Title of the Paper: Remote Sensing of Environmental Impacts for IMACS

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Keywords: Sustainability, Sustainable economy, biodiversity, protection, restoration, carbon neutrality, carbon negativity, Carbon capture engineering, Sustainability sciences, international protection of human rights

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Remote Sensing of Environmental Impacts for IMACS

1. Abstract

The Impact Measurement and Conservation System (IMACS) was developed to calculate environmental and human condition impacts and to apply conservation required to neutralize such impacts for products and services purchased by end-user consumers *(1- 6).* With its implementation, the IMACS system would allow the fastest return to the best approximation of pre-industrial sustainable conditions. All environmental impacts take place on a location. Location Based Impacts (LBIs) are environmental impacts assigned to parcels (land) or designated areas (marine). Under IMACS, LBIs are distributed in a dynamic fashion over the products made and services rendered using these areas. This article focuses on the use of remote sensing instruments systems used to accurately measure the underlying variables needed for parcel and designated area delineation and the environmental impacts taking place on them (LBIs). These impacts include landscape change and the subsequent use as cultivated area, changes in biodiversity, greenhouse gas emissions, fresh water consumption, soil and surface water acidification, soil & sediment loss, coastal area at risk of flooding, atmospheric ozone layer damage and includes all applicable types of conserving impacts, including wildlife area conservation, carbon storage and protection of coastal areas from flooding due to sea level rise. Using currently available remote sensing technology and after training using ground data, area mapping, parcel delineation and the measurement of most environmental impact variables can be done using satellites, by using aerial sensors or by using combinations. Implementation of IMACS requires the development of data products that combine remote sensing based environmental data with civic databases (users of parcel and designated areas), allowing easy, automated and low-cost extraction of LBI data.

2. Introduction

An Impact Measurement and Conservation System (IMACS) is developed to calculate environmental (E) and human (H) condition impacts and to apply conservation required to neutralize such impacts *(1,2).* The system assigns costs to resources used and damage done, creating strong incentives to minimize resource use and prevent environmental (E) damage while maintaining and improving human (H) conditions. The system uses Environmental Supply Chain Step (ESCS) calculations, with Individual Supply Chain Steps (ISCS) for individuals, Product Supply Chain Steps (PSCS) for products & services and Rating Supply Chain Steps (RSCS) to estimate impacts not resulting from ISCS or PSCS calculations. Each ISCS represents one individual, while each PSCS represents one or a series of identical product or services. All E-impacts enter the system as Location-Based Impacts (LBI), while all H-condition impacts enter the system through ISCSs. Although ultimately highly automated, LBIs and H-impacts are always estimated using a RSCS calculated (or audited) by an Impact Rating Organization (IRO). Employees can live sustainable; in which case the employee labor output is free of impacts. All impacts from non-sustainable employee labor are transferred to products and services made. For services provided, all impacts are transferred to the new organization during the sale transaction. For products made, all impacts are temporarily stored in the product, until sold. All impacts that enter the supply chain, exit as Individual Sustainable Absorption (ISA) *(3)* and as Excess Impact Deduction (XID) *(4).* See figure 1. The system allows transformation of products and services with damaging impacts, to products and services free of damaging impacts through the application of neutralizing conservation. IMACS allows the acceleration of the transition to global sustainability and to humane conditions, on a global scale, for all impact variables carried. A few dozen impact variables are divided over eleven impacts groups. Conservation in the form of protection and restoration can be made available to end-user consumers, while paid for by sellers. Under IMACS, conservation of all types needed can be made available in small and fractional amounts, such that conservation of the exact amounts required can be applied during the purchase, in name of the buyer. Such “title-to-conservation” (TTC) is purchased at market prices by the end-user consumer under condition or permanency *(5).* This means that existing and new types of conservation need to meet stringent IMACS requirements in order to allow their sale as TTC. Many types of conservation needed are not yet available or only in very small quantities, while none of the above requirements are met. The amounts of conservation available as TTC will start at zero and only gradually increase. This in turn means that initially only a very small fraction of all products and services can be consumed impact-free. On the positive side, this means that all types of conservation made available as TTC each week, will be fully sold that week, maximizing the growth of conservation organizations and their capacity. The IMACS organization sets the daily product participation percentage for participating organizations, such that demand for conservation is kept equal to the supply, by increasing the percentage of products and services that is required to "participate". Impact variables are shown in capitalized supply chain step notation as [L, U_m, P_n] | [C] when expressed in their customary units, or are shown in regular font notation as [l, u_m, p_n] | [c] when expressed under normalized (unitless) conditions (*2*). In figure 1, impact variables [l, u_m, p_n] | [c] are shown under normalized conditions for resource use and historic impact variables. Except for the inputs for "Supplies" and "Locations-Based Impacts" (for which the values can vary), figure 1 also represents reference conditions (100% sustainable conditions).

