Earth System Impact Metric
Excel Tool User Manual

The Earth System Impact (ESI) score is a tool that can allow investors to assess the planetary scale impact of assets, companies or portfolios. It is systemic, context-sensitive and science-based, and can be valuable for guiding improved decision-making.

The ESI Excel tool allows companies and investors to test the ESI metric using their own data, and gain further insights into the planetary-scale environmental impact of their activities.

Please note that this tool is currently a prototype. We advise caution when interpreting its results, and it should not be used to replace regulatory requirements. Given its focus on planetary-scale impacts, it also does not replace assessments of local environmental impacts, such as pollution or biodiversity impacts.

GLOBAL ECONOMIC DYNAMICS AND THE BIOSPHERE
THE ROYAL SWEDISH ACADEMY OF SCIENCES

Stockholm Resilience Centre
Sustainability Science for Biosphere Stewardship

Stockholm University

Table of Contents

About the tool 3
- Overview 3
- Data Requirements 4

Getting started 5
- Interface Overview 5
  - Input Tab 5
  - Error Messages 6
  - Results Table Tab 8
  - Results – Plot Tabs 9

Interpreting results 10
- What does the score mean? 10
  1. ESI as a comparative tool of Earth system impacts of assets or projects 11
  2. Using ESI to set context-sensitive, holistic targets 12
- Troubleshooting 13
- Dealing with missing data 14
- Limitations and Disclaimers 15

Support and Resources 16
- Relevant papers 16
- Team 16
- Contact Information 16

About the tool

Overview

The stability of the Earth's climate system depends on reducing GHG emissions while simultaneously bolstering the resilience of key regions (biomes) of the planet. Mitigating severe systemic risks related to climate change and concurrent nature degradation, therefore, hinges on our ability to rapidly reduce the harm incurred through economic activities.

The Earth System Impact (ESI) metric is a novel tool developed by researchers at the Royal Swedish Academy of Sciences, the Stockholm Resilience Center and the Australian National University. This tool calculates the impacts of an asset's economic activities on the Earth system. It aims to help investors and corporations improve their decision-making by allowing them to better assess the environmental impact of their portfolios and economic activities.

This manual accompanies the Excel *ESI_prototype_tool.v1*.

The ESI tool is:

- **Systemic**: it accounts for Earth system components other than climate (CO_2), specifically, water and land use, and most importantly, the interactions between these three
- **Context sensitive**: It incorporates the current state of human impacts on water and land in each region and vegetation type.
- **Science based**: it accounts for impacts and current states relative to scientifically estimated guardrails (i.e. relative to total availability).

Thus, the ESI tool incorporates aspects of biodiversity in two ways. First, land cover and freshwater flows are proxies for the state of biodiversity on land and in freshwater. Second, it incorporates some of the drivers of biodiversity loss through interactions between climate, land and water (moisture recycling).

For more details on how the prototype was developed, see Lade et al. 2021
For a short introduction to the ESI, see this brief, and for more information on how it can be applied by corporate actors, banks or other financial institutions, see Crona et al. 2023, which also includes a case study applying the ESI on a sample of mining companies.

Data Requirements

In order to calculate the ESI score for one asset, you only need four pieces of data:

1. Geocoordinates of the asset
2. Carbon dioxide equivalent (CO_2e) emissions (in metric tonnes)
3. Water consumption (in thousand m^3)
4. Land disturbed (in km^2)

If the exact geocoordinates are not available, an ESI score could still be calculated by providing the region and vegetation type in which an asset is located.

DISCLAIMER: This tool is still in the prototype phase. It is possible that other errors might be encountered, or that the steps suggested above do not help resolve the issue.

In these cases, we would love to hear from you so that we can further improve the tool. Please reach out to giorgio.parlato@su.se and explain the issue you are encountering.

Getting started

Interface Overview

The Excel tool includes four tabs:

1. **Info:** Includes information on all other tabs, general information about the ESI metric, and brief instructions on how to use the tool.
2. **Input:** This is the tab where you input information on each of your facility's coordinates and environmental pressures (CO_2e emissions, water consumption and land use).
3. **results_table:** This tab includes a table displaying the ESI results based on the input data.
4. **results_plots:** These tabs, display a plot with the breakdown of ESI into its three components. Facilities are displayed in descending order by carbon emissions (black line), allowing one to see the difference in impact if one is only considering carbon emissions as opposed to the ESI. The plot in the *results_plots_intensity* tab, is the same, except that it displays ESI intensity and carbon intensity.

Input Tab

This is the tab where users can input data about the facilities to be analyzed. The tool currently allows inputting information for 500 facilities. The ESI is calculated at the asset level, so inputting information for just one facility will be enough to obtain an ESI score.

The screenshot below shows what the tab looks like and gives some information about the input columns.

