Introduction to Sustainability Analysis

The Human-Technical-Environmental (HTE) Systems Framework and its associated matrix-based approach provides a four-step process to analyze sustainability issues from a systems perspective.[1] The HTE framework and the matrix-based approach help analysts to identify the most important components of a system, classify and examine interactions among these components, and inform efforts to identify interventions that can advance sustainability. By using a common framework and approach, those analyzing sustainability challenges can structure their analysis of complex problems, and compare insights across many different topics and cases. The approach has shown to be particularly useful in analyzing systems in which material flows are prominent, but is generalizable to a broad range of different types of sustainability problems.

System Components

The first step is to identify the relevant human, technical, environmental, institutional, and knowledge components that are important for systems analysis. In the discussion below, sample components of each type are identified by italics. An example of a table of system components is shown as Figure 1.

Individual components are the building blocks that determine the state, structure, and function of a system at various points in time. Analyzing a problem from a systems perspective requires deciding which components to include and which to leave out of the system description. The identified components need to capture important system dynamics, but they also need to be few enough to allow for applied analysis of system operations and outcomes.

Aim to identify no more than 5-7 components of each type, potentially fewer, for a first round of analysis. If you find yourself needing more, think about whether your topic could be narrowed, or whether components could be usefully aggregated together. On narrowing the topic: if your focus is on waste, for example, rather than looking at all kinds of wastes in large geographical area, it may be more useful to look at only one category of waste, possibly also in a smaller geographical area. On aggregating components, rather than treating different kinds of wastes as individual components, it may be possible to combine these into one system component.

The framework identifies five different types of components: three are material component types (*human*, *technical*, and *environmental components*) and two are non-material component types (*institutional* and *knowledge components)*. Each material and non-material system component of the HTE framework has associated attributes, which describe the component in space and time (for example, an attribute can be a location, age or date, or other similar metric).

Human components are people living in different places and under varying circumstances. It is often useful to analyze groups of people with similar interests and characteristics. Examples could include *workers* in different occupations, *residents* of particular areas, *producers and consumers* of goods or services, or demographic groups such as *children*. People have both physical attributes (such as their genetic conditions and age) and social attributes (such as occupation, education, and level of income).

Technical components consist of infrastructure and material artifacts of human society. They might include infrastructure such as *roads, electricity grids*, or *factories*, technologies such as *pollution control devices*, or manufactured products in commerce (e.g. *single-use plastics*). Technical components have attributes related to their mass, quantity, and operational efficiency.

Environmental components consist of Earth's life-support systems and the biosphere, including all living organisms in aquatic and terrestrial ecosystems such as *fish*, *mammals*, or *trees*. They can also be non-living things: geological resources such as *minerals*, *oceans*, the *atmosphere*, or *polar ice caps*. Attributes of environmental components include their physical properties and biological characteristics.

Institutional components are social structures of rules, norms, and shared expectations that shape the behavior and interactions of material components. These could include, for example, laws and regulations such as global treaties (e.g. the *Framework Convention on Climate Change* or the *Minamata Convention on Mercury*) or domestic laws (e.g. the U.S. Clean Air Act). Rules and norms such as *markets* and voluntary agreements such as *sustainability certification schemes* are also institutional components. Importantly, institutional components are not the organizations themselves, which are treated as either collective human components, or interveners (actors) below. That is, where a certification scheme would be an institutional component, the organization that administers it would not be one. Attributes of institutional components include their scope and stringency.

Knowledge components involve information about the other components and their interactions. New knowledge can reveal, and a lack of knowledge can obscure, important connections and dynamics within a system. Knowledge can relate to *inventories* of resources or pollutants*, health or environmental damages,* or *techniques* for production or pollution control. Attributes of knowledge components include the awareness of, or the degree of certainty or uncertainty about, specific data and information.

Interactions

The second step identifies the interactions between the material components, in the context of the non-material components. See Figure 2 for a sample full interaction matrix, and Figure 3 for a qualitative summary. Figure 4 shows how a flow chart can capture pathways of linked interactions.

a) Create an *interaction matrix* by identifying which material components influence each other in the context of the non-material components

Create a matrix (a square table of rows x columns) by putting each material (human, technical, environmental) component in a row entry as well as a column entry.

For each material component in a given row, identify any other material components which it influences, and note that interaction in the column that corresponds to the second component. Components can also interact with themselves, representing dynamic processes. Record the non-material (institutional, knowledge) components that affect each interaction. See **Figure 2** for an example.