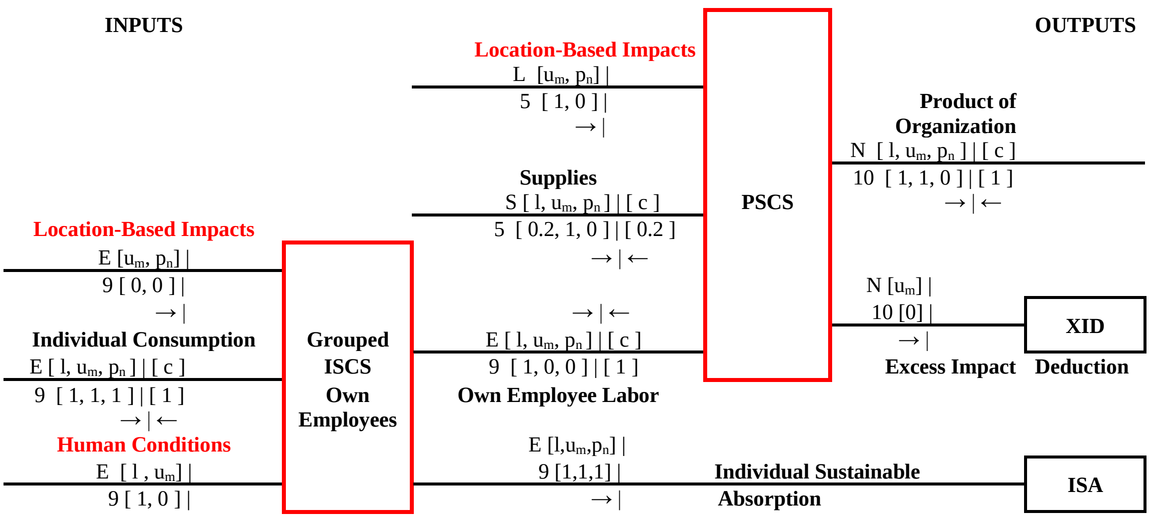

Figure 1: Combined ISCS-PSCS under normalized (unitless) and reference conditions (100% sustainable) for resource use and historic damage variables *(2).* The PSCS represents one product of an organization. One ISCS represents one employee and their labor. The ISCSs of multiple own employees are combined in a grouped-ISCS to use as an input to a PSCS. Except for financial compensations paid, all impacts flow from left (resources) to right (end-users) through the figure as indicated by the arrows above or below the values. Impacts for each variable balance over each supply chain step. All original variables with their specific units, L = labor hours worked, U_m = resource *m* used, P_n = conservation *n* applied and C = salary or price paid, can be expressed as normalized (unitless) values by division by their corresponding reference value: $l = L/L_{ref}$, $u = U/U_{ref}$, $p = P/P_{ref}$, $c = C/C_{ref}$. Each reference value reflects 100% sustainable conditions for the specific variable. All impacts first enter the supply chain as Location-Based Impacts (LBIs). All impact (except for salary paid) enter the supply ISCS or RSCS as human-condition impacts. Of all H-impacts, labor hours and salary paid are always carried and shown in supply chain step notation in all figures. Other human condition variables can be added to the ISCS input labeled "Human Conditions". Under reference conditions, all current damage is zero, the resource use is equal to the individual allowance, conservation applied is equal to requirements, while resource use and conservation applied leave the supply chain as ISA *(3),* rendering the labor output free of impacts. For numerical simplicity of the example values in figure 1, the Location-Based Impacts of employees (mostly low in developed countries) are set to zero, while the impacts for products are evenly distributed over Location-Based Impacts and Supplies used. Under non-sustainable conditions, impacts are recycled with products made and consumed by employees. A fraction of al impacts enters the PSCS twice, requiring an Excess Impact Deduction (XID) to prevent supply chain accumulation of impacts. The XID *(4)* is zero under sustainable conditions. For current damage variables under normalized reference conditions, the same figure can be used, with the difference that all values for u_m and p_n are zero. For grouped-ISCSs, the multiplier E represents the number of own employees and is used for all ISCS inputs and outputs. N represents the number of products made, while L and S represent respectively the number of "batches" of Location-Based Impacts and Supplies used.

For each ISCS or PSCS figure and calculation made, LBIs only include E-impacts that pertain to or originate from the land or sea area assigned to the specific ISCS or PSCS. While all E-impacts originate at a specific location, and enter there as an LBI, some LBIs are easier to follow and calculate through purchases made. For example, an individual renting an apartment uses the projected surface area of the apartment floors and a fraction of the apartment grounds (parking lot, garden, etc.). This surface area used could be calculated for the individual, independent of the amount of rent paid. However, it is much easier to include this surface area used as part of the payment data for the service of "providing the apartment". While theoretically qualifying as an LBI for the renting individual, once included as part of the rent data, the apartment surface area is no longer a separate LBI input, since that would lead to erroneous double counting. LBI inputs thus only include the theoretical LBIs that are not already included with purchases made. For products and services purchased, impacts will include those collected before and anticipated after the purchase. For example; fuels purchased will reflect all impacts up to the point of sale, plus all impacts for the future burning of the fuel. Under *reference conditions*, no damage is done, the resource use is exactly equal to the individual sustainable available amounts (individual allowances), while all conservation is applied as required to render all resource use sustainable and to neutralize the required amounts of current and historic damage done. Under sustainable conditions, the resource use amounts and the required amounts of conservation applied are deducted in the ISCS calculation as individual sustainable absorption (ISA), rendering the labor output free of impacts *(3).* Under non-sustainable conditions, the resource use, current damage done and historic damage assigned are larger than can be deducted as ISA, and the labor output carries impact values for resource use, current and/or historic damage larger than zero (non-sustainable), while the excess impact deduction (XID) becomes larger than zero *(4).* The various types of conservation (protection and restoration) needed and applied are discussed in *(5).* The impacts for employee labor, products and services can be calculated accurately, when all LBIs and human condition impacts of all employees are accurately determined, and when all other impacts that are inputs to the ISCS and PSCS, themselves result from ISCS and PSCS calculations. Using the calculated impacts, sustainability values can be calculated for products, services and individuals *(6).* However, early after first implementation of the IMACS system, no accurate determinations of LBIs and human condition impacts are available, while very few ISCS and PSCS based impacts are calculated for employee labor, products and services. All LBIs that enter the supply chain for organizations and persons, need to be measured in order to calculate impact and sustainability values for products, services and persons and need to be measured at the lowest possible cost.

3. Detailed Determination of Location Based Impact

3.1. LBI General

Location Based Impacts and Impact Groups. All environmental (E) impacts enter the supply chain as Location-Based Impacts (LBI), while all human condition impacts (H) enter the supply chain with the labor inputs of individuals (figure 1).
Both LBIs and human condition impacts, require some (human) work to determine their value and enter through a Rating Supply Chain Step (RSCS). At full implementation, a few dozen main variables, distributed over eleven impact groups, are used in the IMAC system (table 1) *(2).* Implementation will start with the easiest to measure impact variables, likely *cultivated area used* and *carbon dioxide emitted*, followed by the corresponding conservation variables *wildlife area protected* and *carbon sequestered*. As an example; the impact group "cultivated area use" has two main variables: *cultivated terrestrial area use* and *cultivated marine area use*. These two main variables are split up in sub-variables representing the 867 terrestrial ecoregions, the 450 freshwater ecoregions and the 232 marine ecoregions *(7,8,9).* Under IMACS, all cultivated area use needs to be recorded per ecoregion, since the wildlife area that needs to be protected must be within the same ecoregion in order for the cultivated area used to be "sustainably available". With "title-to-conservation" (TTC) initially available for only one or a few wildlife areas, this "ecoregion linkage" will be relaxed, such that initially any wildlife area protected (meeting IMACS standards) would qualify as a means of conservation, until sufficient wildlife areas can be matched to cultivated area within the same ecoregion. Similar "ecoregion linkages" between use and damage variables and conservation variables exist for variables in many of the other impact groups. Such linkages do not exist for impact variables in the *Climate Change* and *Atmospheric ozone layer damage and conservation* impact groups, since emission of greenhouse and ozone layer damaging gasses affect the atmosphere independent of their release location.

1	Cultivated area use (all areas not protected for their biodiversity)	7	Coastal area used and conservation applied (protection from flooding due to sea level rise)
2	Biodiversity change	8	Atmospheric ozone layer damage and conservation
3	Climate change	9	Infectious disease prevention and mitigation
4	Fresh water use and conservation	10	Human reproduction
5	Soil and surface water acidification or pH reduction	11	Human conditions
6	Soil & sediment use and conservation		

Table 1: The eleven IMACS impacts groups

This list of impact variables carried for each impact group at any time will be set by scientific steering groups for each impact group. Each of these groups must be made up of experts in each field. In addition to the impact variable to be included, the scientific steering groups also need to decide on the methods and formulas used to calculate the various impacts. At full implementation, a dozen human condition variables will be used to reflect human conditions. These include labor conditions (hours worked, salary paid, safety aspects, job stress, freedom to change employers, daycare options), living conditions (living surface area, features, construction quality and external energy requirements), commuting distance, educational opportunities, healthcare and all cost aspects. Until systems are set up to reliably measure human condition variables, only the variables *hours worked* and *salary earned* (total compensation) will be used. As with environmental variables, human conditions variables will likely be added "one-at–a-time". While human condition impacts take place at a location, they will not be addressed here, but separately in future publications. LBIs thus only include environmental impacts.

Relative Share of Impact Contributions for Individuals and Organizations. All E-impacts enter the supply chain somewhere as LBIs. For large organizations operating at the resource end of the supply chain (i.e., mining, farming, fishing, fossil fuel extraction and processing) the largest fractions of all impacts (area use, emissions, water use, pollution) enter the PSCS for their products as LBIs. Since materials and products at the resource end have relatively low costs, the impacts per dollar costs are high. For most individuals and micro-organizations, the largest fractions of all impacts enter their ISCS or PSCS with products and services purchased and with salaries paid (see table 2).

