and coatings	0.25	#N/D
	Tufted carpets, rugs, and artificial grass	0.24	14.79
	Metal flooring and siding	0.24	10.70
	Hard surface floor coverings	0.23	#N/D
	Hardwood flooring + Hardwood dimension lumber and flooring	0.20	21.30
	Ceramic wall and floor tile	0.17	20.37
	Millwork	0.15	19.00

Figure 1 below illustrates in graphic form the difference between the baseline building and the BaselineGreen™ Benchmark. For each input to construction within the major Uniformat Level 2 Building Group Elements, material substitutes like the ones mentioned above have decreased the external environmental cost ratio (EECR). In some cases this reduction can be more than 50%. The BaseLine Green™ Benchmark is then used as a reference for evaluating the environmental performance of the proposed building design.

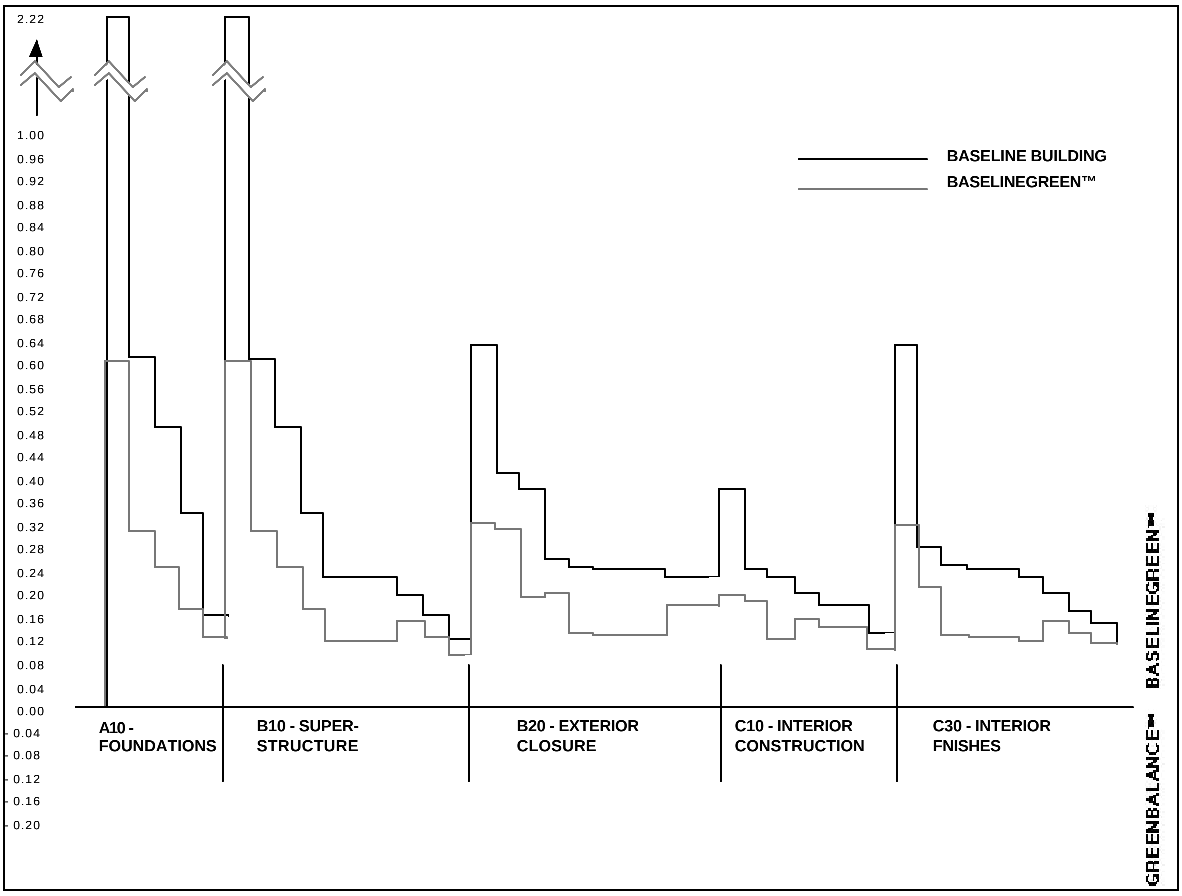

Fig. 1: External Environmental Cost Ratio (EECR) values from Table 3 for inputs to construction of a baseline building are indicated by the black line. EECR values for a hypothetical BaselineGreen™ benchmark building are indicated by the gray line. The assumed BaselineGreen™ inputs to construction have reduced upstream (or "embodied") external environmental costs of the materials and products comprising a particular input to construction by 25-50% through the selection of appropriate environmentally preferred substitutes. BaselineGreen™ establishes a "greener" benchmark than the baseline building for evaluating the environmental performance of a proposed building design. GreenBalance™ offsets or balances upstream environmental burdens in attempting to attain a "zero-impact" or even "negative impact" building design.

An example of decision making at the specification level is demonstrated in the following spread sheet.

