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Document description:	This document describes the main definitions of societal metabolism and the formal theoretical models, their advantages and disadvantages and how the theoretical notions of flows of energy and material can be translated to elements of everyday life. It contains links to videos, pictures and interactive exercises that clarify the definitions and elements with the purpose of helping students understand the complexities of modern urban systems.

Disclaimer
This project has been funded with support from the European Commission. This publication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

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1. Introduction

Societal Metabolism is equally an approach and a framework, a way of looking at how society interacts with the environment by analysing the flow/exchange of materials between society and the environment (Fischer-Kowalski and Huttler 1999) in an effort to increase the sustainability of the way society provides for its basic needs. Figure 1 below illustrates a very simple conceptual model of the Societal Metabolism framework.

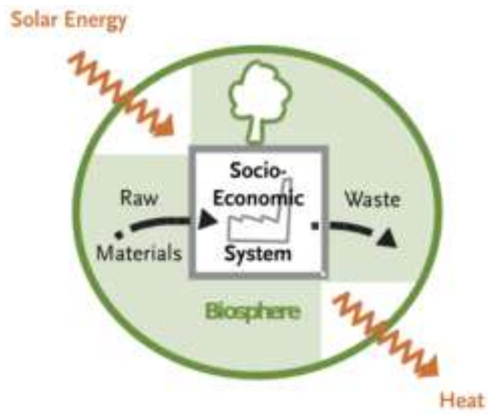


Figure 1. Social metabolism describes the exchange of energy and materials across social and environmental systems.

Human-controlled material and energy flows between nature and societies are a basic feature of all societies but their magnitude and diversity differ from culture to culture. The set of such flows that occur between nature and society, between different societies, and within societies are defined as societal metabolism. The term is also referred to as social metabolism, or socioeconomic metabolism.

Over the last decade, the concept of Social Metabolism has gained reputation as a theoretical instrument for the required analysis at different scales in space and time. By looking at the sets of flows of materials and energy that occur between nature and society, between different societies, and within societies, it is useful in addressing multiple sustainability challenges posed by the increase in human population, economic activities, environmental impacts, and urbanization.

1.1 Background and need of Societal Metabolism an integrative approach towards development

Population in the world is currently approaching 8 billion, growing at a rate of around 1.09% per year (World Population Clock 2018). While in 1804 there were just around 1 billion people on the planet, estimates show that it is soon expected to reach the 10 billion milestone. Figure 2 illustrates how world population has changed since 1800 until today, and its projected increase until 2100.

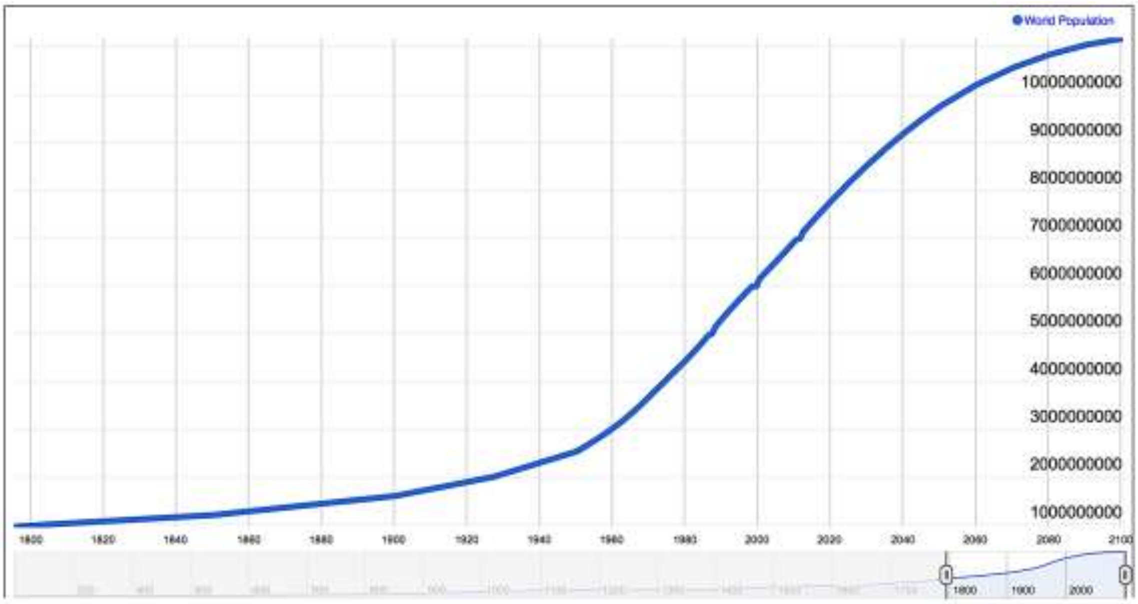


Figure 2. Change in world population throughout history. *Image source: [Worldometers](), based on United Nations data.*

Everyone in any society needs water, food, shelter, green space, and mobility, and in order to have access to those commodities they simultaneously produce waste and consume resources. In fact, the levels of consumption of natural resources have been increasing on average both at the per capita and global levels (figure 2). Figure 3, for example, shows how the estimated global water use has changed from 1900 to 2016. In figure 4 the increase in production/consumption of food globally is expressed as the increase in food supply (kcal) per person per day from 1961 to 2012. When the per capita increase is combined with the growing population, the picture becomes even more revealing. Besides that, all household, industrial, agricultural and other activities carried out to meet the demands of a growing population requires energy resources. Figure 5 shows the change in global energy consumption trend from 1990 to 2016.

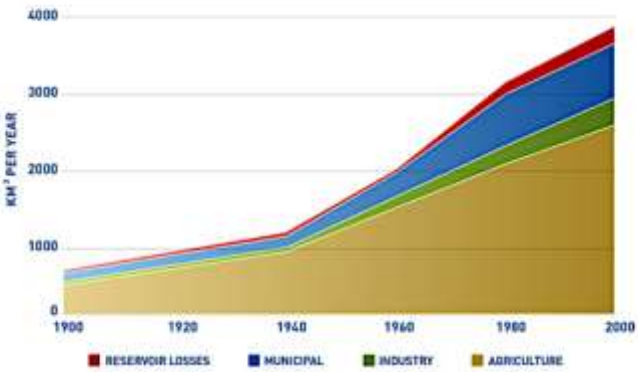


Figure 3. Estimated global water use from 1900 to 2016. *Imagesource: [UN Food and Agriculture Organisation]()*

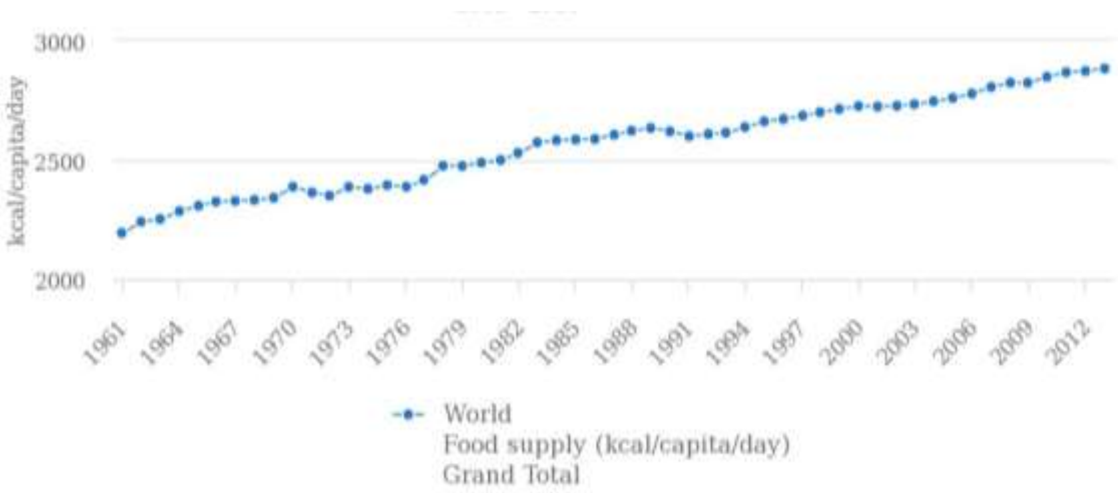


Figure 4. Food supply in the world from 1961 to 2012, expressed in kcal produced per capita per day. *Image source*: *FAOSTAT*