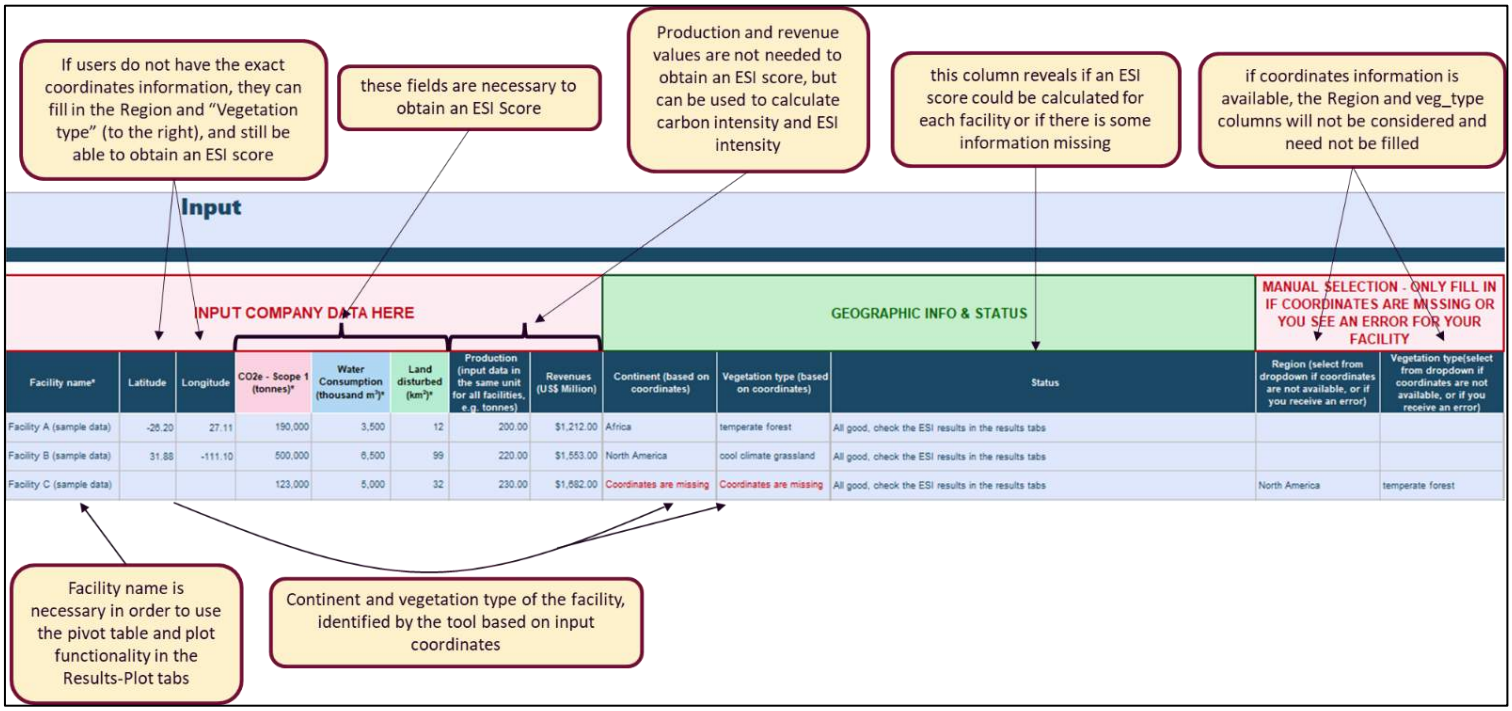

Figure 1. Input Tab – This tab allows users to input the necessary data to calculate an ESI score, plus additional information that could be used for further analysis

Error Messages

The ESI score of a given facility can only be calculated if the vegetation type where the facility is located can be clearly identified. The tool identifies the vegetation type of each facility by matching the coordinates provided by users with the vegetation map used by the ESI (for more info, check Lade et al 2021). In case the user encounters errors in obtaining an ESI score, we included in the tool specific error messages to help users understand the nature of the error and how it could be addressed. The figure and text below display and explain the four error messages that users can encounter on this tab.