ENV'T COST RANK 1	UNIFORMAT LEVEL II - BUILDING GROUP ELEMENT B10 SUPERSTRUCTURE					ENVIRNMENT AND EMPLOYMENT IMPACT		FINAL RANK
	LEVEL III IND. ELE	EECR	EIR	TCBU	TCBA	ENV'T COST	EMP'T COST	
1.1	READY MIX CONC. COLUMN	.49 /$M	15.5 /$M	$71 /VLF		3.5	1.1	*2*
1.2	FAB. STRUCT. METAL COLUMN	.23 /$M	13.5 /$M	$97 /VLF		2.2	1.3	*1*

EECR = EXTERNAL ENVIRONMENTAL COST RATIO FROM FIGURES 1.232-1.236
(EXTERNAL ENVIRONMENTAL COST / BUILDING INPUT TO CONSTRUCTION COST IN $)
EIR = ENVIRONMENTAL IMPACT RATIO FROM FIGURES 1.331-1.335
(JOBS / $M CONSTRUCTION)
TCBU = TOTAL COST PER BUILDING UNIT
(SUPPLIED BY ARCHITECT / SPECIFIER OR REFERENCE SUCH AS MEANS)
TCBA =TOTAL COST PER BUILDING AREA
(SUPPLIED BY ARCHITECT / SPECIFIER OR REFERENCE SUCH AS MEANS)

ENV'T. COST (externalities) = THE PRODUCT OF EECR x TCBU IN DOLLARS

EMP'T = THE PRODUCT OF EIR x TCBU IN THOUSANDTHS (10^{-3}) OF JOBS

NOTES:

1. Ready mix concrete column definition does not include rebar. Design load equals 800 kips, unsupported height 10 ft., 14 story building. (Source: Means Cost Estimating Data)
2. Structural steel column definition does not include fireproofing. Design load equals 800 kips unsupported height 10 ft., 14 story building. (Source: Means Cost Estimating Data)

4 GreenBalance™

The analysis thus far has described the inputs to a generic baseline building in terms of a) upstream environmental burdens equated to external environmental cost for each input to construction and b) regionalized economic impact in terms of employment per $M of input to construction. In addition, a new benchmark, has been established as the "green" reference for the proposed building design (see Figure 1).

GreenBalance™ attempts to neutralize or "balance" upstream environmental burdens with the objective of mitigating and, in some cases, actually counteracting upstream external environmental costs. To date, this procedure has been applied in the design phases of several proposed building and infrastructure projects in response to the following high-priority environmental issues:

1) Greenhouse gases (GHG): balance atmospheric carbon dioxide and methane emissions with carbon accumulation in long-life biomass building materials and forest mantle wastewater treatment systems.

2) Atmospheric pollution: balance sulfur dioxide emissions with the use of sulfur in long-life, sulfur-based construction materials such as within roads.

3) Indoor air quality: balance volatile organic compound (VOC) emissions by indoor vegetation.

4) Water supply and quality: balance annual on-site surface water supplies and on-site wastewater treatment with building and site needs.

5) Renewable energy: balance annual consumption with site-available (e.g., daylighting) and site-generated (e.g., photovoltaics) energy supplies.

6) Toxic releases: obtain the goal of zero upstream toxic releases and/or incorporate interior and exterior landscapes that bio-remediate toxic chemicals and render them harmless.

5 PRESENT AND PROSPECTIVE APPLICATIONS

Projects now being undertaken that include these principles include: paving specifications for the U.S./Mexican border with the North American Development Bank (NADBank); the University of Texas Health Science Center Nursing and Biomedical Sciences Building (NBSB) in Houston, Texas; and the Advanced Green Building Demonstration Project (AGBDP) in Austin, Texas.

The NADBank project investigates the potential for all present SO2 pollution emanating from petroleum refining industries in both countries to be balanced through the use of proven sulfur paving technology. The chemical balancing that has resulted showed complete alleviation of SO2 pollution over a 15 year period when paving only within the four county area needs. Proven paving strategies demonstrated that low-cost, durable, sulfur-modified paving materials can be made along the border and that the annual demand for alternative paving materials greatly exceeds annual sulfur emissions.

The NBSB project demonstrates how upstream carbon dioxide (CO2) emissions can be balanced with the carbon content of long-life biomass building materials that are used as infill to compensate for problem materials associated with structural components of high rise buildings. For example, Interior Construction and Interior Finish product types such as medium density fiberboard, cellulose board, and strawboard, if manufactured from renewable or by-product sources, can store more carbon dioxide (in the form of carbon) in biomass then emitted upstream during their manufacture. These “CO2 sink” product types can offset (or balance) the CO2 emissions of other product types used in the structural components of the interior of the proposed NBSB project. The design objective is that the Superstructure, Exterior Closure, Interior Construction, and Interior Finishes Uniformat categories be CO2 balanced, i.e., have zero net CO2 emissions for the life of the building.

The AGBDP exemplifies the CO2 balancing concept in the selection of Superstructure and Interior Construction material and product types. Upstream CO2 emissions are significantly reduced by using high recycled content (95% or more) structural steel and fly ash substitutes for portland cement. Long life CO2 accumulation in the carbon content of biomass materials is accomplished through the use of fiberboard and strawboard panel products in movable partitions. Balancing of water and wastewater is also demonstrated at the ABGDP.

These cases of applying the GreenBalance™ methodology suggest that a deeper re-evaluation of many sustainable architecture performance assumptions, including design objectives, material and product specifications, and operational performance, is needed, both within the boundaries of the building as well as the supporting landscape and infrastructure. GreenBalance™ attempts to balance the upstream environmental burdens with use/downstream building environmental mitigation to promote and develop a new set of standards that could bring building environmental performance to a new and more relevant level. GreenBalance™ attempts to shift the focus of building design from general (and often vague) sustainability guidelines to quantitative and more definitive materials balance assessment tools.

The procedure can be applied to other industries and can be used to evaluate alternatives for regional development alternatives comparing different resources and technologies and their possible combinations, provided adequate data is available. The regional analysis can be designed to search for the most effective industry technological scale compatible with the renewable resources base of a region and the social and economic regional background.