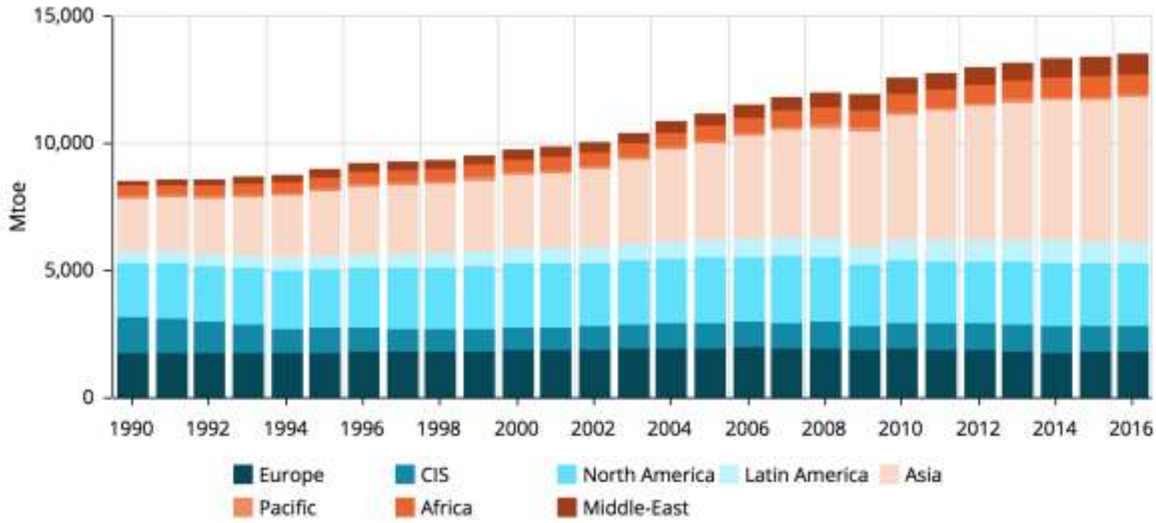


Figure 5. Global energy consumption trend from 1990 to 2016. *Image source: Enerdata Global Energy Statistical Yearbook 2017*

Meanwhile, although all people have the need and right to live in clean, healthy and safe environments, the levels of pollution, and connected environmental degradation in many areas on the globe has been increasing. Since the start of the industrial revolution in the 19th century, environmental pollution has grown into a global transboundary problem that affects air, water, soil and ecosystems. These, in turn, are linked directly to human health and well-being. Pollution is linked to three main human activities: ***fossil-fuel combustion***, primarily by industry and transport; the application of ***synthetic fertilisers and pesticides in agriculture***; and the growing ***use and complexity of chemicals***. Figure 6 depicts the change in global CO_2 emissions from 1751 (before the Industrial Revolution) to 2015. CO_2 is one of the main outputs from fossil fuel consumption. It is equally one of the main Greenhouse Gases (GHG), which contribute to global climate change. Alongside growing emissions, the area of forests has been steadily decreasing. Figure 7 shows how the forest area as percentage of total land area has been decreasing in the world between 1990 and 2015. Forests play a key role is CO_2 absorption, as they reduce the CO_2 concentration in the atmosphere. The bigger the

CO_2 concentration in the atmosphere, the bigger the effects and impacts of climate change on our society and the environment. Figure 8 illustrates the direct and indirect impacts of climate change on human health, while figure 9 depicts the amount of vertebrate species that has been going extinct between 1500 and 2014, as recorded by the International Union for Conservation of Nature in 2012.

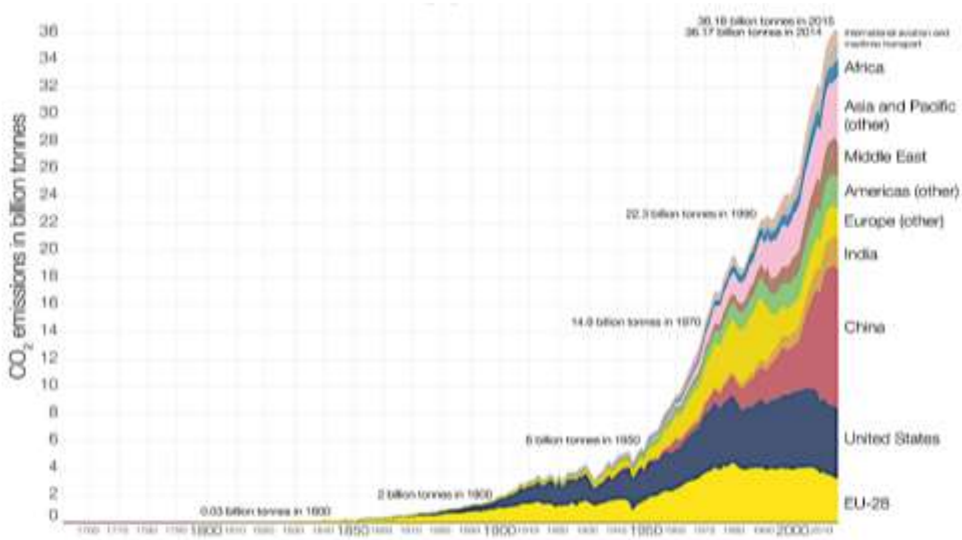


Figure 6. Global CO_2 emissions by world region from 1751 to 2015. *Image source: Our World in Data based on CDIAC data*

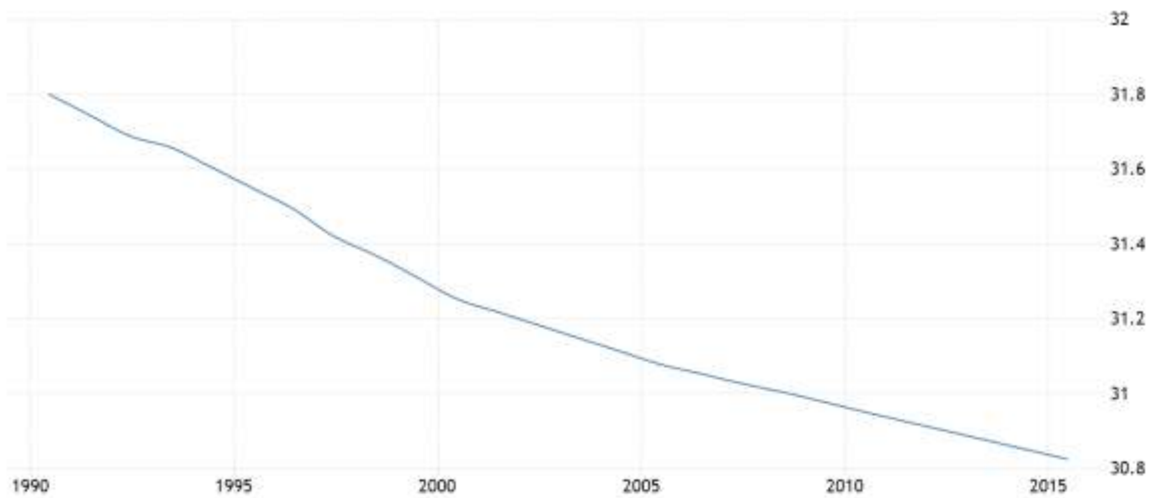


Figure 7. Forest area as % of land area in the World was reported at 30.83 % in 2015. The graph illustrates the decrease in forested area in the world between 1990 and 2015. *Image source: Tradingeconomics.com based on World Bank data*