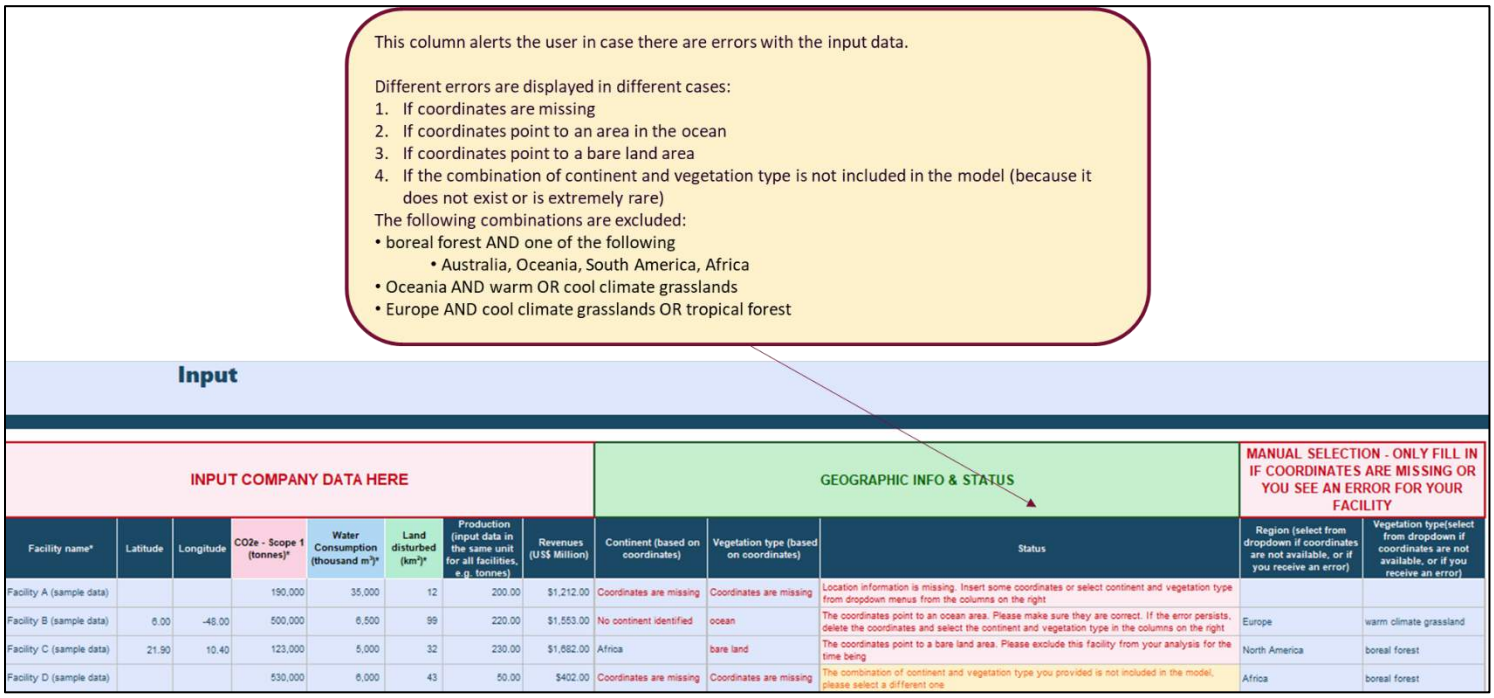

Figure 2. Error Messages in the input tab – Displaying the 4 possible error messages that could be displayed in the 'status' column of the input tab. These help users to understand why there is an error, and to correctly input the data necessary to calculate an ESI score.

Error message 1: "Location information is missing"

As the title says, this error shows up when the information about a facility's location is missing. This can be remedied by either:

- Inputting the geo-coordinates of the facility, or
- If coordinates are unknown, users can manually select a continent and vegetation type for the facility from the dropdown menus in the two rightmost columns

Note: If users both input geo-coordinates information, and manually select a continent and vegetation type, the tool will consider the coordinates and disregard the manual selection.

Error message 2: "Coordinates point to an area in the ocean"

The ESI score can currently only be calculated for land-based assets. If your asset is on land and you're incorrectly encountering this issue, we recommend double-checking your coordinates information. If the error persists, please select your continent and vegetation type manually, and feel free to reach out to giorgio.parlato@su.se.

Note: In some rare cases, it is possible that an asset on a small island or close to the coast receives this error. In such cases, please select the location information manually (region and vegetation type).

Error message 3: "Coordinates point to a bare land area"

If an asset is located in an area that is considered "bare land" by the model, this tool cannot estimate an ESI score for that asset. Bare land areas (deserts, mountain regions or ice-covered areas), may occasionally include fragile ecosystems that are important for biodiversity and other Earth system processes. Since we cannot, in the current version of the tool, model these ecosystems and therefore cannot provide a score, we advise users to exclude such assets from the analysis.

Error message 4: "The combination of continent and vegetation type is not included in the model"

If you did not input any coordinate information and instead manually selected the asset's region and vegetation type, the error you encounter is due to the selected combination not being included in the model. Some combinations of continent and vegetation type are not included in the model since they do not exist or are extremely rare. In this case we recommend double-checking that the inserted information is correct. These combinations are:

- boreal forest AND one of the following
    - Australia, Oceania, South America, Africa
- Oceania AND warm OR cool climate grasslands
- Europe AND cool climate grasslands OR tropical forest

Results Table Tab

The results table provides an overview of the data by displaying both the values input by users, and the values calculated by the tool. The formulas behind the ESI outputs calculated in this sheet are password-protected and cannot be edited. However, for users wanting to perform further analysis of the data, they can save the tab as a CSV file. Alternatively, the content of the table can be copied and pasted on a new, blank spreadsheet.