Location Based Impacts **(All E-impacts of or originating from the location, not already covered by products, services and labor purchased)**	**Contributions of Large Organizations (group A)**	**Contributions of Individuals & Micro Organizations (group B)**
1. Cultivated area used as land (i.e., mining, farming, fishing, fossil fuel extraction) Cultivated area used as marine area (fishing, fossil fuel extraction, mining, other)	large large	small NA
2. Biodiversity loss due to landscape change, hunting/removal of native predators, use of pesticides and herbicides.	large	medium
3. Biodiversity Conservation: Wildlife area managed for its biodiversity and changes versus time (protection and restoration)	large	NA
4. Greenhouse gas emissions: a. CO2 emissions from fossil fuel furnaces, stoves, cars and from wood burning fireplaces and firepits. b. Methane and nitrous-oxide, other c. Nitrous oxide (leading to soil and surface water acidification)	 large large large	 small small small
5. Carbon dioxide sequestration (above ground and soil)	large	NA
6. Fresh water withdrawal and generation (reverse osmosis, condensation)	large	small
7. Waste water management (biological treatment, irrigation and re-infiltration of cleaned water close to source)	large	small
8. Air pollution (from fossil fuel furnaces, stoves, cars and from wood burning fireplaces and firepits).	large	small
9. Soil and surface water pollution impacts (chemical waste, sewage and other waste water released, settled and rain extracted air pollutants)	large	small
10. Soil and sediment erosion or removal	large	small

Table 2: Relative contributions of the most important Location-Based Impacts (LBIs) by large organization (A) and individuals & micro-organizations (B) to the overall impacts. Except for emissions of ozone depleting materials (low for both groups), the fraction of impacts that enter as LBI is large for large organizations. The fractions of each LBI not already covered under products, services and labor, are mostly small or non-existent for individuals and micro-organizations.

For most individuals almost all impacts enter their ISCS as products and services purchased, for which the impacts are known or can be estimated. The remining LBIs are typically small and can be computer estimated without any further need for local IRO verification. The same applies to most micro-organizations (employing a handful of employees in an office). This is different for organizations larger than micro-organizations and for individuals owning more that the average land area. For a detailed LBI determination, a IMACS licensed Impact Rating Organization (IRO) needs to evaluate the organization's land and marine area uses, as well as all impacts that take place in/on and originate from those areas. Land use includes lands owned, leased rented, borrowed or otherwise used. The same applies to marine areas. This would start with a list of land and marine areas used, buildings and other "improvements" the organization owns and/or uses. In order to assign E-impacts to individuals and organizations, these E-impacts first need to be associated with the lots (parcels) used. This requires the availability of maps with parcel delineations.

Accurate Parcel Delineation and Mapping. Maps in developed countries are generally quite accurate, especially with the advent of modern technologies like satellite imagery and GPS. Airborne and satellite imagery have made documentation of many areas possible that were previously inaccessible *(10).* Free online services such as Google Earth have made accurate maps of the world more accessible than ever before. However, when it comes to parcel delineation, especially for older parcels using geographic descriptive markers like trees and ditches, there can be potential conflicts. This is because these markers can change over time due to natural processes or human activities. For example, a tree used as a boundary marker could die or be cut down, or a ditch could be filled in or eroded away. The generation of accurate maps and parcel delineation can vary significantly between developed and developing countries due to differences in resources, technology, and infrastructure. In developed countries, the location and land surface area used for most buildings, roads and other man-made structures can be extracted from maps and public documents. The construction of man-made structures typically requires governmental permits, while illegal construction is rare. Cultivated sections within wildlife area can be delineated and their surface areas can be calculated. However, improvements are possible even in developed countries, where mapping can still significantly lag construction.

There are significant challenges in mapping the developing world. Slums and other illegal settlements may not be represented on official maps. Accurate parcel delineations on maps often don't exist. Many developing regions lack coordinated capacity, infrastructure, and technologies to produce accurate maps and a robust land cover monitoring system that meets land management needs *(11).* Newer methods of parcel delineation have been developed to address these issues. These include deep learning, object-based image segmentation, and conventional (edge-detection) filters using remote sensing data from both satellites and planes. Satellites providing remote sensing data are Landsat 7, 8 and 9, Sentinel-2 (A and B) and the 200 "Doves" operated by Planet. Nearmap provides products based on photographic images using aircrafts. Remote sensing data can also help in the measurement of area used for buildings, roads and infrastructure and make such changes visible much earlier. For instance, AI4Boundaries is a dataset used to train models on field boundary detection using images from Sentinel-2 and aerial photography *(12).* Another approach uses machine learning algorithms for agricultural parcel delineation through agglomerative segmentation *(13).* These methods can provide more accurate and up-to-date parcel delineations compared to traditional geographic descriptive markers and promise to do so at much lower costs. It's important to note that while these newer methods can improve accuracy, they may not always align with older parcel delineations based on geographic descriptive markers. This could potentially lead to conflicts in certain cases. Tech companies like Google and Microsoft have resources and expertise that can be leveraged to improve maps and parcel delineation in developing countries. Partnerships between such companies and governments or NGOs could lead to significant improvements in map quality and parcel delineation, but will take time. In the meantime, open-source mapping platforms like OpenStreetMap provide tools for anyone to contribute to a map of their area. The OpenStreetMap platform can be effectively used to create land use and land cover maps as long as a sufficiently detailed list of tags is used to identify features *(14).* This can be particularly useful in areas where commercial map providers do not have detailed coverage or for developing world areas where users cannot afford the costs of commercial products. Engaging local communities in the mapping process can ensure that the maps produced are relevant and useful to those who live there. This can be done through participatory mapping projects where local people are trained to use GPS devices and other mapping tools. This is especially important for farmers in developing countries who want to participate in IMACs, in areas where maps and parcel delineations are poor or non-existent.

Environmental Impact Measurement. Remote sending data can also be used as the basis for calculation of environmental variables and impacts. Where such data are required on massive scales, remote sensing data likely offer access at the lowest costs. All remote data measured, modeled or otherwise calculated need to be overlayed with maps delineating the parcels/areas used by individuals and organizations, as well as all publicly used (roads, parks) and non-used areas (wildlife areas). The area delineation and ownership data need to be extracted from public and private cadastral databases. Data can be stored in various types of databases: 1. *civic data* (maps, parcel delineation, cadastral data, individual and business data, including data on who rents or otherwise uses the parcel if not the owner), 2. *remote sensing data* (the raw data from satellites, planes, ships and drones), 3. *ground data* (data measured accurately at or close to Earth surface, used to train remote data sets in order to improve satellite-based-