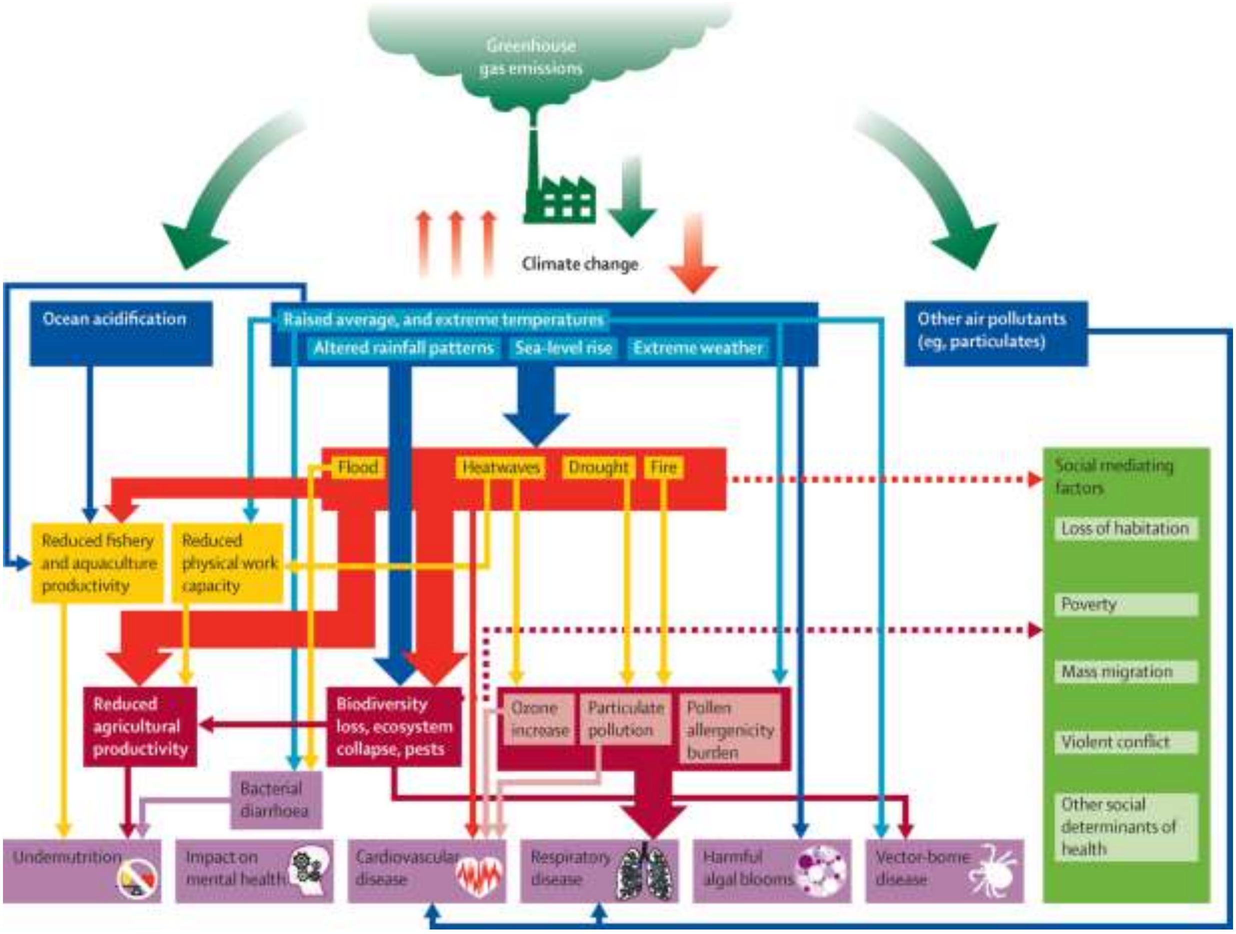


Figure 8. Direct and indirect impacts of climate change on health. *Image Source: Lance Commission on Health and Climate Change*

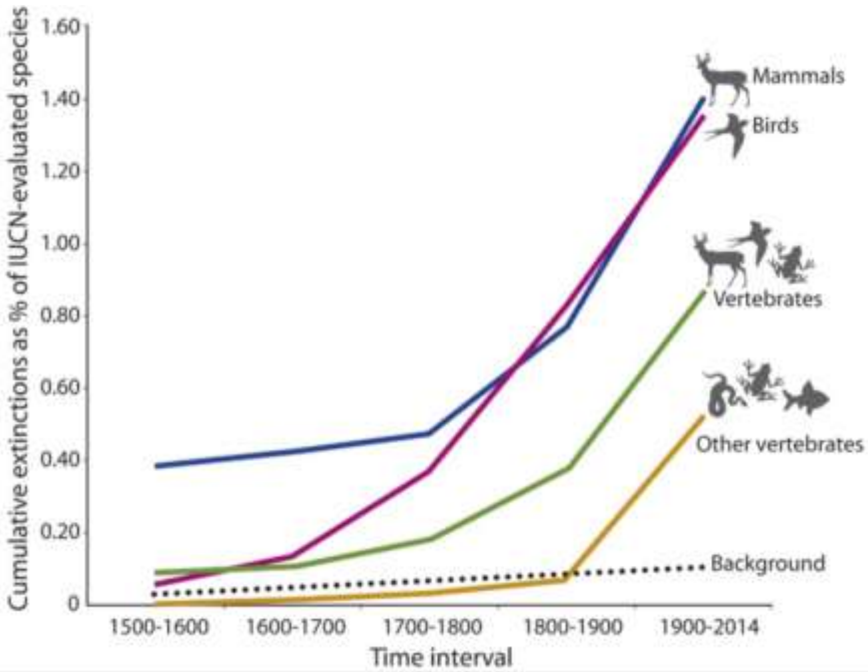


Figure 9. Cumulative vertebrate species recorded as extinct by IUCN (2012). *Image source: Science Advances*

1.2 Objectives of this Module

The purpose of this module is to help students better understand the complexities of modern urban systems. Going through this module, the students will be:

- Introduced to main definitions used in the societal metabolism analysis, and familiarized with these definitions through examples of and inference from real-life applications.
- Presented with displays and descriptions of formal theoretical models based on real-life cases. This should help them understand how these theoretical notions can be translated to elements of everyday life, and make it easier for students to transfer/translate them to any context.
- Acquainted with the rationale and the concepts that are in the background of the SUSTAIN game.

This e-book contains links to videos, images, and interactive exercises that clarify the definitions, which students will need in order to better understand the material in the following modules.

1.3 Understanding the Key Terminology in this Course

- **Societal Metabolism**
- **Urban Metabolism**
- **Stocks**
- **Flows of materials**
- **Flows of Energy**
- **Environmental Impact**
- **Sustainability**
- **Systems Thinking**
- **Circular Economy**
- **Sustainable Urban Mobility**

As in any other discussion, whenever a topic is being introduced, one needs to make sure that the terms being used are well understood. This is especially important in case of certain core principles and concepts. This chapter aims to introduce the main definitions used in the societal metabolism analysis. When correctly understood by a group, it helps in assessing situations better, have more meaningful conversations and make better decisions. To help students grasp the meaning of the core concepts more easily, this chapter will feature graphics, examples, and also encourage students to check some additional resources.

2. Societal metabolism

Social metabolism, also sometimes referred to as ***social metabolism*** or ***socio-economic metabolism*** is a framework, a way of looking at how society interacts with the environment by analysing the flow/exchange of materials between society and the environment (Fischer-Kowalski and Huttler 1999).

The most common use of the word "metabolism" is usually linked to the metabolism of a body, or of a cell. When talking about metabolism, one likely thinks of:

- how much food and what type of food a human consumes;
- how quickly it is being digested, and what are the nutritious elements in which the food is being broken down by the body and turned into something useful for a person's health;
- how much water a human body consumes and how quickly it is being released from the body.

For those who are fond of cell biology, the image that comes to mind might be similar to the one in figure 10.

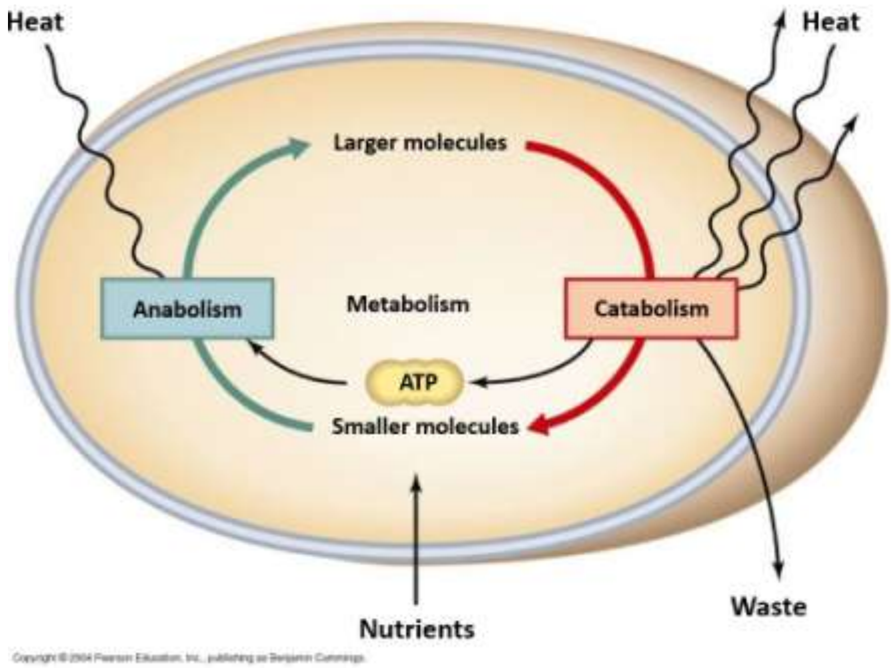


Figure 10. A simplified graphical representation of metabolic process in a cell. *Image source: Portland Community College*

Whether it is a cell or a body, metabolism means that an entity takes something in (material or energy), transforms it and releases it in a changed form. Therefore, when we talk about societal metabolism, one can easily thing along these lines. The difference would be that instead of talking about a single cell or body, we talk about a community, a village, a city, a country, etc. That is to say, regarded as a process, societal metabolism is when of a group of people take from nature materials and energy, use it and transform it to secure their existence and development, and release back into nature energy and wastes.

Regarded as a framework of understanding society-environment interaction, societal metabolism supports the analysis of:

- types and quantities of material and energy a society takes from the environment;
- what processes this material and energy goes through within the society;
- what types and quantities of waste and energy is being released back to the environment;
- what can be improved about the above process so as to minimise society's negative impact on the environment.

For example, if we were to look at the societal metabolism of water in a village, we would look into such things as:

- what is that village's water source
- how much water the population of that village consumes;
- what the water is used for within the village;
- possible ways to minimise the use of water in the village;
- whether the wastewater is treated before being released back into the environment;
- possible ways to improve the treatment technology of wastewater before discharging it;
- alternative ways to use wastewater within the village instead of directly discharging it, etc.

To find more about the origins and evolution of societal metabolism framework, students may consider checking the following resources:

http://pdf.wri.org/weight_of_nations.pdf

https://www.aau.at/en/social-ecology/research/social-metabolism/

2.1 Urban metabolism

Urban metabolism is a model of analysing interactions between natural and human systems in specific regions. This model/way of looking at the human-environment interaction describes and analyses the exchange of materials and energy within cities, such as undertaken in a material flow analysis of a city (Pincetl, Bunje, and Holmes 2012).