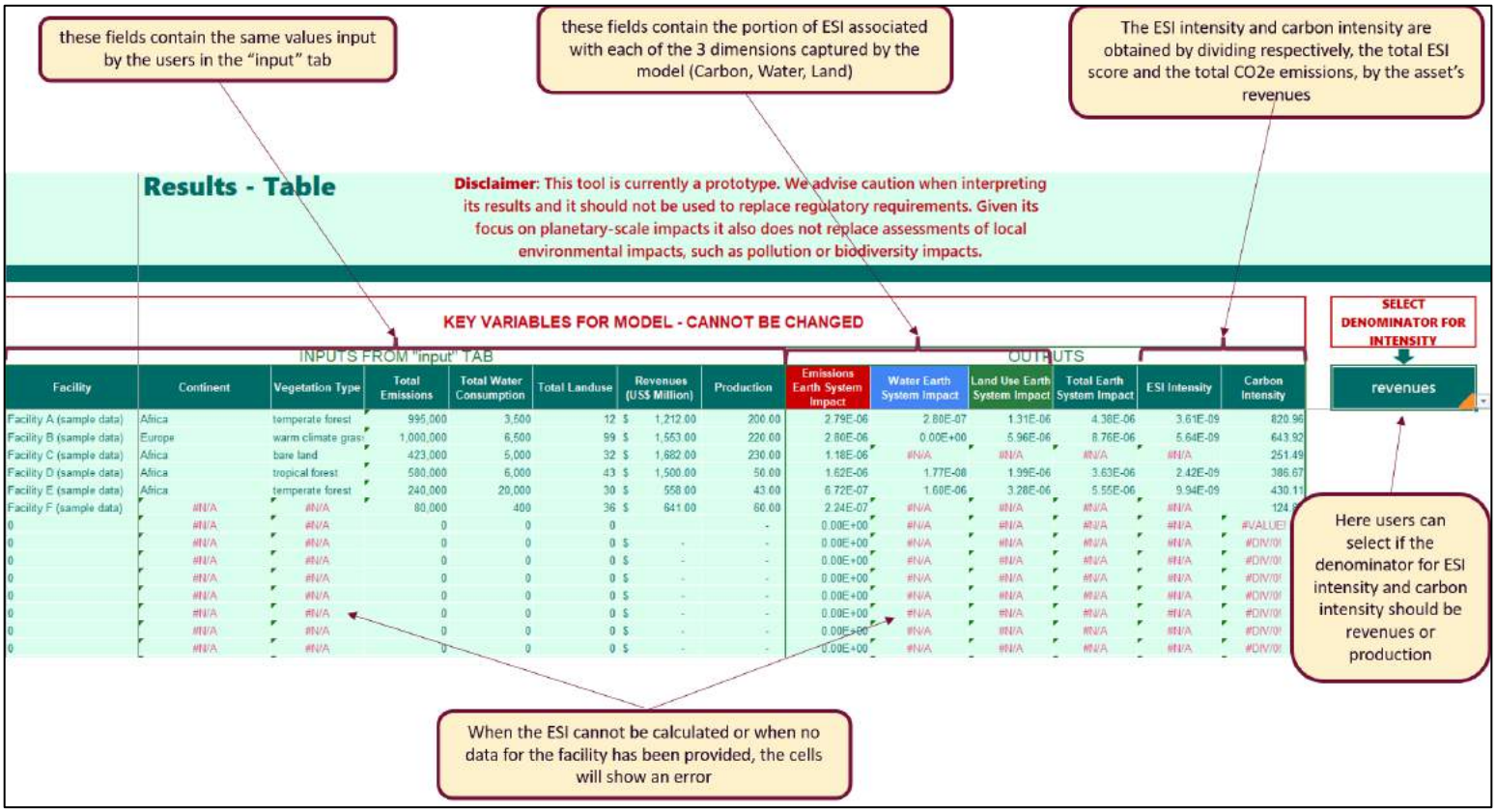

Figure 3. Results Table. Table with an overview of input data and ESI calculation for each facility

The ESI values provided in this table are calculated as follows:

$$\textbf{Carbon ESI} = emissions\ (tCO_2e/yr) * CO2\ ESI\ coefficient\ (this\ is\ the\ same\ across\ regions\ and\ vegetation\ types).$$

$$\textbf{Water ESI} = water\ consumption\ (10^3\ m^3/yr) * Water\ ESI\ coefficient\ (depending\ on\ regional\ location\ and\ vegetation\ type).$$

$$\textbf{Land ESI} = landuse\ (km^2) * Land\ ESI\ coefficient\ (depending\ on\ its\ location's\ region\ and\ vegetation\ type)$$

$$\textbf{Total ESI} = Carbon\ ESI + Water\ ESI + Land\ ESI$$

Results – Plot Tabs

These two tabs display plots that can help users make better sense of their data. The intuition behind the plots is similar, but they differ in the underlying data. Both plots display a version of the ESI score (in bars, broken down by each component), and carbon emissions (displayed as a black line, and associated to a secondary axis).