Location Based Impact Variable	Steps and Methods Used	Data Source, Measurement or Determination Method
Cultivated area use	• Delineate roads, buildings, parcels and public areas not yet or not accurately located on maps. Add to databases. • Assign parcels to owners and calculate surface area. • For public areas used (roads, parks), the surface areas need to be calculated, distributed and assigned to surrounding non-public parcels proportional to parcel area and distance. • Ecoregion designation of area • If the area is not protected for its biodiversity, the "cultivated area" status is assigned. • Assign surface area of parcel and distributed public areas to owner or distribute over users	Remote sensing data Civic databases Civic and IMACS databases IMACS database IMACS database IMACS database
Wildlife area protected or restored for its biodiversity	• Delineation of wildlife area. • Is the area protected for its biodiversity? With adequate proof, the status of "protected wildlife area" is assigned. • Determination of wildlife area fraction used for cultivated purposes (buildings, roads, infrastructure). • Ecoregion designation of area • Current biodiversity, biodiversity loss compared to the undisturbed biodiversity for the ecoregion and recent changes in biodiversity are determined for area/parcel. • Assign net wildlife area and biodiversity values to organization	Remote sensing data IMACS database Civic and IMACS databases IMACS database Model and IMACS Data IMACS database
Greenhouse gas emissions	• Delineation of area to which emissions are assigned • CO2, methane and nitrous oxide concentrations • Calculations of emission amounts for the area / parcels based on mass balance of surrounding air volumes	Civic databases Remote sensing data Mass balance calculations
Carbon storage	• Delineation of carbon storage area/parcel • Above ground carbon storage changes • Soil carbon storage changes • DAC carbon storage changes • Assigning carbon storage changes to areas/parcels	Civic databases Remote sensing data Ground data IMACS database IMACS database
Fresh water consumption	• Delineation of area/parcel for which water consumption is determined. • Evapotranspiration and water extraction and reinjection data • Estimated evapotranspiration for the original ecoregion • Water consumption is calculated from evapotranspiration data and extracted water not returned to source • Assigning water consumption to areas/parcels.	Civic databases Remote sensing, ground data Model data IMACS database Mass balance calculations IMACS database
Air pollution	• Delineation of area to which emissions are assigned • Carbon monoxide concentrations • Lead concentrations • Nitrogen Oxides concentrations • Ground level Ozone concentrations • Particle matter concentrations • Sulfur oxides concentrations • Calculation and assigning of air pollution amounts to areas/parcels.	Civic databases Remote sensing data Remote sensing data Remote sensing data Remote sensing data Remote sensing data Remote sensing data IMACS database
Soil and water pollution	• Delineation of area/parcel to which pollutions are assigned • Agricultural chemicals (fertilizers, pesticides, pathogens, toxins from algae blooms • Sewage and wastewater (urban, industrial, agricultural) • Industrial chemicals (methanol, ammonia, VOCs, petroleum products, Manganese, sodium, Nitrite, Zinc, Barium) • Assigning soil and water pollution to areas/parcels.	Civic databases Remote sensing data Remote sensing data Remote sensing data IMACS database
Soil and sediment erosion or removal	• Delineation of area/parcel to which pollutions are assigned • Changes in soil or sediment levels • Assigning soil and sediment changes to areas/parcels.	Civic databases Remote sensing data IMACS database

Table 3: Overview of environmental variables used as LBI, the steps and methods used to determine impacts and assign these as LBIs and the source, measurement or determination method for the data used.

data models) and 4. *modeled data* (using remote sensing and ground data). These data are the basis of calculated environmental impact data and 5. *IMACS data* (individual data, area use data, product and service data, organizational data and calculated impacts for products, services and individuals). Environmental impacts are calculated by evaluating environmental variables over time and are assigned to the delineated parcels. Examples of environmental impacts are: landscape change, biodiversity change, water use (all compared to the original ecoregion landscape values), greenhouse gas emissions and polluting emissions and precipitation (acid rain, others), the latter all compared to the pre-industrial atmospheric concentrations. LBI values for parcels are then calculated using their underlying databases data (table 3) and assigned to the user (individual or organization).

Local Area Inspections. While most LBIs will be determined using modeled data, the IRO will need to carry out a field determination for most organizations to verify or adjust the LBI values. The same applies in principle to LBI determination of areas used by individuals. LBIs must be determined per participating location of operation. For example, if a grocery chain wants to start IMACS participation, not all stores, distribution or business centers can be included at once. Participation starts with one store or facility at one location, while other stores or facilities at other locations can be added one-at-a-time. A non-participating organization *headquarters* would be treated as an independent *supplier* of services to the local participating store. For individuals all areas owned and used need to be including at first application. The E-impacts are calculated from a combination of remote data, ground data and civic database values. Location based impacts reflect the E-impacts for a specific location over time, but are only meaningful when they can be tied to a product, service or individual. By itself, remote sensing data are "point at time data", where each value represents the variable for a specific geographic location with the size of multiple hectares at a certain time. To be meaningful to the organization or individual, the data need to be processed (summed, averaged, other) over a specific area and time period, to reflect values representative for the lot, area or crop field used over the required period. Additional calculations may be needed to derive the desired variable value (calculation of local water withdrawal from precipitation, surface and underground runoff and evapotranspiration data). For an individual, this means that all E-impacts are associated with the lot the individual uses. For a farm business, this means that E-impacts need to calculated for the total farm area, or better (if possible) for each crop field the farmer uses and over the time each crop is grown. For any other organization, the impacts need to be tied to location, building or factory where a specific product or service is produced and need to be distributed equitably over products or services sold.

Multiple additional databases are needed to do this. In addition to satellite data products, public data sources are needed. Public sources can include town records with names and addresses of inhabitants, property tax records, land records, fresh water extraction systems (permits and flow data), septic systems and fossil fuel systems installed. While likely varying per country, emission data of chemical companies are typically publicly available. Remote sensing data are typically publicly available as well. Software needs to be developed to provide the most efficient extraction of all relevant data from available databases, to convert these into impacts and assign these via (terrestrial or marine) areas used to organizations or individuals owning and/or using the areas. E-impacts need to be assigned to lots and to owners/users using an overlay of maps with cadastral lot delineation, linked to databases with lot ownership and lot users. Different types of databases need to be combined; remote sensing source data, geolocation data, cadastral data and data on the actual land user if different from the owner (leased, borrowed or otherwise used land). Using such hybrid environmental and civic databases (HECD), all lots can be globally assigned to owners and users or remain unassigned. Geolocation data for infrastructure (canalized rivers, canals, highways, dense built-up areas, fences and walls) may allow interpretation that areas are fragmented wildlife areas or sufficiently connected to bordering wildlife areas and/or have safe wildlife corridors. By comparing remote sensing data over time, changes can be measured. This applies to biodiversity increases due to wildlife area protection and restoration, biodiversity losses due to landscape change, greenhouse gas emissions, fresh water balance, soil and surface water acidification, soil and sediment erosion or removal and changes in global forcing due to changes in surface albedo. The same combination with geolocation and cadastral data can be applied to all other types of remote sensing data. Once such hybrid environmental and civic databases (HECD) are available, such primary LBI determinations can be carried out fully automated.

Separate software modules would be needed per impact group. Each module would need to be expanded with each impact variable added (e.g., expansion of the number of greenhouse gasses carried or expansion of biodiversity variables used). Using such software, for all terrestrial areas, landscape types can be assigned (cultivated, wildlife) and water infiltration, water extraction, evapotranspiration, carbon dioxide emissions, methane emissions, carbon storage, surface salinity, soil loss, surface acidity, surface heat reflection and biodiversity values can be measured. While less rich in the number of sustainability related variables that can be measured using remote sensing, a similar approach can be applied to a selection of remote sensing variables applicable to marine areas and is of special importance for shallow marine areas.

Remote sensing data can be compared with ground-based data in order to allow more useful data interpretation. Such comparisons may designate an area as a crop field growing wheat, or corn or soy or palm oil trees. Alternatively, if the biodiversity is much higher, it may indicate a wildlife area, or a patchwork of small crop fields with overall higher biodiversity as could be explained by crop fields separated by strips of land of higher biodiversity. Various land-use types can be assigned to land (crop fields, built-up areas with low biodiversity, commercial forests, wildlife area and subtypes of each). A similar approach may be applied to marine areas.

For some LBIs, various parameters can be measured remotely, but require additional ground/field determination. This applies to wildlife areas protected for their biodiversity, and includes determination of cultivated area sections within the wildlife area (roads, buildings, water withdrawal), effectiveness of protection against hunting, fishing and poaching, adherence to procedures and policies and the review of monitoring records for vessels entering protected marine "no-take" and "no-entry" zones. This also applies to agricultural organizations, where aspects of the operation cannot be determined from satellites. Examples are manure digestion, waste water treatment, pesticides used, temporary storage of runoff water for fertilizer and pesticides recycling, soil retention practices applied, wildlife strips maintained, wildlife corridor practices applied.