To put it in simpler terms, urban metabolism is societal metabolism applied to an urban community (figure 11). It has become an increasingly popular approach in the recent years, due to increased urbanization. According to the UN Environment-led Global Initiative for Resource Efficient Cities, since 2007, for the first time in history more people live in cities than in rural areas. Cities consume 75% of Earth's resources, and account for 60-80 % of global greenhouse gas emissions, and these numbers are growing.

In other words, urban metabolism looks at what happens to resources in a city between their points of entry and their exit from the city as wastes. By viewing the city as an organism that consumes resources and produces wastes, we can find ways to improve resource use, and reduce environmental impact.

Figure 11. A simplified representation of urban metabolism model as an application of societal metabolism framework at an urban level. *Image Source: Cooperative Research Centre for Water Sensitive Cities*

For a better insight into the concept, the following are some of the many simple, clear and accurate resources:

1. Short video on "What is Urban Metabolism?" from the UN Environment: https://www.youtube.com/watch?v=uu-a1hFEV7Q
2. Website with informative visualisations and data on urban metabolism of Paris, France: http://metabolisme.paris.fr/#t/paris/matter/1

2.2 Stocks

A stock is, simply put, an accumulation of something. For example, a bathtub that accumulates water flowing from the tap, as shown in figure 12 is a stock of water.

Figure 12. A bathtub with water is an example of a stock/an accumulation of water. *Image source: PBS Learning Media*

Likewise, if we think about the atmosphere that accumulates CO_2 in a similar way in which a bathtub accumulates water (figure 13), then we can refer to the atmosphere as a stock for CO_2 and other greenhouse gasses, for that matter.

A battery (figure 14) is another and perhaps one of the most straightforward examples of stocks, because that is what it used for; stocking electrical energy. The stock of electrical energy increases as we charge or recharge it, and decreases as it is being consumed by an electronic device, such as a phone, a player, etc.

Figure 13. The atmosphere is a stock of CO_2 in the same way in which a bathtub is a stock of water. *Image source: WorldBank and Climate Interactive*

Figure 14. Batteries are stocks of electrical energy that, increasing as they are being charged and decreasing as the electricity from them is being consumed by electronic devices. *Image source: Colourbox*

In the context of urban metabolism, one example of a stock can be the waste disposal facility where all the waste collected from the inhabitants of a town/city is deposited (figure 15).

Figure 15. In more sustainable waste management practices, the depositing facilities are temporary. After the waste is stocked at such a facility, it is then sorted on types of waste (plastic, metal, glass, paper, etc.) and sent to corresponding recycling facilities. As the recyclable waste is taken away, the stock of waste at the facility decreases. *Image source: Urban One*

As more waste is brought in, the total volume of waste piles up, increasing the stock. In some unsustainable cases, the waste is deposited on landfills, leading to multiple sustainability challenges (bigger stock of waste requires bigger landfills and ever larger space for landfills).

2.3 Flow of materials (Material flow)

In the context of Urban Metabolism, flow of materials is the description of the transportation of raw materials, objects, and products as a flow of entities within an urban area (city), and between a city and the surrounding environment.

One way of thinking about it is going back to the example of the bathtub in figure 7. While the bathtub itself accumulates water, or acts as a stock of water, the water coming from the tap is an incoming flow of the stocked material, i.e. water. Similarly, the water going out from the bathtub through the sink is the outflow of the same material. Thus, the water is transported from the tap and through the sink as a flow.

An alternative simple way of understanding the flow of materials in an urban metabolism context is, for example looking at a milk pasteurization process (figure 16). The “raw milk in” is the inflow of material. After it goes through the heat treatment process results in an outflow of pasteurized milk.

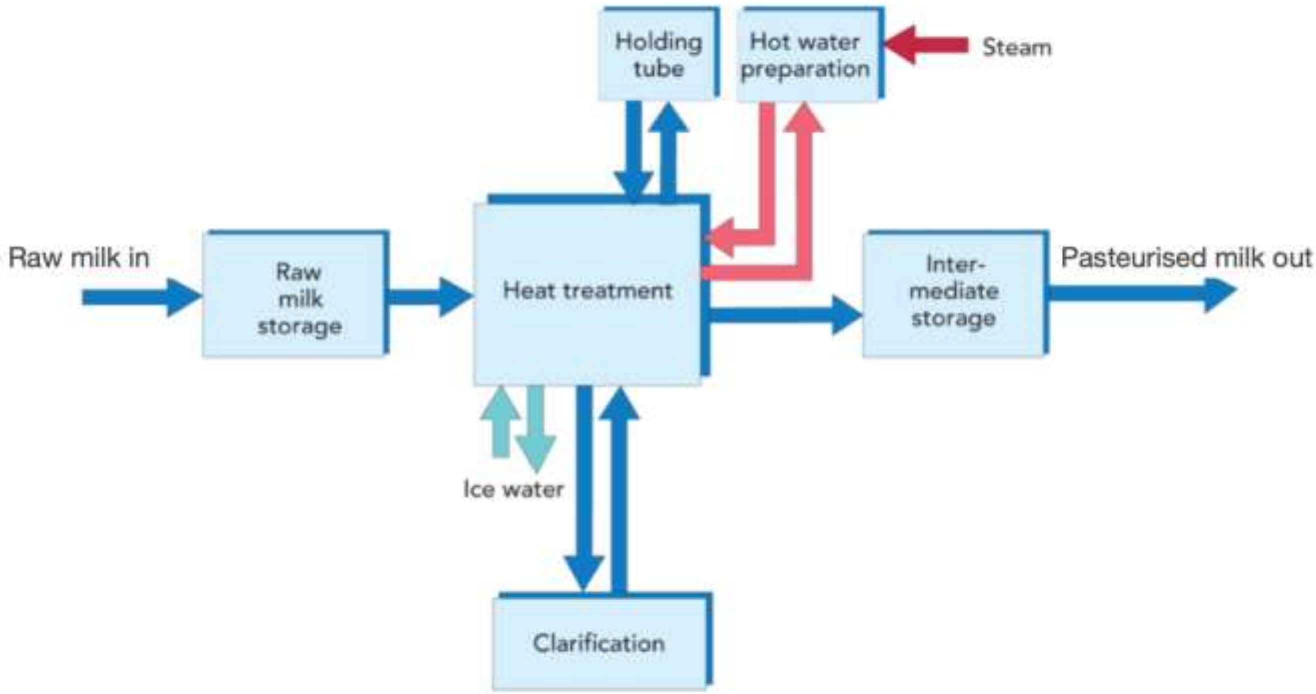


Figure 16. Generalized block chart of the milk pasteurization process. *Image sources: Dairy Processing Handbook*

Likewise, one can think of a flow of materials through an urban settlement, as a throughput of various types of inflowing and outflowing materials (figures 17 and 18), which flow into the city with a certain consistency and physical, chemical and biological quality, and flow out with different consistencies and qualities.

It is important to keep in mind that when talking about flows, an inflow of materials can also be an outflow of materials, and an outflow can also be an inflow in a continuous process. Figure 19 illustrates one such example embodied by the carbon cycle, i.e. flow of carbon naturally throughout across the globe in various forms.

Figure 17. Flows of material (and energy) through an urban settlement. *Image source: Biopolus*

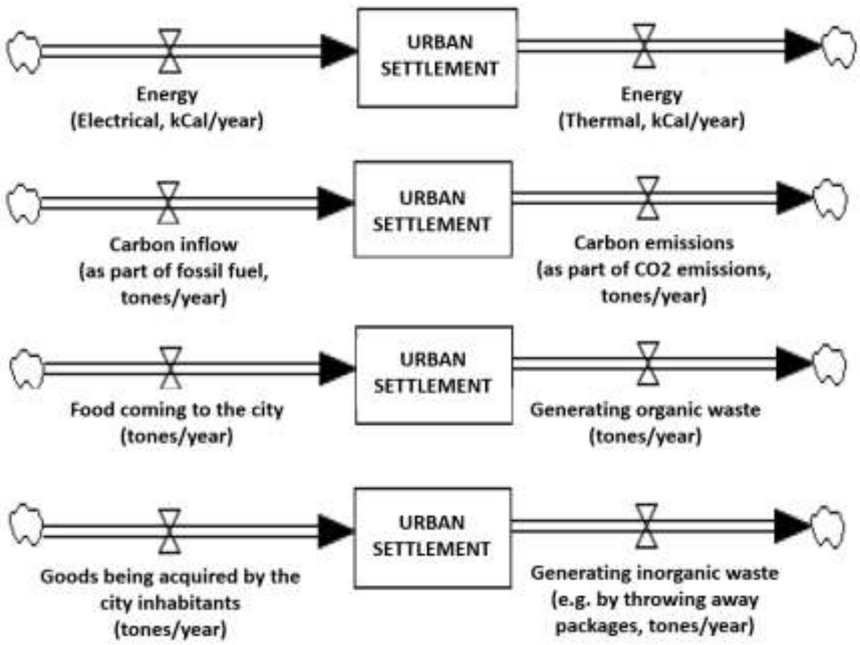


Figure 18. Examples of flows of material and energy depicted as inflows and outflows using specialised software Vensim.