IMPORTANT: In order to see the plots relevant to your data users need to refresh the pivot table in the following steps:

1. **Make sure each facility was assigned a unique name (otherwise values of different facilities with the same name would be summed up)**
2. **Click anywhere on a pivot table**
3. **Go to the "PivotTableAnalyze" tab on top**
4. **Click on refresh**

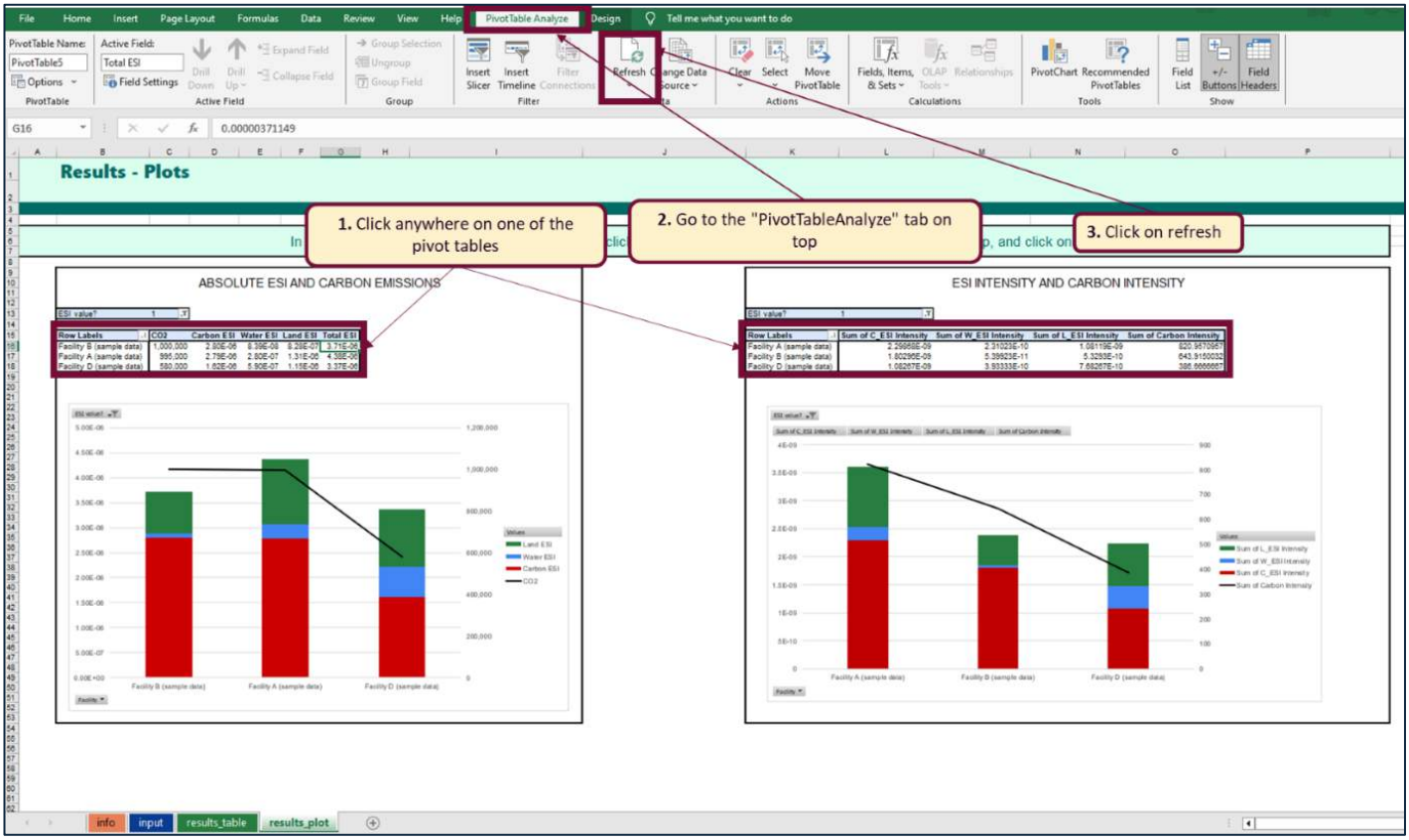

Figure 4. Results Plots. The tool will output bar plots displaying how ESI score measures (absolute ESI, and ESI intensity) compare to carbon measures (carbon emissions and carbon intensity respectively).

The screenshot above displays both plots in the same tab, while for ease of use we created a separate tab for each plot. The *results_plot* tab shows absolute measures of both ESI and carbon emissions, while the *results_plot_intensity tab* displays the corresponding relative measures (ESI intensity and carbon intensity) in relation to revenues or production (depending on what the user selects in the results tab). The intensity plot will only be displayed correctly if the user inserts revenue or production data; however, this is not necessary to obtain an ESI score. For an explanation of why ESI intensity may be relevant and important to examine, see the next section on interpretation of results.

Interpreting results

The ESI score captures a complex set of Earth System interactions and outputs an estimate of the impact on the Earth System, in total as well as on each of the three Earth system components (water, land and carbon) separately, when amplification of impacts caused by their interaction are taken account of. This makes the interpretation of ESI scores less straightforward than e.g. carbon emissions. This section, therefore, aims to dissect the ESI score and guide users on how to interpret it.