In some categories of cases, LBI aspects cannot be measured remotely, but require full ground/field determination. This applies to organizations operating chemical processes, chemical storage, landfills and waste treatment facilities. In these cases, monitoring equipment needs to be installed on stacks, vents or in surrounding fields to measure chemical compositions and allow chemical mass balance calculations. This includes, water treatment and recycle, landfills and landscape changes. Measurements of point source emissions of greenhouse gasses from chimneys and vents could help reduce the uncertainty of emissions calculated using satellite data and reduce the CO2 and methane emissions assigned. For water management, field determination is needed for fresh water generation, water withdrawal, subsoil water composition, water purification, injection of rainwater in underground aquafers, re-injection of purified water to locations close to the withdrawal source, and for amounts of water evapotranspired or sent to salt sinks. Full field determination also applies to worker living and working conditions for all organizations.

Limitation of the initial variables to be implemented (to one or two) will reduce the initially required amount of work to be done by the participating organization and by the IRO. For example, if we only use *cultivated area use* to start, only the cultivated area used will need to be determined as a LBI variable. Once *wildlife area protected for its biodiversity* are added as variables, the biodiversity and changes need to be determined for the first (few) participating protected wildlife areas and for all cultivated areas used. When *greenhouse gas emissions* are added as a 3rd impact, this could initially be limited to only carbon dioxide; carbon dioxide emissions would need to be determined for all participant areas. Three types of LBI values can be used; *default values*, *improved estimates* and *detailed determinations*.

3.2. Determination of Location Based Impacts

3.2.1. Cultivated Area Used

With the accurate delineation of parcels/lots, buildings and other human built structures, and the availability of such data in databases, the cultivated area used and/or assigned to individuals, organizations (homes, apartments, offices, businesses, governments) and public places can be calculated over the period of interest. For organizations or individuals who are the single user of a parcel, the full parcel area is assigned to the organization as cultivated area used. For organizations or individuals using a section of a building (one floor, one suite, one apartment) the floor surface area used is divided by the total floor area used in the building. A similar correction is applied to the fraction of the grounds used. For the simple case of a renter of an apartment in a 10-story building where all floors have the same floor surface area, the cultivated area used for the apartment itself is 1/10 of the apartment floor area. In case the parcel size is twice the building footprint, the correction factor of two will be applied to the cultivated area use of the apartment, in order to correct for the grounds around the building. This leads to a cultivated area use of 2 * 1/10 = 1/5 of the apartment floor space.
Organizations and individuals can make sections of their land publicly accessible (free of charge) as parks or indoor spaces and thus reduce their cultivated area use. The cultivated area use of public areas (streets, parks) is no longer assigned to its owners, but divided among all non-public areas/parcels based on the distance between each of the public and the non-public areas and proportional to the size of the both types of areas, such that the total of public areas is distributed among all non-public areas. An apartment renter with twice the average cultivate area assigned to his apartment and grounds, will have twice as much public area assigned compared to the average apartment renter.

For two parks of 1 Ha and 2 Ha, both at a 1 km distance for an apartment, the larger park will add twice as much cultivated area as public area to the apartment's cultivated area use, compared to the smaller park.
If the building owner is a IMACS participant and rents the space as a IMACS *rated* service, the cultivated area used for the apartment is already included in the rent data and no longer reported separately as LBI data. If not included in the rent data (the person living in the space owns it or the space is rented without being an IMACS *rated* product), the LBI data need to be reported separately.
For farm land growing a single annual crop of a season, the full 12-month period has to be assigned to the crop. For multiple crops per year, the annual fractions need to be assigned to each crop corresponding to actual periods for preparing the fields and growing and harvesting the crops.

3.2.2. Wildlife Area Conservation

Wildlife Area Classification: Wildlife areas come in different forms. Some areas are rewilding after being abandoned. This does not guarantee that they will not be put back in cultivated service in the future (agriculture, roads, urban development, loss of protected status). Other areas have been rewilding for decades or centuries and can have recovered much or most of the undisturbed/original ecoregion biodiversity, especially when they border undisturbed wildlife areas. However, without the effective protection for biodiversity and the commitment do so forever, wildlife biodiversity can be degraded over time (hunting, fishing) or be lost completely after landscape use change *(15).* Commercial forests can harvest timber after 2 to 50 years *(16)* and are cultivated areas. However, forests grown for decades can contribute to biodiversity protection for example by providing shelter to animals. Birds and larger animals can move to bordering forest sections when the timber is harvested. This biodiversity contribution of commercial forests is higher for longer harvest cycles, for forest growing a wide range of (preferably) native trees, bordering wildlife areas and especially when smaller sections are harvested at a time. Terrestrial wildlife areas without an effective protection of its biodiversity are therefore classified under IMACS as cultivated areas and have an expected lifecycle and biodiversity protection contribution at the lower end of the range for commercial forests. To classify (under IMACS) as a wildlife area protected for its biodiversity (*Nature Protectorate*), the area needs to have a legal status to create the best foundations for the permanent protection of its biodiversity and must be managed accordingly. The options for such legal protections differ per jurisdiction and need to be improved and implemented globally *(17 - 21).* For terrestrial areas, a conservation easement must be created stating that the lands must be protected for their biodiversity in perpetuity. A better but more expensive option is to buy the land to be protected outright *(22).* Creating conservation easements for areas surrounding lands already owned by wildlife protection organizations can further improve biodiversity protection *(5).* Freshwater bodies and (especially coastal and shallow) marine areas need protection from fishing and shipping. Larger freshwater bodies and coastal marine areas are universally owned by governments. To qualify as a freshwater or marine wildlife area, protected for its biodiversity, governments need to create protected "no-take" and/or "no-entry" zones and effectively protected such areas for their biodiversity. All other areas are classified under IMACS as cultivated areas. The use of cultivated areas can be assigned to individuals and organizations based on fish catch data. Since wildlife areas managed for biodiversity should over time approach the original ecoregion biodiversity, they need to have their natural complement of grazers and predators. In many terrestrial areas, larger grazers and especially larger predators were eliminated in the past and need to be re-introduced. Under IMACS, Nature Protectorates can file and qualify for *Environmental Conservation Organizations* (ECO) status in order to sell *"Title-To-Conservation"* (TTC) to *Conservation Fund Organizations* (*CFO*), who in turn sell the TTC to end-use consumers in order to neutralize the damaging environmental impacts of purchases they make *(5)*. Wildlife areas qualifying as ECOs are (over time) self-funding based on the TTC income they receive. Nature Protectorates not qualifying as ECOs cannot sell TTC. In contrast, participating organizations or individuals owning wildlife areas not qualifying as Nature Protectorates will need to buy and pay for TTC in order to neutralize their use as cultivated area.

Biodiversity Measurement: Environmental resource variables vary across landscapes (light, humidity, soil structure, prey size) and over time. Each location reflects a niche of conditions suitable to certain species. Species communities will change along these multi-dimensional gradients of resource variables. The total biodiversity of a landscape (gamma diversity) can be expressed as a combination of the diversity at local scales (alpha diversity) and the differentiation in diversity along resource gradients and time (beta-diversity) *(23)*. Alpha diversity can be expressed in various ways (e.g., species richness, Shannon index, Simpson index, Effective Number, Phylogenetic diversity) and can be calculated for plots of any size (small to landscapes). Beta diversity can also be expressed in

different ways (Whittaker beta diversity, Absolute species turnover, Whittaker species turnover, Proportional species turnover), using gamma diversities calculated for a landscape (total data set) and alpha diversity calculated for sites (subsets). Field determination of alpha, gamma and beta diversity is labor intensive and is carried out at small sampled locations, but would not be feasible for all global areas.
Airborne laser scanning (Light Detection and Ranging or LiDAR) is capable of characterizing the three-dimensional structure of terrain and vegetation and can successfully be used in monitoring biodiversity *(24)*. Animals modify the vegetation, allowing the inference of animal diversity from vegetation structure. Airborne laser scanning has advanced animal ecology and biodiversity conservation *(25, 26)*. LiDAR measurements take place using aircraft flying over areas at low altitude. While this allows the coverage of contiguous areas, the strips of land for which data can be collected are narrow, limiting its use to areas of very high interest. Satellite radar based remote sensing was shown to have the same sensitivity to measure alpha and beta diversity and has the potential to do so on global scales at very low costs *(27)*. As for LiDAR, satellite-based radar systems need to be trained using field data. Models using satellite-based radar systems were successfully trained on vegetation in central Europe. To be used globally, models need to be trained using field data for all global ecoregions. With IMACS qualifying wildlife areas filing for Nature Protectorate and ECO status, field studies will be required to determine the biodiversity of such wildlife areas. The increasing number of field study data will ultimately cover all terrestrial ecoregions, allowing training of diversity model for all ecoregions. Satellite remote sensing for monitoring freshwater and marine biodiversity is still challenging and research is ongoing to improve such methods *(28)*.