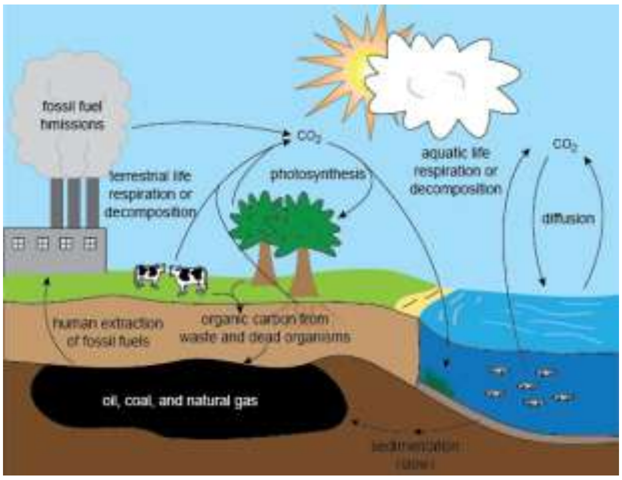


Figure 19. Carbon cycle is an example of continuous and complex flows of carbon in various forms throughout across the globe. *Image source: [Thinglink]*

2.4 Flow of energy

In the context of Urban Metabolism, the flow of energy is the description of the transportation of energy in its various forms (depending on what and why we're analysing this flow) within an urban area (city), and between a city and its surrounding environment.

While the flows of materials are rather simple to understand, flows of energy could pose some difficulties because there is no material to visualise energy. Below there are some illustrations that could help students in developing a better understanding of what this concept means.

Taking heat transfer as a first example (figure 20), the heat that is being transmitted from the warmer object to the cooler object can be referred to as a flow of thermal energy from the stock that has more of it (warmer object) to the stock that has less thermal energy/heat (cooler object).

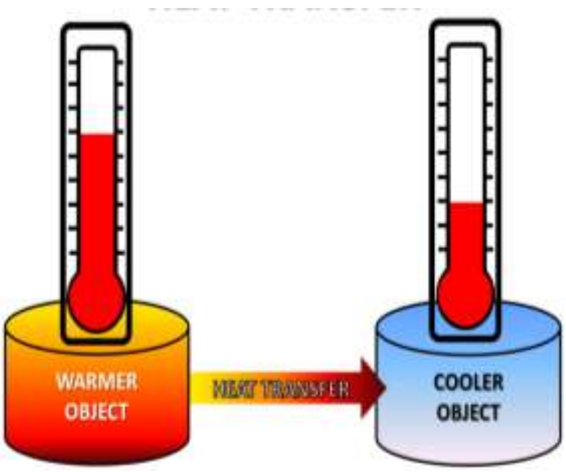
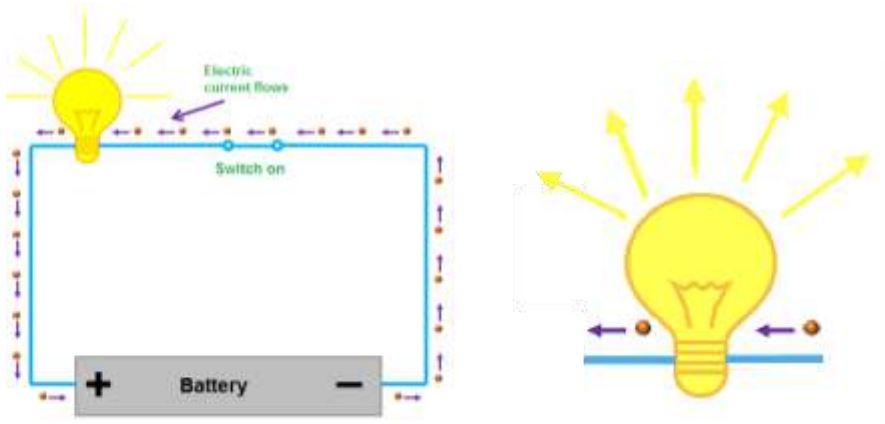


Figure 20. Heat transfer is an example of flow of thermal energy. *Image source: [Climate Science Investigations South Florida]*

Most people are familiar with another type of energy - electricity, or electrical energy. This is the type of energy that we as society mostly use to light up our homes, offices and streets, to make electrical equipment function, etc. Figure 21.a illustrates the flow of electrical energy as another type of energy that flows from the battery (or a generator, or another energy source/stock) to the light bulb.

However, it is important to note that inflows and outflows of energy are not always of the same type. In the example of electric energy illustrated above, the light bulb does not only act as a stock of electric energy, but metabolises (transforms) it into light energy (figure 21. b). The energy outflow from the light bulb then lights up the room.



a. **b.**

Figure 21.a. Electric current flow is another example of flow of energy. **b.** The light bulb transforms (metabolises) electric energy flow into light energy, which flows out to light up the surroundings. *Image source:* [Physics and Radio-Electronics]

Other examples of energy flows within the city and between the city and its surrounding are illustrated in figure 22 below.

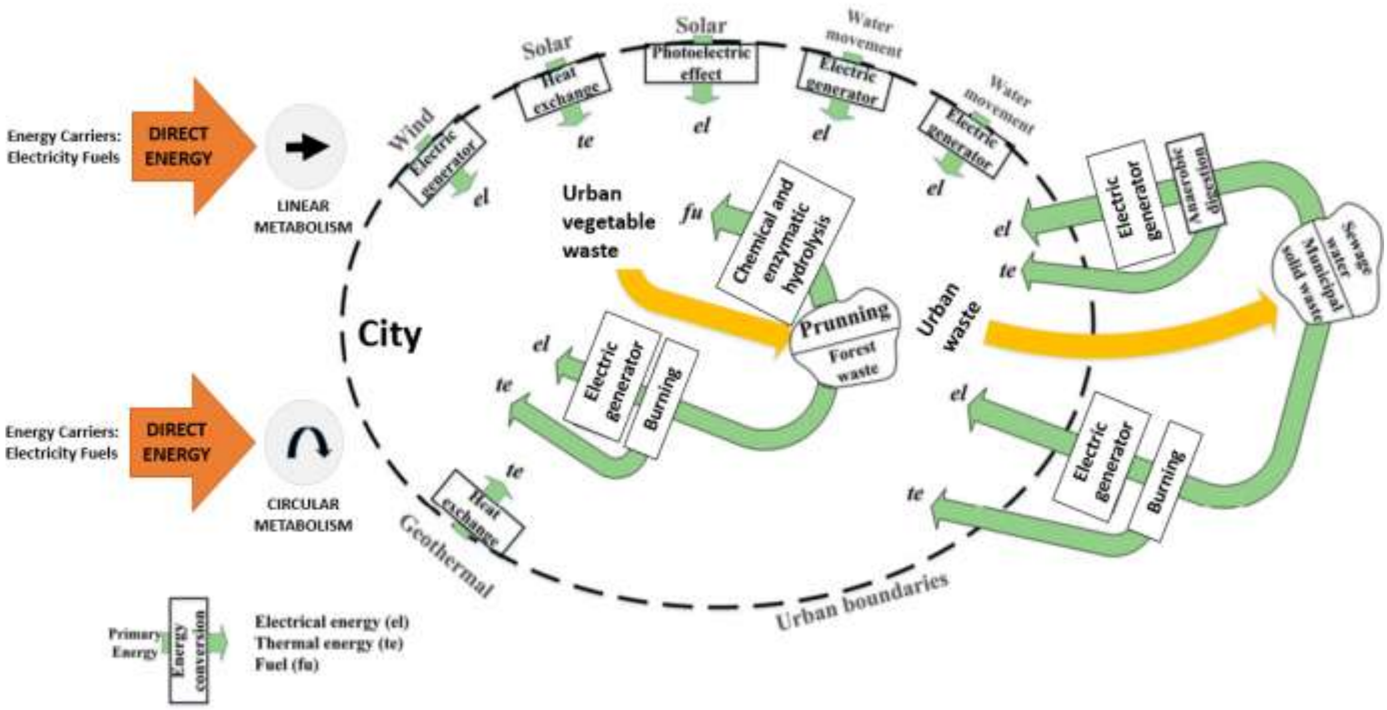


Figure 22. The flow of electricity is another example of flow of energy into and within the city. *Image source: Barragán-Escandón et al (2017)*

To find more about the flows of energy and materials in cities, students may consider checking the following resource:
https://www.cmcc.it/article/urban-metabolism-and-flows-of-energy-and-materials-in-cities

2.5 Environmental Impact

When we talk about environmental impact, the meaning is what we commonly refer to as the impact on the environment created by humans either as a community, or through an industry, service, plan, or project. It can be negative or positive - depending on the consequences for the environment. However, generally environmental impact is associated with a negative consequence on the environment. In more specialized terms, human impact on the environment is also known as anthropogenic impact on the environment, and refers to the alteration of the natural environment by human activity.