It can be useful to describe these interactions qualitatively in general terms. Think of a sentence that describes what is happening – for example, an interaction in which *consumers* interact with *single-use plastics* might be summarized as "consumers purchase single-use plastics." This interaction takes place in the context of *laws and regulations* – for example, a municipality might have an existing plastic bag or plastic straw ban, which will affect the consumers' ability to purchase those items.

You might find in describing an interaction that you are missing a key component, that a component you identified in step 1 is not necessary to describe critical behavior, that single components need to be separated into two or more, or that multiple components should be aggregated to facilitate further analysis. In that case, you should return to step 1 to revise your list.

Once you have determined all of the components and relevant interactions, fill out a matrix such as that illustrated in **Figure 3** that includes the qualitative sentences associated with the interactions. Write the text describing the interactions that you have identified in the appropriate box indicating which types of material components are involved.

For those who are more mathematically inclined, you can think of the interaction matrix as providing a sort of first derivative of the system of equations. If each interaction could be quantified, the interaction matrix would specify how a change in one component influenced a change in another component.

b) Identify the pathways through which components influence each other.

Once you have identified the interactions, identify 2-3 key interactions that are most relevant to sustainability. Then trace pathways through the matrix by identifying interactions connected to that outcome. Pathways can be linear (for example, in Figure 2, where H_1 influences T_1, which in turn influences E_1), or they can incorporate multiple causality (both T_1 and T_1 influence E_2), or reciprocal interactions/feedbacks (H_1 influences E_3; E_3 influences H_1).

Creating a pathway diagram using the short sentences you used to describe the actions in the interaction matrix can help visualize these causal linkages. You can do this by hand, but one way to produce these in an automated way is by using graphviz (see link under Figures below for an example online). In **Figure 4**, an illustrative pathway diagram is presented showing the linear, multi-causal, and feedback pathways described above.

Note that in Figure 4, the boxes represent interactions, and the arrows links between these interactions (which is different from traditional box-and-flow diagrams, where boxes indicate stocks and arrows indicate flows).

Interventions

In Step 3, identify interveners – actors that can modify interactions in the system, and create a matrix that shows which interactions they can influence and how. Figure 5 shows an aggregated, qualitative intervention matrix.

Interveners might include *national and local governments*, *international organizations*, *industry groups*, *environmental organizations*, *producer organizations*, or *consumers*.

Note that there might be some overlap between interveners and system components, in particular for humans (e.g. consumers). From a conceptual perspective, the HTE framework treats actors as interveners when they consciously try to modify system behavior or operations. Thus, consumers can be interveners when they organize (e.g. to collectively boycott certain producers), but their purchasing habits in general would be represented as interactions. This raises a question of timing: once an intervention occurs, its change then becomes part of the regular system operation, and would be treated as an interaction. Thus, depending on the temporal extent of your analysis, there might be some overlap in classifying interactions vs. interventions that occurred in the past.

For each intervener, identify at least one intervention – a way in which they can act to modify the system components and/or their interactions. This might involve adding, subtracting, or modifying institutional or knowledge components. For example, in the example interaction given above, an actor such as a government can make (or repeal) a law about plastic straws, which would alter the interaction in which consumers purchase single-use plastics.

Note each of the potential interventions in the associated matrix square in a short sentence (e.g. "local government bans single-use plastics"). **Figure 5** shows an example of the types of interventions which might appear under each category.

Insights

The fourth and final step is to draw insights from the analysis, by examining the interaction and interventions.

The results of the matrix-based approach can be used to examine issues of relevance to sustainability. For example, you might think about whether different interventions would bring a system closer, or further away, from sustainability – and reflect on different ways in which that could be defined with relevance to the system you are studying. You could assess, and perhaps model, the dynamics of the system, examining the evolution of system behavior, examining nonlinearities and modes of adaptation over time. One area of particular interest is to look at how systems might transition or transform, and the prospects of different interventions to lead to such changes. Examining how systems are governed (or not) can inform recommendations for policy and decision-making.

You might think about the following questions to structure your analysis:

→ What are the relevant spatial scales of the issue? Are different components, their interactions, or those who intervene, occurring in specific places, or at different levels of governance (local, national, regional, global)? Do physical processes or policy efforts at one level influence others?

→ How have interactions changed with time, and on what timescales? Are there shorter and longer processes happening? Do they interact?

→ Which actors have the largest ability to make change, and why? Which have the least? What are the prospects for different actors working together?

→ What actions would you recommend to maintain and enhance human well-being for present and future generations? Who do you think should take these actions, and why?