What does the score mean?

The ESI score is a metric that captures environmental impact at the Earth System level, in relation to regional guardrails (i.e. downscaled planetary boundaries to continental levels).

Since any single company or asset will contribute a small fraction of the total regional or global impact relative to these boundaries, ESI numerical values are usually much smaller than 1. This small number, however, does not represent a negligible impact.

Furthermore, like other measures of environmental impact (e.g. carbon emissions) which sometimes get divided by operational outputs (such as revenues or production) to obtain an intensity metric (e.g. carbon intensity), an ESI intensity score can also be calculated. ESI intensity would thus indicate the Earth System Impact generated by an asset for each dollar of revenue, or for each unit of output produced.

We note that relative intensity measures can be useful for comparing impact across different companies or assets. However, relative measures also come with a set of problems, further elaborated in Wassenius et al 2024.

Using an intensity version of the ESI score can nonetheless be useful for identifying which assets deviate from the general pattern of carbon intensity, since ESI intensity captures a broader set of environmental factors than merely carbon. It can, therefore, lead to different conclusions about what assets are the most harmful. For a longer discussion on this, and an example comparing carbon and ESI intensity for a set of mines, see Crona et al 2023.

For most companies or investors, the ESI score can be used in three different ways:

1. **Identifying the main drivers contributing to the impact of a given asset/company/portfolio**
2. **Comparing the total impact of different planned projects, assets, companies, or portfolios**
3. **Setting context-sensitive targets for environmental harm reduction**

In the following paragraphs, we will expand on each of these.

By construction, the *Total ESI* score incorporates three components, one for each Earth System component considered by the model (water, land, and carbon). Breaking down the total ESI score by its individual components can be insightful since it reveals

what is driving the biggest part of a given asset's environmental impact, thus helping to prioritize how to reduce impact.

This is why whenever we display a plot or a table of ESI scores, we make sure to include the information about all the ESI components, as shown in the example plot below.

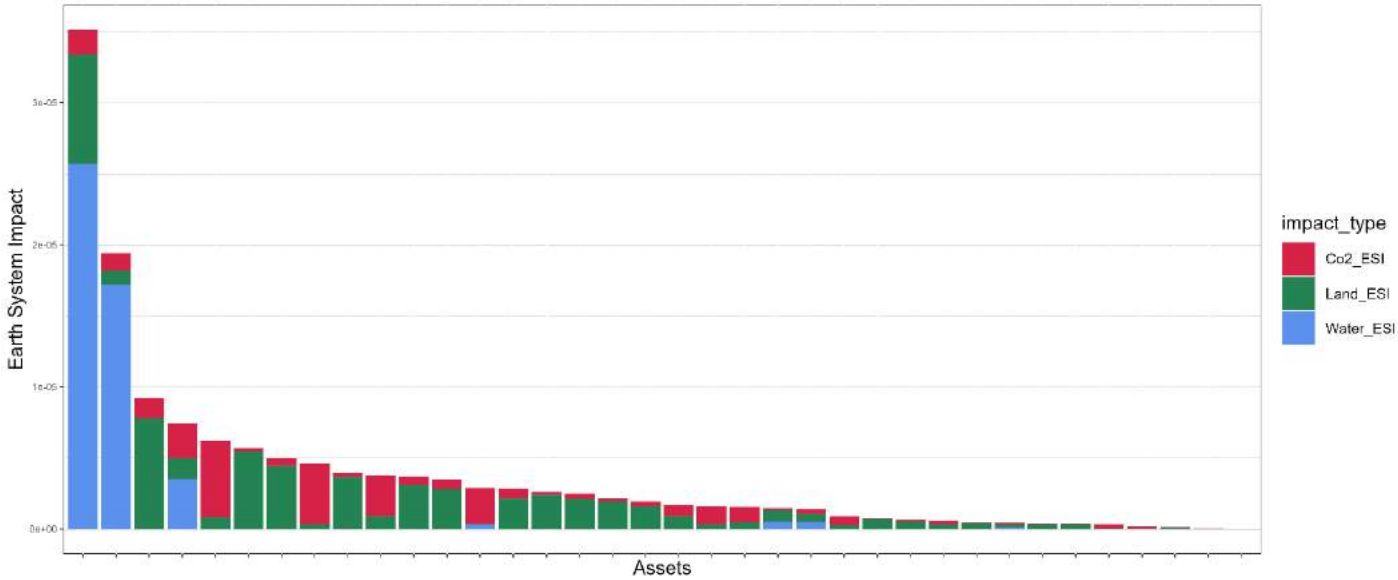

Figure 5. Sample Results. Example of the bar plots displaying the ESI score broken down into its three components

1. ESI as a comparative tool of Earth system impacts of assets or projects

Used in this way, the ESI is used as a relative measure, allowing decision-makers to compare the (Earth System) environmental impact of different investments. This could be done to decide in which kinds of projects to invest in, or to identify the most harmful investments or high-impact assets to prioritize mitigation actions. For start-ups or venture capital investors, this could also be used to assess different scaling trajectories and compare the impact of these trajectories under different sourcing policies. Below we offer two brief examples to provide an idea.