In very general terms, environmental impact can be summed up into a few categories, including: pollution, deforestation, loss of biodiversity, overproduction of waste, overuse of natural resources, accelerated climate change, and others. Indeed, the diversity and complexity of such impacts is too wide to be covered in this chapter alone. The examples illustrated below are meant to give the students a better insight into what could constitute environmental impacts in an urban metabolism context.

Example 1 - Plastic pollution

Think of a person going to shop for household products and food in a supermarket. As it usually happens, most of these goods are covered in plastic or mixed packaging, which makes plastic and packaging one of the greatest pollutants on earth (figures 23.a and b).

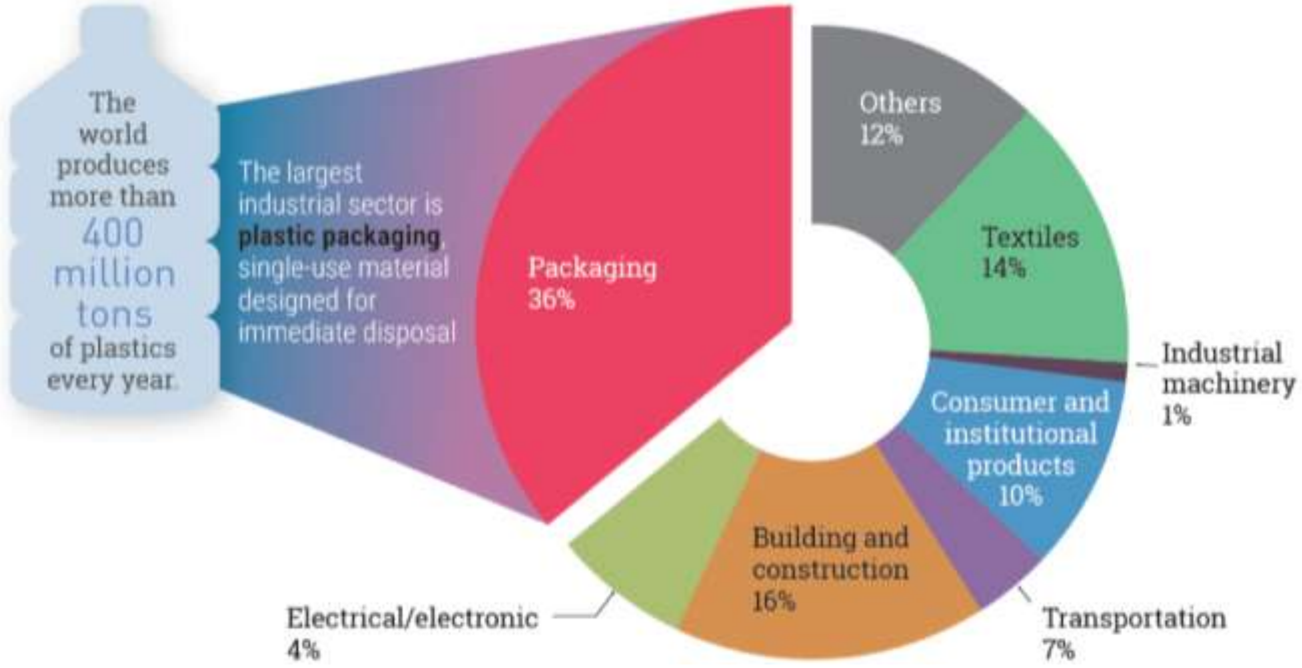


Figure 23.a. Global plastic production by industrial sector (2015).

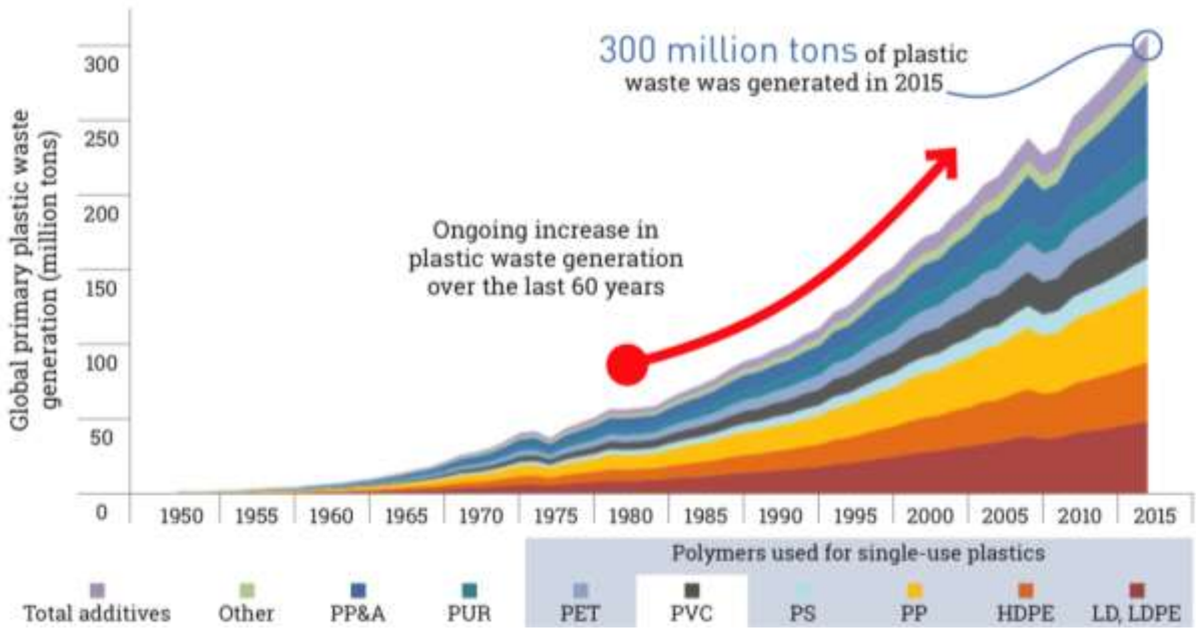


Figure 24.b. Global primary plastics waste generation, 1950 - 2015

Source of images: [United Nations Environment Programme]

When disposed of improperly, plastic packaging is blown by the wind and ends up in river valleys. The same happens when waste is deposited on the side of riverbanks. It is then carried to the seas and ocean all over the planet (figure 24). Once it reaches habitats of various animal species, plastic poses multiple threats to health and livelihoods of those species. Videos below are short, interesting and informative on this topic:

1. Short news report on “Pacific Garbage Patch” by Sky News: https://www.youtube.com/watch?v=0uU1ZyQ1OwA
2. Short video about “When birds eat plastic”: https://www.youtube.com/watch?v=mYsJESXhnu0&t=17s

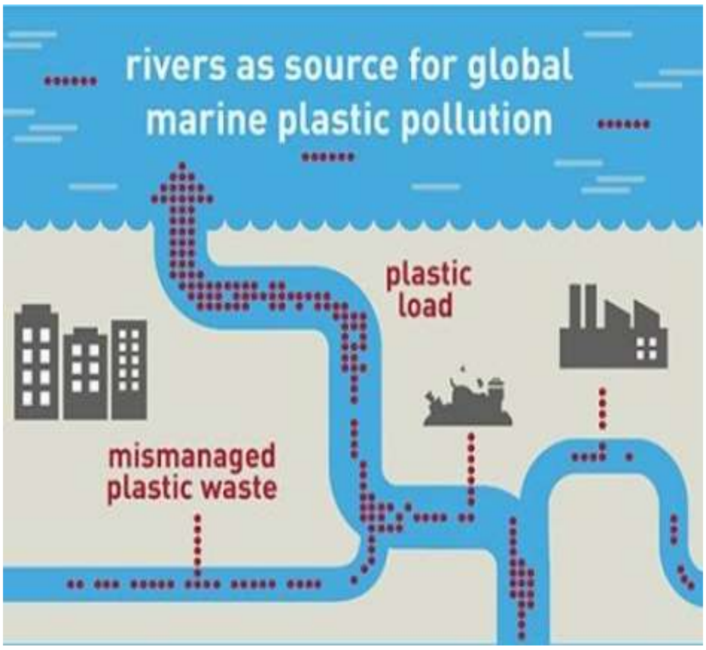


Figure 25. Plastic pollution is one example of environmental impact. Mismanaged plastic waste flows towards and ends up in rivers, seas and oceans. *Image source: Helmholtz Centre for Environmental Research*

Example 2 - **Impact of car use**

Cars have made our lives much easier in many regards. Yet, besides running on a finite resource, which is the fossil fuel, our automobiles cause all sorts of pollution. Car pollutants cause immediate and long-term effects on the environment, be it air, water, noise or even land. Car exhausts emit a wide range of gases and solid matter, causing global warming, acid rain, and harming the environment and human health. Engine noise and fuel spills also cause pollution.

Congestion, air and noise pollution, and road safety are examples of commonly shared problems in European cities. More on the impact of car use in our cities is available in the 2017 Report of European Commission on European Urban Mobility: https://ec.europa.eu/transport/sites/transport/files/2017-sustainable-urban-mobility-policy-context.pdf

2.6 Sustainability

Sustainability is the ability of something to be maintained at a steady level without exhausting natural resources or causing severe ecological damage. It also means that something can keep going, can continue into the future and go on forever. From a human perspective, sustainability for our planet means that it can continue to provide fresh air, clean water, produce food, and allow us all to have a high quality of life indefinitely.