Figures

To create your own figures in this format using fillable pdfs, you can download templates at the following web site:

https://www.mercurystories.org/hte-framework

Human components	Technical components	Environmental components
People/groups of people (e.g. consumers, workers, children)	Infrastructure (e.g buildings, roads, bridges, manufacturing plants, communication networks) Products in commerce	Non-human living organisms (fish, mammals, trees, etc.) Geological resources Ecosystems and their components: atmosphere, oceans, lakes/rivers, land

Institutional components	Knowledge components
National and local laws and regulations International treaties Markets Voluntary guidelines	Scientific information or data Techniques (e.g. for production, pollution control)

Figure 1. System Components.

	H_1	T_1	T_2	E_1	E_2	E_3
H_1		I_1, K_1				I_3
T_1				I_4	I_2, K_2	
T_2					K_4	
E_1				K_3		
E_2						K_4
E_3	K_5					

Figure 2: Detailed matrix of interactions. This system, for illustration purposes, has one human component (H_1), two technical components (T_1 and T_2), three environmental components (E_1, E_2, E_3), four institutional components (I_1 through I_4), and five knowledge components (K_1 through K_5). Shading in a box indicates that an interaction occurs with the component in the row influencing the component in the column. Interactions among the material (human, technical, environmental) components occur in the context of specific institutional and knowledge components (the specific institutional and knowledge components involved are noted in the shaded boxes that illustrate the interactions).

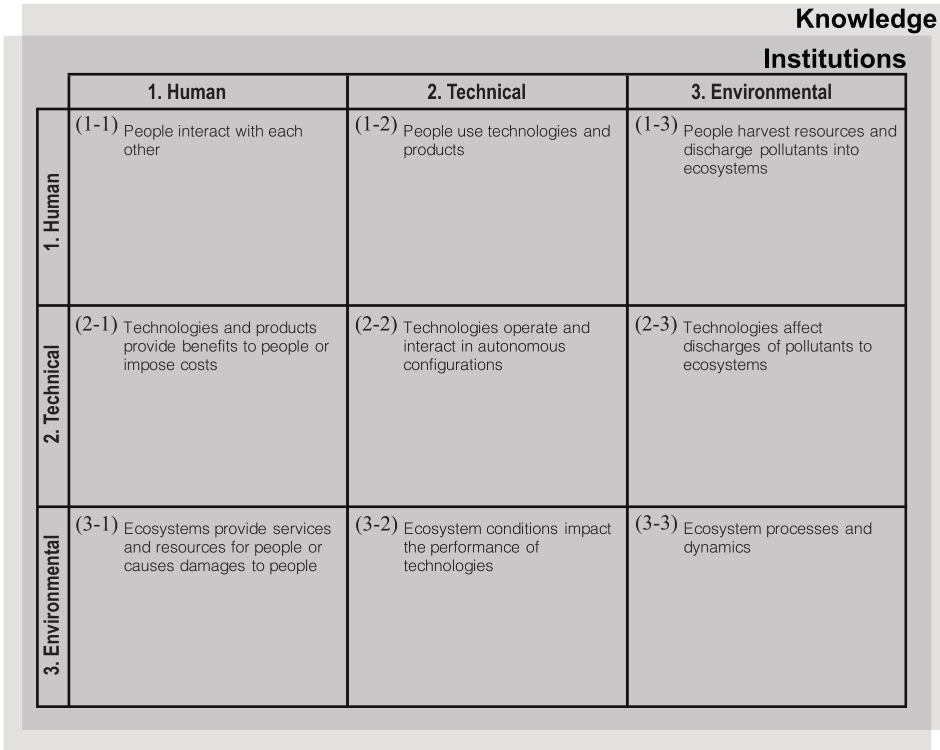

Figure 3: Qualitative interaction matrix. Each interaction is described in a brief sentence, which is written in the relevant category of interactions. In this figure, the type of interactions located in each category are described in the text.