3.2.3. Greenhouse Gas (GHG) Emissions

Based on air sample concentrations for 2022, GHG emission contributions to global warming were 66% for carbon dioxide (CO_2), 19% for methane (CH_4), 6% for nitrous oxide (N_2O) and 11% for the sum of the various fluorinated gasses (F-gasses) *(29)*. This excludes the increasing fraction of aircraft contrails estimated to contribute 2% of global warming for 2011 *(30)*.

Methane emissions can be monitored from space by 16 satellites of two broad types; Area flux mappers and Point sources imagers (6 each) all observing in the short-wave infrared. Point source imagers are intended to measure larger methane releases from point sources; they can pinpoint the emission location with high spatial accuracy (nadir pixel sizes of 3 to 30 m2), but have higher detection limits *(31)*. Threshold detection limits for point source imagers are in the range of 100 to 10,000 kg/h and can measure emissions from oil and gas exploration, coal mining, waste water treatment systems, landfills and permafrost thaw. Area flux mappers are intended to measure smaller methane emissions arising from larger areas. Expressed in kg per m^2, methane emissions from livestock roaming in meadows, natural gas equipment and distribution piping, rice field and swamps are much smaller. The nominal detection limits for area flux mapper such as the MethaneSat *(32)*, correspond to 100 kg for a 1 km^2 area section. However, within the 1 km^2 pixels, MethaneSAT can potentially retrieve CH_4 enhancements at finer spatial resolution (400 m x 400 m pixel size) at 0.5% or better precision, corresponding to a detection threshold of 628 kg/hr. For a 50 x 50 km^2 area of an oil and gas field, MethaneSAT's 0.1% precision can detect emissions averaging only 2.25 kg/hr.km^2 *(32, 33)*. With life stock emissions at 32% of all methane emissions *(34)*, the measurements of such emissions are important. However, methane emissions from livestock and productivity of the meadows they graze in varies. Combining these two factors, the methane emissions expressed in kg/h.km^2 can vary strongly. The detection threshold is a function of the area over which the signal is collected. Using values for the low and the high ends of the methane emission range for cows of 7.2 and 320 kg/h.km^2, the MethaneSat detection thresholds would respectively correspond to 180 kg/h.km^2 for a 0.56 km^2 area, to 27 kg/h.km^2 for a 3.72 km^2 area, well within the example range given in the MethaneSAT documentation *(35)* (see figure 2). The minimum parcel sizes for assigning CH_4 emissions for high-end and low-end cow methane emissions are thus respectively 0.56 and 3.72 km^2. It would thus be possible to create data products, producing sets of values for detection thresholds and the corresponding parcel areas within the range for cow emissions expressed in kg/h.km^2. For all data sets where the emissions are significantly larger than the detection threshold, methane emissions could be calculated for areas of smaller size. The launch of MethaneSat is planned for Jan 2024 by SpaceX.

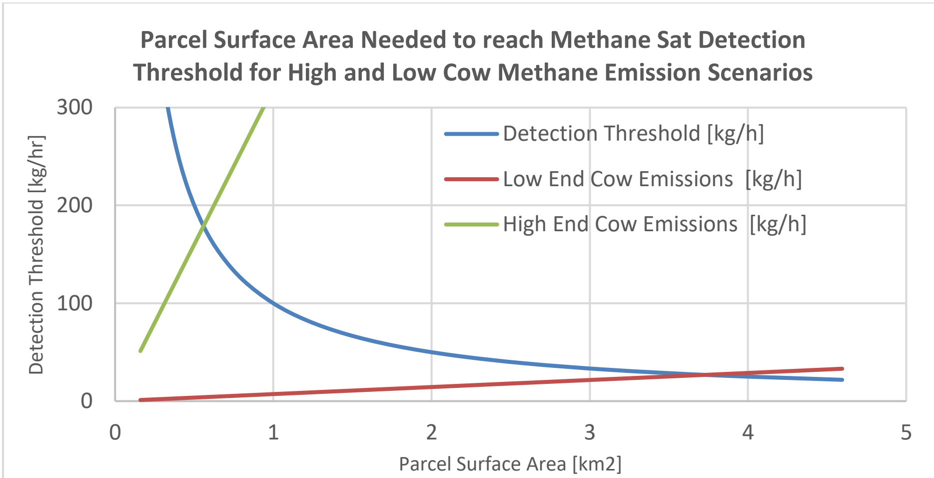

Figure 2: Calculation of detection threshold for methane emissions for the low and the high ends of the methane emission range for cows from 7.2 to 320 kg/h.km^2. The MethaneSat detection thresholds would respectively correspond to 27 kg/h.km^2 for a 3.72 km^2 area and to 180 kg/h.km^2 for a 0.56 km2 area. For values above the detection threshold curve (blue), the area size can be reduced, leading to values larger than the detection threshold for smaller areas *(35, 54)*.

Carbon dioxide emissions can be measured by a suite of satellites of which OCO, OCO-2, TanSat and GeoCarb have the smallest sounding size *(36)*. Studies show that OCO-2 is capable to quantify CO_2 emissions of the largest coal fired power plants, revealing emission changes consistent with hourly output modulation of the power plant. The increasing number of CO_2 monitoring satellites, improved ground and other monitoring of the most critical variables and better modeling would allow monitoring of facilities of smaller sizes *(36)*. Since about half of all fossil fuel-based CO_2 emissions originate from smaller sources *(36)*, it is important to map all areas with smaller sources. Global databases exist providing CO_2 emissions at 0.1 x 0.1-degree grid-map resolution at the global level *(37)*.

Nitrous oxide (N_2O) emissions currently cannot be measured from space; however, an instrument was specified for this purpose. The Monitoring Nitrous Oxide Sources (MIN2OS) satellite project aims at monitoring global-scale nitrous oxide sources. The project has been submitted to the European Space Agency Earth Explorer 11 mission ideas *(38)*.

One drawback for all satellite GHG measurements is that low emissions for an area will be strongly affected by much higher point source emissions of the same GHG within the same area. The large point source emissions remain usable, but no value can be assigned to much smaller emissions of the same GHG from smaller emission sources. To effectively use these satellites for monitoring over areas with very different emissions amounts of the same GHG, data products are needed combining data from different satellites. Large point source emissions should be calculated for the very small area they originate from. After deduction of larger point source emissions, the remaining lower area emission for areas surrounding the point sources need to be calculated and converted to emissions attributed to all delineated parcels.