This 2 minute video on “Sustainability explained through animation” simply and briefly explains the concept: https://www.youtube.com/watch?v=B5NiTN0chj0

Let’s go back to the example of a bathtub to think of sustainability as something that depends on a balance, or on “just about the right balance” between inflow and outflow (figure 25). Suppose a person wants to take a bath in the bathtub that has a permanent inflow and outflow of water. If the inflow rate would be higher that the outflow rate, then the water would flow over the edges. This is not something anyone would be happy about, as it would flood the bathroom. On the other hand, if the drainage/outflow rate of water is higher than the inflow, then there would not be enough water in the bathtub, and it would eventually run empty.

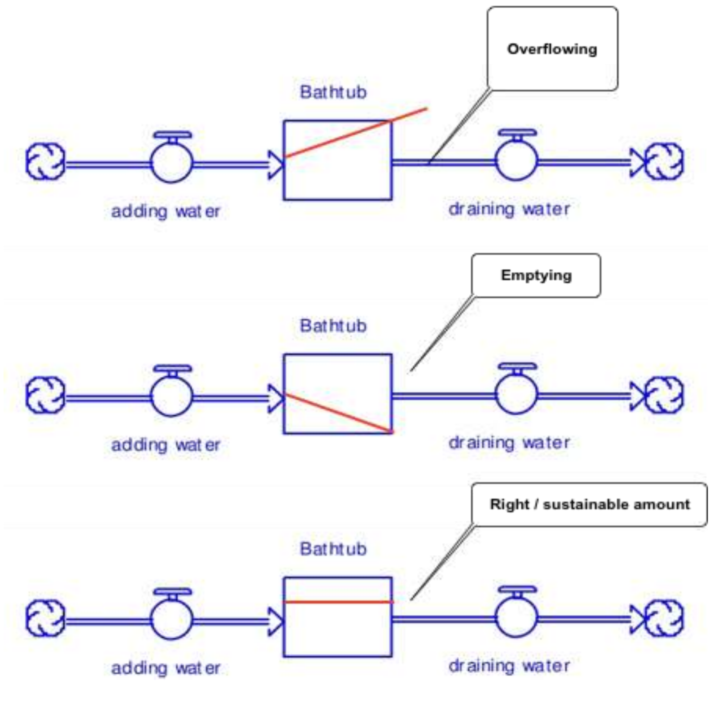


Figure 26. The challenge to finding the right amount of water in a bathtub as a parallel to the quest for sustainability.

Similarly, we can think about finding the right balance between emissions and reduction of greenhouse gases from the atmosphere as finding the right balance between adding and draining water in a bathtub. Hence, in climate sustainability, the challenge is to maintain just the right amount of greenhouse gasses in the atmosphere that can be balanced enough to not cause further global warming.

Sustainable development is a perspective on how our society should develop. It is based on the concept of sustainability. It has been defined in 1987 by the General Assembly of the United Nations as the “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. To put it simpler, it has three dimensions: Environmental dimension, Social dimension and Economic dimension (figure 26).

Figure 27. Three pillars of sustainable development: a safe and healthy environment supports the development of human society. A healthy society is the basis of a healthy economy.

The Environmental dimension deals with the way society uses natural resources and ensures environmental protection. The Social dimension covers issues related to civil rights, social inclusion and cultural identity. The Economic dimension looks at wealth creation, property and employment. All in all, this perspective seeks to ensure that we don’t drain the stock of resources and safety on our planet while increasing the stock of welfare for the society.

To make the overarching goal of sustainability in our development more reachable, in 2015 countries adopted a set of goals to end poverty, protect the planet and ensure prosperity for all (figure 27). Each goal has specific targets to be achieved over the next 15 years.

Figure 28. Sustainable Development Goals (SDGs) are part of the new sustainable development agenda adopted by countries on September 25th, 2015. *Image source: United Nations*

2.7 Systems thinking

Systems thinking can mean different things to different people. A system is any kind of entity that is made up of parts that interact. Together these parts and interactions create a whole, which in turn produces some kind of result. Using a systems perspective is important, because it helps us to better understand what helps or hinders the success of an intervention into a particular system, such as public transportation system (figure 28). In the context of this course, we shall refer to systems thinking as a discipline (or a way of looking at and perceiving things around us) that concerns the understanding of a system by examining the linkages and interactions between the components that comprise the entirety of that specific system.

An example of looking at public transport intervention from a systems thinking perspective is Wollongong, Australia. As such, the transport system is not regarded only as the totality of infrastructure items - busses, computers, passengers, etc. It also takes into consideration how the components are connected, how they interrelate and influence each other.

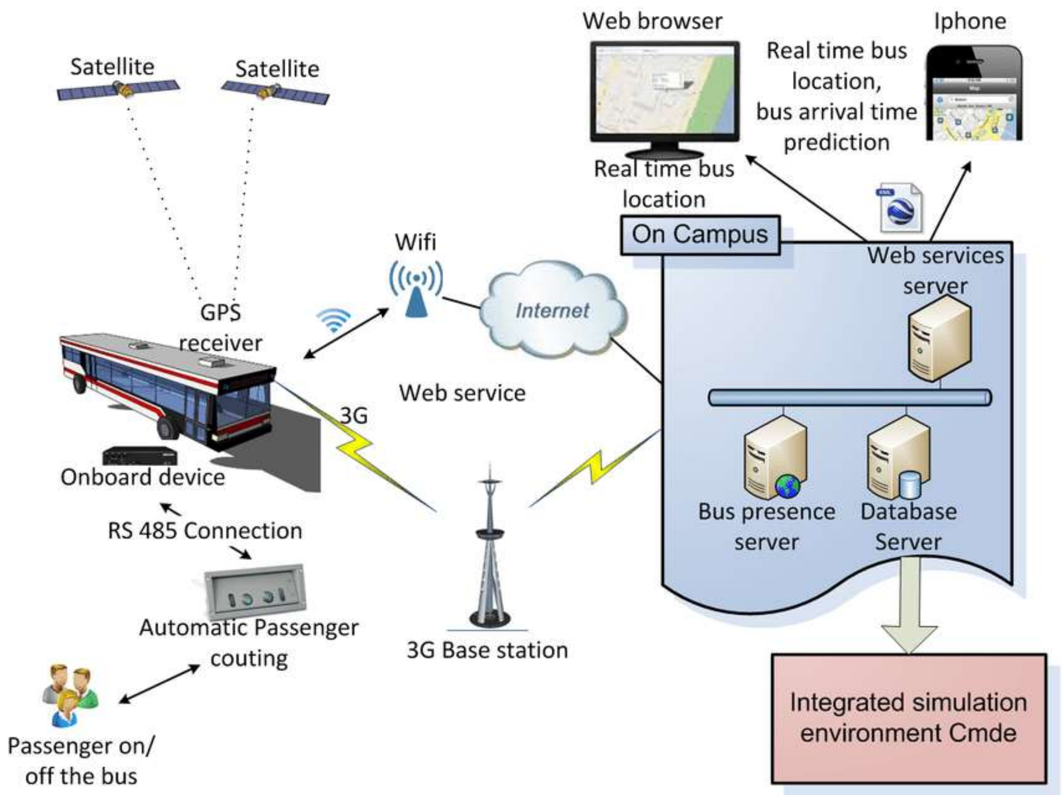


Figure 29. Advanced public transportation system architecture for Wollongong, Australia. *Image source: Vu The Tran, P.V. Eklund and C. Cook (2013)*

Standing in contrast to traditional, reductionist thinking, systems thinking sets out to view systems in a holistic manner(figure 29). Systems thinking is a new paradigm that encourages and enables us to understand complex systems. It shows us how all the various components within systems interact with and depend on one another. By using systems thinking, we are better able to understand our world and develop meaningful, strategic, and lasting solutions

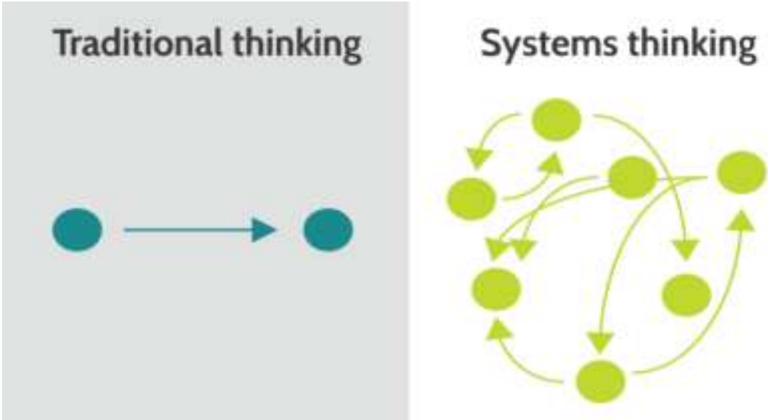


Figure 30. Traditional thinking in comparison with systems thinking. *Image source: Kindling*

To understand what differentiates a systems thinking perspective from a traditional thinking perspective, figures 30 and 31 illustrate different approaches towards solving a traffic congestion problem. In the first case (figure 30), a linear, traditional way of, thinking perspective would reason that more parking manoeuvre time in city centres leads to increased congestion, and therefore more parking spaces inside city centres would potentially lead to less traffic.