Example 1 – Equity investors

A coalition of investors wants to engage with a company well-known for its harmful impacts on the environment. As large shareholders, they obtain from the company the asset-level data needed to calculate an ESI score and use the ESI Excel tool to calculate the impact of all of the company assets. They find out that a small number of assets of the company contribute the majority of its ESI. In their company engagements, they encourage the company to prioritize mitigation activities in the most harmful assets, and to enact specific strategies to reduce the ESI components that most contribute to the overall impact. As different measures are set in place, the coalition would be able to measure the percentage reduction in environmental impact over time.

Example 2 – Financing and insuring specific projects

Banks and other lending institutions, providing debt capital to finance specific projects or green bonds, could start incorporating the ESI as part of their consideration of ESG factors. Aware of the systemic risks stemming from environmental impacts, they could begin by prioritizing financing projects with a lower expected ESI, while also raising the cost of capital for projects with a higher ESI.

In a similar way, insurance companies, that are highly exposed to systemic risks, could start including the ESI score as one of the factors determining the issuance and costs of insurance coverage.

2. Using ESI to set context-sensitive, holistic targets

Due to growing public concern about mitigating climate change, many large corporations have begun setting ambitious targets regarding the carbon emissions generated by companies' activities. Since carbon emissions have the same impact on the Earth System irrespective of where the emissions are generated, companies have been reporting CO_2 and setting targets at the company (HQ) level. However, with the increasing awareness of the importance of protecting and restoring nature and staying within Planetary Boundaries, it becomes necessary to account for the location and context of where other environmental impacts are happening.

By construction, the ESI metric is context-sensitive and relies on asset-level data. Thus, the ESI enables companies to set company-wide targets while taking into account how the location of environmental pressures affects the impact these have on the Earth System.

Concretely, this could mean that a company committing to reduce its overall ESI by 30% would need to assess which of its assets are having the most impact, and what is driving their ESI score. This could then support the development of specific mitigation plans for different assets/facilities based on their locations and impact.

Setting ESI targets and identifying asset-level contribution to the total company ESI could also guide and influence companies' expansion plans. For example, setting up new plants in areas with a high Land ESI impact may significantly increase company ESI. As such, the tool could be used both to guide internal strategy or investment decisions within companies, or guide investors in their assessment of investee companies and their likely adherence to/alignment with publicly set targets.

Troubleshooting

In order to calculate the ESI of individual facilities, the Excel ESI tool needs to identify the relevant ESI coefficients of each asset. ESI coefficients for Land and Water depend on the location data provided (coordinates, or combination of vegetation type and region).

As mentioned, the input tab includes an error column that provides guidance in case there is an error in the data inserted. If you cannot manage to resolve the error you encounter, follow this list of steps to troubleshoot and find the source of the issue.

1. Make sure that all the necessary input data for the facility have been filled in. Necessary fields are:
    a. Scope 1 CO_2e emissions
    b. Water consumption
    c. Land disturbed
    d. Coordinates (or a combination of vegetation type and region)
2. Double-check that the coordinate information provided is correct
3. In rare cases, errors could occur even if an asset is not located in a bare land area. For example, an asset in a coastal area, could, in some cases be mistakenly considered in an ocean area. This is due to the 0.5x0.5 degrees grid used by the model. In this case, if one is certain of the correct vegetation type of the asset's location, they can delete the coordinates and manually select the region and vegetation type from the rightmost columns of the input tab.
    a. However, we advise manually assigning a vegetation type to an asset only when one is certain that vegetation type accurately describes the ecosystem in which the asset is located.

If the Results_Plot Tab does not display any plot, or only shows one or few assets

1. Make sure that each asset was assigned a unique name in the Facility name column
    a. The plot and pivot table differentiate different assets based on their names. Therefore, if two or more assets have the same name (even if blank), the plot will display the sum of the ESI scores for all those facilities

DISCLAIMER: This tool is still in the prototype phase. It is possible that other errors might be encountered, or that the steps suggested above do not help resolve the issue.

In these cases, we would love to hear your feedback so that we can further improve the tool. Please reach out to giorgio.parlato@su.se and explain the issue you are encountering.

Dealing with missing data

It is not always easy or possible to obtain accurate data about an asset's environmental pressures. One way to estimate such missing data is to use Life Cycle Analysis (LCA) factors relevant to the products produced by your asset. Such factors usually estimate the average environmental pressures generated by producing a certain amount of a product.

Below are some tips on how to find reliable sources for LCA factors, and an example.