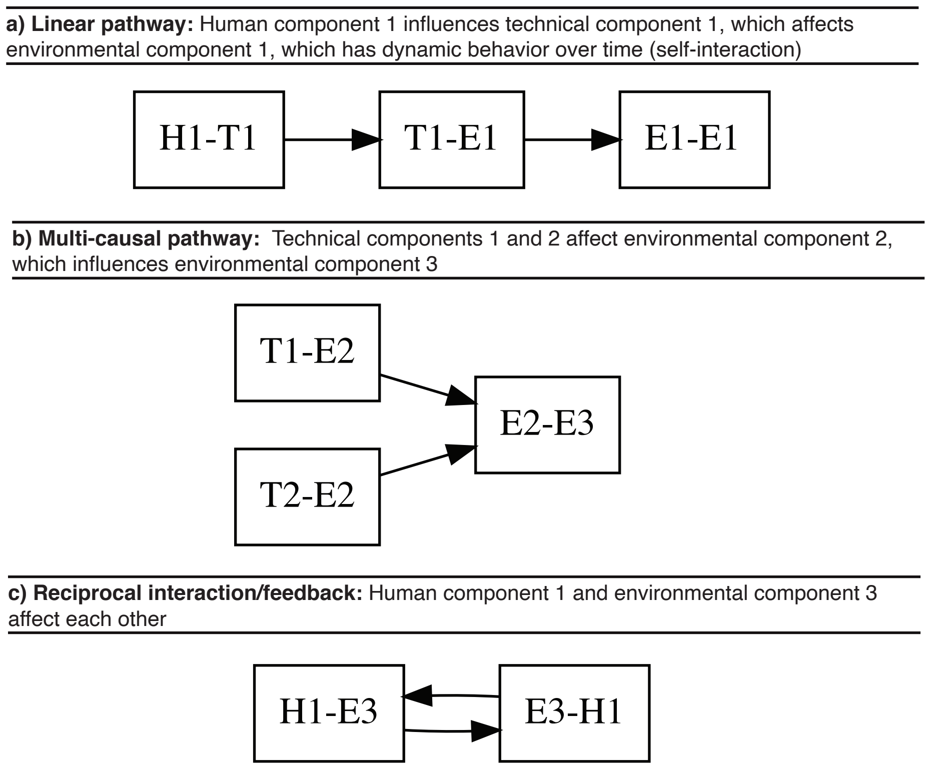

Figure 4: Diagram of pathways, showing types of pathways, based on detailed matrix in Figure 2.

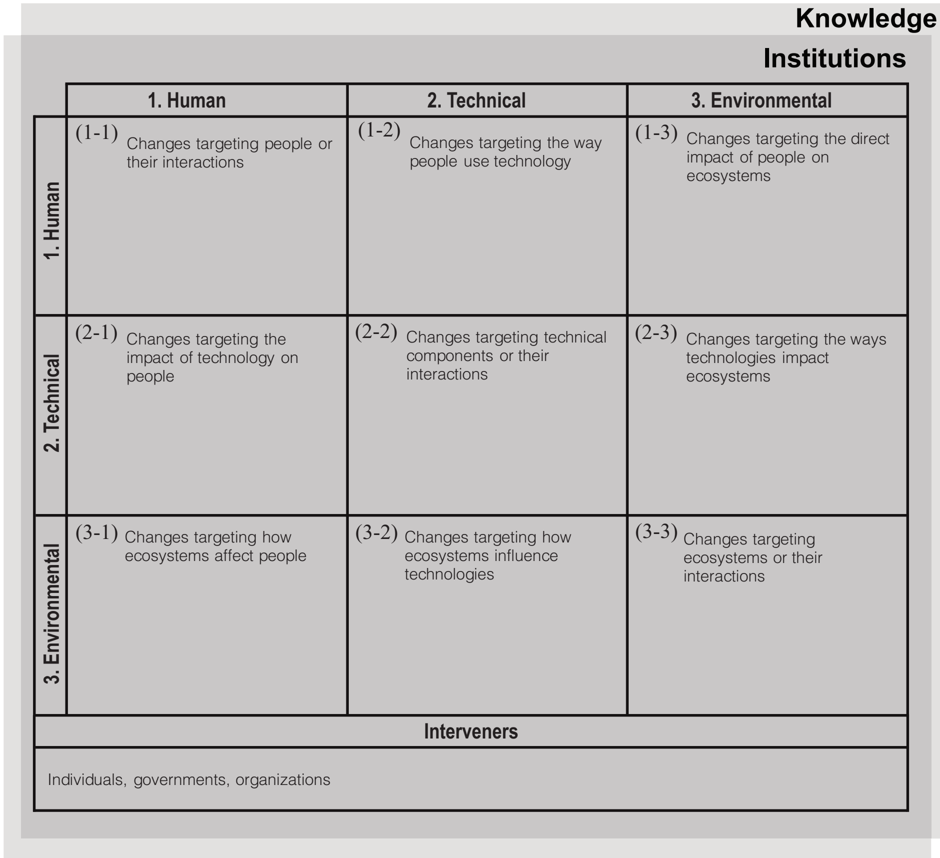

Figure 5: Intervention Matrix showing interveners and categories of interventions.

References

1. Selin, H. & Selin, N. E. *Mercury Stories: Understanding Sustainability through a Volatile Element*. (MIT Press, 2020).