3.2.4. Carbon Sequestration

Carbon sequestration can take place over short and long timescales. To return to a pre-industrial atmospheric carbon dioxide concentration within a century, only carbon sequestration taking place over short timescales are effective. Since the amounts of fossil fuel burned since the start of the industrial revolution are much larger the carbon stored in the world’s forests (above and below ground), prior to the industrial revolution and most lands on Earth are needed to grow food, growing trees can only store a small fraction of all carbon that needs to be removed from the atmosphere. This forest carbon storage will mainly take place in new and expanded *Environmental Conservation Organizations* (ECO) wildlife area. Most carbon will be removed using Direct Air Capture (DAC) followed by carbon sequestration (CS) deep underground. The DACCS amounts stored can be easily and accurately measured while pumped from above ground storage reservoirs to underground (basaltic) rock formations. Changes in carbon dioxide stored in ECO wildlife area can be measured using remote sensing *(39)*.

3.2.5. Fresh Water Consumption

Under natural conditions all fresh water precipitating over land follows a route through the watershed via rivers or as groundwater, where it supports freshwater habitats, and subsequently flows into the ocean, where is can support species assemblies that favor brackish habitats. On its route to the ocean, a fraction of the water evaporates from surfaces and is transpired by plants (evapotranspiration). Fresh water consumption is defined under IMACS as the amount of water that evapotranspired in excess of ecoregion vegetation evapotranspiration under the same conditions or leaves the watershed via a shortcut. Such shortcuts can be created by increased runoff (less soil infiltration) compared to the natural ecoregion vegetation, by pumping (fresh) wastewater out to sea, or by creating additional, shorter or faster routes for water to reach salt water (storm sewers & canals, canalized rivers, or rivers made shorter by cutting out bends). A water consumption equal to zero can be achieved under IMACS by withdrawing water from a source, using it, followed by quantitative return of the water to its source. For users not using utility provided fresh water, the water consumption is calculated as the excess evapotranspiration, corrected for difference of precipitation and infiltration and corrected for aquafer water pumped up from depths for amounts at which natural seasonal replenishments are insufficient. Hydrological models can be made per watershed using precipitation and evapotranspiration data *(40, 41)* and applied to all parcels. Excess evapotranspiration and shortcut amounts need to be corrected for the distance the water did not run through the watershed (the shortcut distance), including the brackish water section, such that the correction factor is unity if water is withdrawn at the upstream precipitation location and zero if withdrawn at the brackish water to ocean border.

3.2.6. Fresh Water Recycling and Reverse Osmosis Water

In order to minimize anthropogenic water consumption, all fresh water used should be purified in waste water treatment facilities, followed by recycling close to the point of extraction. To minimize water consumption, crops should be selected that match the water consumption of the original ecosystem vegetation, corrected for anthropogenic reductions in precipitation. In that case, irrigation could be limited to a few days each season. Agricultural areas with annual evapotranspiration of crops equal to the local mature ecosystem vegetation, can have reduced soil infiltration due to soil compaction below the tilling depth. Any excess surface runoff would be a reduction of the waterflow to the aquifer, representing a watershed shortcut and thus a water consumption. A small fraction of the daily fresh water flow of rivers and streams (10 to 20%) can typically be consumed without ecological risks. Detailed studies of natural daily water flows of all sections of rivers and streams are needed to determine whether and for which days more than 10 to 20% of the daily flow can be consumed without ecological risks *(42)*. Water consumption above moderate levels of ecological risks would need to be made up with reverse osmosis (RO) water, in order to render the water consumption sustainable under IMACS. Just as carbon sequestration is used to offset CO_2 emissions of products and services, the use of RO water can offset the consumption of fresh water when consumed at levels above moderate levels of ecological risks.

3.2.7. Remaining Environmental and Human Impacts

Coastal area used at risk of flooding can be treated as a subset of landscape types, overlaid with a flooding risk layer, reflecting the risk of flooding due to sea level rise over the next centuries. Using hundreds of thousands altimetry measurements, see levels and its changes can be measured with millimeter accuracy, when averaged over the globe *(43)*. The existing tidal gauges can be used to calibrate the satellite measurements *(44)*. All areas at risk of flooding need to be adequately protected against such flooding (the measure of conservation used). Since it is unlikely that much of the biodiversity of fresh water wildlife areas will survive salt water flooding, the dike failure probability of dike protected wildlife areas at risk of marine flooding needs to be extremely low. Elevations of floodplains relative to sea level can be measured using satellite system in combination with ground control points with an accuracy of about 2 m *(45)*. Combining satellite and GPS data can increase the accuracy for areas with vegetation to 0.26 m and without vegetation to 0.02 to 0.04 m *(46)*. Once elevations of coastal lands are accurately measured, the flooding probabilities in the required flooding protection systems can be calculated using existing methods *(47, 48)*.

Soil and surface water acidification leads to the disappearance of the more alkaline habitats and the species populations they support. Soil acidification can have different causes; acid rain, agriculture, leaching of Ca and Mg, organic matter decay, harvesting of high yielding crops, nitrification of ammonium *(49)*, while surface water acidification is caused by acid rain and water draining from acidified soils. Soil and surface water pH can be measured from space *(50)*, but data products will need to be developed to make the measured pH levels globally available.

Soil & sediment use and conservation could be measured using the above satellite system in combination with ground control points. Current systems may be sufficiently accurate to measure sediment losses of many meters (dredging of coastal or fresh water sediments), but will be more difficult to measure for the much smaller soil losses in farmer's fields (up to 15 ton/ha/y corresponding to 0.1 to 1.2 mm/y) *(51)*. Remote instrument systems need to be improved to accurately measure annual changes of this magnitude globally.

Atmospheric ozone layer damage and conservation can be measured though the atmospheric column *(52, 53)*. Emission locations of ozone layer damaging gasses are spread globally. Emission periods can be short (releasing the entire amount used in an AC system) or can be very small (leaks), leading to emissions "missed" or too small to measure from a specific parcel. It may be easier to monitor their manufacturing locations and to follow the buyers and users of these materials using reporting systems.

Human Impacts. The last three impacts listed in table 3 reflect impacts by humans on humans and need to be determined or measured by humans.

3.3. Assigning LBIs to Organizations and Individuals

Assigning Impacts to Areas
Satellite data are typically surface area based or degree squared based. Using the various satellite data products, landscape type, biodiversity, methane and CO2 emissions, vegetation-based carbon sequestration and fresh water consumption estimates are assigned to all global delineated parcels. Where no parcels ownership or use information is available, are data are recalculated to a 1 km x 1 km grid. For organizations, participation takes place at the location level (e.g., per store for a retail chain). For parcels used by the client, parcel IDs and/or delineation data are submitted to the IMAC organization with the participation application. For most organizations (and for individuals with much larger than average land holdings), the satellite-based impact data need to be IRO reviewed, possibly adjusted, and validated during an IRO visit to the location. All impacts for the delineated parcel are then assigned to the parcel as LBIs. LBIs need to be re-evaluated when impacts change. For micro-organizations and individuals with close to average or smaller parcels, environmental impacts are determined as for organizations, but IRA validations typically take place without visits.

Examples of LBIs determination

- Cultivated area use: In most cases, the cultivated area used for lots can be extracted from municipal or regional records. For organizations and single-family residences, the total lot size is assigned to the lot user as *property related cultivated area* (PRCA). For multi-family residences and office space, the area assigned to each residence or office is based on floor surface area, the number of floors of the building and the building footprint, such that the full building footprint is assigned to all floor space on a proportional basis. The remaining "yard area" around the building is also assigned to the residences and offices proportional to the floor surface areas per residence and included in the PRCA. All *common accessible cultivated areas* (CACA), like streets, roads and parks that are accessible to the general public at no additional cost, in a large circle around each parcel, are assigned to all parcels in the circle. This is done proportional to the above assigned PRCA area and is otherwise a function of the distance between the private property and the public area, such that all such public area is fully assigned to individuals or organizations. The LBI for cultivated area use is the sum of PRCA and CACA. For someone living in a 150 m2 apartment, the sum of cultivated area used for PRCA and CACA in a ten-story building is thus 1/10 compared to the same floor area used in a one-story building.
- Biodiversity and biodiversity losses: The remaining biodiversity found on urban lots is typically small compared to the biodiversity of the original ecosystems. Even so, it is worthwhile to support songbirds, bees, butterflies, other insects and as many other native species as possible. Biodiversity losses resulting from

removing trees and shrubs from urban lots can be measured using satellite data overlaid with cadastral maps. The same applies to biodiversity improvements. For small lots, the average biodiversity values for the larger surrounding area may need to be calculated and used for the lot.