Finding reliable sources for LCA factors

1. Determine the product(s) produced by your facility and the environmental pressure to be estimated (in the case of the ESI model, it is going to be CO_2e, water consumption, and/or land use)
2. Search the academic literature and LCA databases (such as Ecoinvent) for relevant studies
3. When you identify a relevant study, make sure that the system boundary matches that of your facility (e.g. copper mining, or growing corn), instead of including the full life cycle of a product (e.g. copper wires or canned corn). In this regard, it is important to distinguish between cradle-to-gate, gate-to-gate, and cradle-to-grave (which include the impact of consumption and disposal) studies, and select the one most appropriate to one's use case.
4. Prioritize factors published in peer-reviewed journals

Example: Finding carbon emissions and water consumption of LCA iron mining

1. We search Google Scholar for "LCA iron ore mining carbon emissions" and "LCA iron mining water consumption"
2. The first result we obtain in the search is "*Ferreira, Hélio, and Mariangela Garcia Praça Leite. "A Life Cycle Assessment study of iron ore mining." Journal of cleaner production 108 (2015): 1081-1091. https://doi.org/10.1016/j.jclepro.2015.05.140*"
3. We confirm that the study's scope only includes the mining part of the process, without considering further downstream processes (such as steel production). Indeed, the paper mentions "*The scope of this study considered all impacts generated from the steps of ore mining (cradle) to the final delivery of concentrated ore (gate)*." Thus, the study does not include further processing of iron into other products.
4. Scanning the paper, we are able to find a factor for both water consumption and CO_2e emissions
5. We note that water consumption is expressed in m^3 for every 1kg of iron ore produced (Table 1), while GHG emissions are expressed in kg of CO_2e for every tonne of iron concentrate produced (Fig. 10)
6. Once we have these factors, we can multiply them by the production output of our facility to obtain an estimate of their environmental pressures.

Limitations and Disclaimers

While the ESI score could be seen as an improvement to current practices to assess environmental impact, it is important to be aware of its limitations, and the need to integrate its use with other measures.

1. **The ESI is regionally aggregated and focuses on impacts at a planetary scale.** While the metric captures some aspects of biodiversity, it does not replace assessments of local environmental impacts, such as pollution or biodiversity impacts.
2. **The score captures only three Earth system components, and four of their interactions.** Further modelling work could integrate more planetary boundaries, more interactions among them, and more detailed representations of Earth system components (e.g. accounting for green water or GHG gases other than carbon)
3. **The score accounts for activities that take us closer to scientifically estimated guardrails but does not currently account for the amplifying environmental effect of crossing these potential tipping points**. Thus, ESI may underestimate the impact in regions that are currently close to tipping.
4. **While the metric is based on CO_2 emissions, companies tend to report CO_2e** (where the "e" stands for equivalents) – a measure that expresses the impact of each different greenhouse gas in terms of the amount of CO_2 that would create the same amount of warming. Using CO_2e in the metric works for all interactions captured in ESI except for the effect of increasing temperature on land cover through photosynthesis, where only CO_2 is relevant. We do note that this could lead to some overestimation of the landcover impact for companies whose emissions have a larger component of non-CO_2 emissions, such as coal mining companies. Accounting for non-CO_2 emissions is a high priority for future development of the score.
5. **It is necessary to periodically update the underlying data upon which the score was built**. The data used to calibrate the 'current state of the Earth System' in the score outlined here refers to the last available appropriate dataset from 2013 and would need to be regularly updated. Further, the planetary boundaries considered in the construction of the metric refer to the 2015 planetary boundaries paper (Steffen et al 2015). An updated version was published in 2023 (Richardson et al, 2023) and remains to be integrated.

We welcome suggestions for future development of the score (see contact information below)

DISCLAIMER: This tool is currently a prototype. We advise caution when interpreting its results, and it should not be used to replace regulatory requirements. Given its focus on planetary-scale impacts, it also does not replace assessments of local environmental impacts, such as pollution or biodiversity impacts.

Support and Resources

Relevant papers

1. Lade, Steven J., et al. "**Human impacts on planetary boundaries amplified by Earth system interactions.**" Nature sustainability 3.2 (2020): 119-128. https://doi.org/10.1038/s41893-019-0454-4

2. Lade, Steven J., et al. "**A prototype Earth system impact metric that accounts for cross-scale interactions**." Environmental Research Letters 16.11 (2021): 115005. https://doi.org/10.1088/1748-9326/ac2db1

3. Crona, Beatrice, et al. "**Going beyond carbon: An" Earth system impact" score to better capture corporate and investment impacts on the Earth System**." Journal of Cleaner Production 429 (2023): 139523. https://doi.org/10.1016/j.jclepro.2023.139523

Team

Beatrice Crona
Global Economic Dynamics and the Biosphere (KVA),
Stockholm Resilience Center

Steve Lade
Stockholm Resilience Center,
Australian National University

Giorgio Parlato
Stockholm Resilience Center

Ingo Fetzer
Stockholm Resilience Center

Sarah Cornell
Stockholm Resilience Center

Contact Information

For any questions, feedback or inquiry, please send an email to giorgio.parlato@su.se

Try the tool here!