- Greenhouse gas emissions: For individuals living in developed countries, the far majority of greenhouse gas emissions can be recorded with purchases made (consumption of power, fossil fuels and all other products and services). The same applies to organizations using office space. This leaves burning of locally found organic materials in stoves, fireplaces and firepits, representing a small fraction of overall emissions. Naturally fallen trees, branches and organic yard waste provide a habitat for various species, most of which will not be stored as soil carbon, but will digest to carbon dioxide and water. Consequently, carbon dioxide emissions resulting from burning these carbon sources are only slightly higher than their natural digestion equivalents and can be ignored. However, the corresponding air pollution from burning wood and other organic materials cannot be ignored and should be measured where possible.
- Fresh water withdrawal: Water utility provided drinking water is already metered; all impacts can be included with purchases made. The same metering needs to take place for non-utility supplies groundwater pumped up. For septic systems used, the leach field flow could be measured and deducted from the groundwater extracted to calculate the net fresh water consumption. This could potentially reduce the water consumption to zero. Similar to current utility water meters, both types of water flow data need to be transmitted to a common database.
- Soil and surface pollution. Municipalities and/or private organizations need to monitor groundwater pollution in local streams, lakes and rivers and trace the pollution sources back to their origins. The pollution must be assigned as LBIs to the individual using the area from which the pollution originated.
- Soil losses: All forms of anthropogenic soil losses must be assigned as LBIs to organizations and individuals using the area. For farms and other large land users, stormwater collection and settlement basins need to be used to collect solids. Solids need to be distributed over the fields they originated from. Some of the fertilizer and pesticides washed out can be returned to the fields with irrigation water reused. Remaining soil losses are measured downstream of the stormwater collection and settlement basins. Soil losses for individually used urban lots are typically small and are assigned to lot on a per surface area basis.
- Human conditions: Hours worked and salary paid must be determined and reported as LBIs at the working and living locations. Additional human conditions will be included once the organizations needed to determine these conditions have the capacity to do so.

Initial Use of LBI Estimates
Satellite data products need to be developed meeting IMACS requirements for easy data extraction by IROs. This requires a combination of data products that delineate landscape types (forests, crop fields, plantations, meadows, built-up areas), measure environmental impacts and combine these with existing environmental and civic databases (property records linking parcels to names and ID data of owners). Using such hybrid environmental and civic databases (HECD) and the software needed to process these data (see paragraph 3.1), conservative (higher than on average expected) estimates can be made for environmental impacts that reflect the use of natural resources or reflect damage done to natural resources. Initially such data products will not be available. In the meantime, best estimated data will need to be used. Starting with the first participating countries, global digital maps/databases can be made for resource using and damaging impacts as well as for environmental protective and restorative impacts. These conservative-resource using and damaging impact estimates, by default used for non-participating organizations, can be reduced for participating organizations during location visits by Impact Rating Organizations (IROs).

4. Results and Discussion

The Environmental Supply Chain Step (ESCS) calculations *(1-6)* require inputs of Location Based Impacts (LBI) representing environmental impact variable values. In order to minimize the costs of assigning LBIs to each particular ESCS and do so on a global scale, the use of remote sensing technology is essential.
In order to be usable under IMACS, E-impacts need to be assigned to a specific area (land parcels and marine designated areas) used by individuals or organizations. This requires delineation of such areas on maps where this is not yet accurately done. Remote sensing technology can strongly improve such area delineation, especially in developing countries. Based on the advances made over the last decades in remote sensing technology, area mapping, parcel delineation and the measurement of most environmental impact variables can be done using

satellites, by using aerial sensors or by using combinations. These impacts include landscape change and the subsequent use as cultivated area, changes in biodiversity, greenhouse gas emissions, fresh water consumption, soil and surface water acidification, soil & sediment loss, coastal area at risk of flooding, atmospheric ozone layer damage and includes all applicable types of conserving impacts, including wildlife area conservation, carbon storage and protection of coastal areas from flooding due to sea level rise. The delineation of parcels and the measurement of environmental impacts typically requires the development of models and the use of ground-based training data in order to link the primary measurements (reflected light or radar signals) to the desired environmental variable (ground cover type, parcel or structure delineation, biodiversity, greenhouse gas emission, carbon sequestration, fresh water consumption and soil and surface water acidification). Where needed to calculate the risk of flooding of coastal areas, the elevation of floodplains relative to sea level can be measured using satellite altimetry systems in combination with ground control points with an accuracy of about 2 m *(45)*. Combining satellite and GPS data can increase the accuracy for areas with vegetation to 0.26 m and without vegetation to 0.02 - 0.04 m *(46)*. For all remote sensing system for which environmental impacts are derived from remote sensed data, one or more models were developed and published. Each such data product was typically trained on a geographic example area. In order to be usable on a global scale, all such data products need to expanded to reach global coverage. The various remote sensing data products need to assign environmental impacts to all global land parcels and marine designated areas. Field verification of LBIs will be needed for organizations. All LBI related data need to be stored in IMACS databases and are in turn assigned to products made and services rendered (organizations) or are assigned to the individuals using the parcel. The largest fractions of impacts enter the supply chain with materials and products typically made by large organizations (i.e., mining, farming, fishing, fossil fuel extraction and processing). Since materials and products at the resource end have relatively low costs, the impacts per dollar costs are high. For end user consumers, most impacts enter their ISCS with products and services purchased and the fraction of impacts entering their ISCS as LBIs is typically small. Inaccuracies in LBI are thus important for large organizations and their products and services but have small and likely insignificant effects on the impacts for most individual labor outputs. Other than the accurate altimetry of water surface and depth, satellite remote sensing for monitoring freshwater and marine biodiversity is still challenging and research is ongoing to improve such methods *(28)*. Remote instrument systems need to be improved to accurately measure annual changes in soil levels for crop fields and meadows in order to calculate annual soil losses (anthropogenic erosion). Remote instrument systems have insufficient resolution to measure emissions and source locations of ozone layer depleting gasses. The remaining option is to monitor manufacturing locations and to follow the buyers and users of these materials using ground-based (mass balance based) reporting systems. Impacts related to prevention and mitigation of infectious diseases, human reproductive rates and human conditions fall outside the capabilities of remote sensing systems and will need to be determined by humans. Prior to the availability of data products capable of assigning environmental impacts to land parcels and marine designate areas, the LBIs could be estimated based on area type, per country or region (residential, commercial, industrial, agricultural, commercial forestry, fisheries, aquaculture, wildlife, biodiversity protected wildlife areas, etc.). For each of these area types, the typical impacts could be estimated (cultivated area used, greenhouse gas emissions, water extraction, wildlife area protected). To allow a faster start, a default automated LBI determination system needs to be created. LBI maps could be made be based on scientific literature or data bases for satellite image recognizable landscape types. Conservative (higher damaging) impacts could be assigned to areas by default and be reduced following a location visit by an Impact Rating Organizations (IROs). This system would not be dynamic, since environmental impact maps and civic databases would not be automatically or frequently updated, but could be used effectively until dynamic HECD systems are available.

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