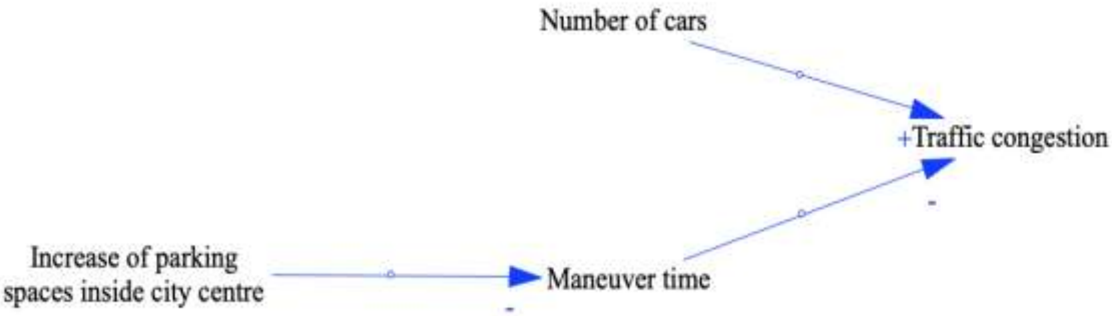


Figure 31. An example of unsustainable solution to a traffic congestion problem arising from a linear thinking perspective.

From a system thinking perspective, that can be though as the sustainable modern way of approaching an issue. However, this might not be the optimal solution, because there are many other factors that are directly or indirectly linked to traffic congestion (figure 31). An example of such a factor is people’s willingness to use public transport instead of cars (adopting a car free sustainable lifestyle). This should decrease traffic congestion, especially when sustainability awareness is high and other accompanying traffic calming measures apply, e.g. when parking spaces inside the city centre decrease (therefore, car restrictions apply), or when investments on public transport are promoted. In short, more parking spaces inside city centres would lead to reduced manoeuvre times and eventually less (perceived) traffic, but it also leads to people being more willing/likely to drive, so there would still be increasingly more cars in (real) traffic. Hence, different solutions or combination of measures (equilibrium) need to be sought in the system.

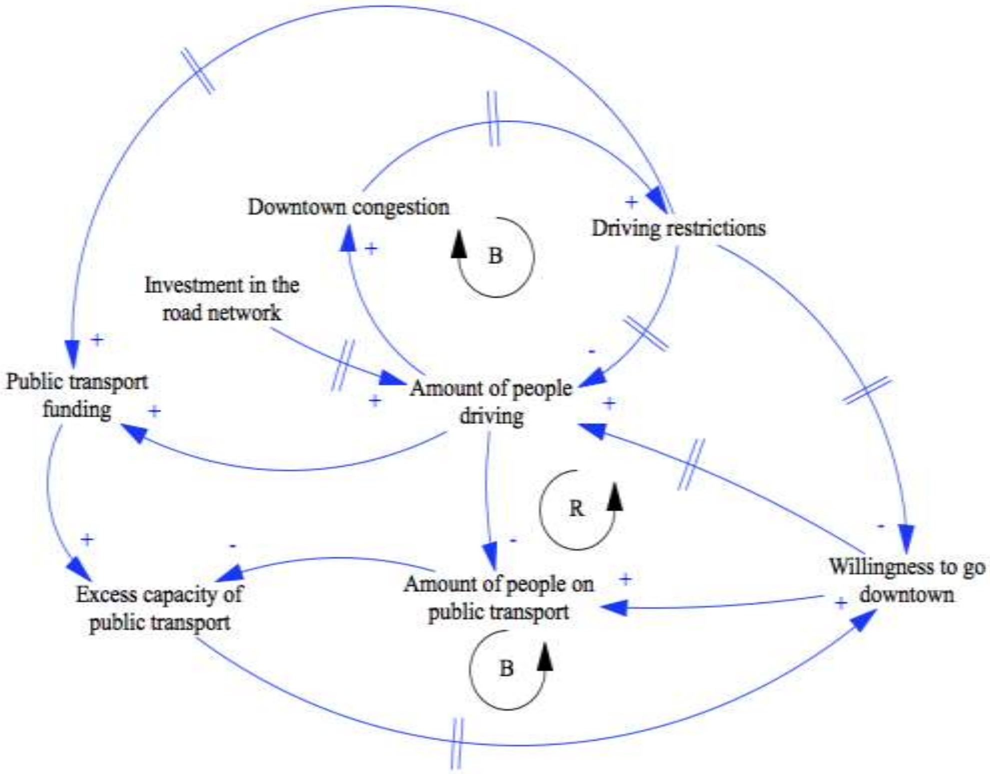


Figure 32. Looking at the causes of traffic congestions from a systems thinking perspective allows decision makers to identify better interventions to address the problem. *Image source: SD Action*

To find more about the systems thinking, the following resources are useful:

- Learning for sustainability website: http://learningforsustainability.net/systems-thinking/
- System Dynamics in Action website: http://sdaction.kytt.org

2.8 Circular economy

The examples before illustrated how sometimes some components in systems are connected through causal loops. That is, what is considered a cause can also be an effect of a change in the component which is influenced by the initial cause. Such was the example of traffic congestion: an increase in traffic congestion causes less people to want to drive. Then, as the people chose not to drive, the congestion decreases. Therefore, congestion, number of people driving and their willingness to drive are all at the same time causes and effects. They are connected through a loop.

Circular economy is a regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing energy and material loops. In a circular economy, when a product reaches the end of its life, it is used again to create further value. This can bring major economic benefits, contributing to innovation, growth and job creation, and cleaner environment (figure 32).

For a better insight into the concept, the following are some of the short and useful resources:

1. Short video on “Circular Economy” from the European Environment Agency:https://www.youtube.com/watch?v=_9mHi93n2AI
2. Short video on “Re-thinking Progress: The Circular Economy” from Ellen MacArthur Foundation:https://www.youtube.com/watch?v=zCRKvDyyHmI
3. Short “Don't waste your waste” video from County Administrative Board of Östergötland, Sweden:https://www.youtube.com/watch?v=Ptp6JGAF3o0
4. Website with informative visualisations and data on urban metabolism of Paris, France:http://metabolisme.paris.fr/#t/paris/matter/1

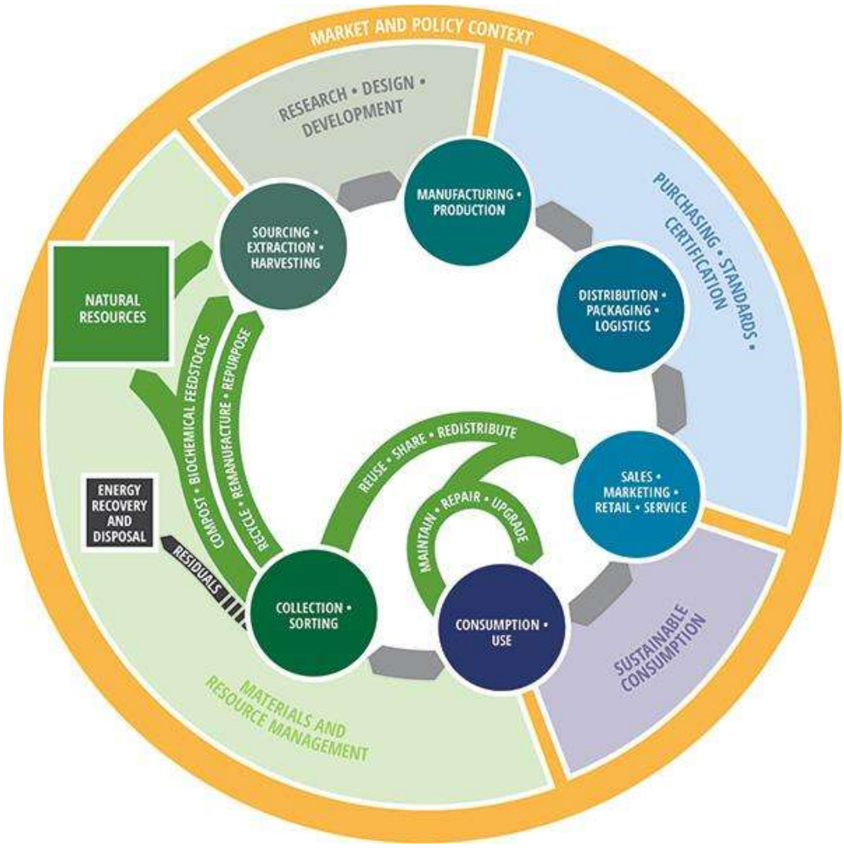


Figure 33. The circular economy is an approach to maximize value and eliminate waste by improving (and in some cases transforming) how goods and services are designed, manufactured and used. *Image source: Circular Economy Lab*

Below is one example of circular economy principles in action:
Around 88 million tonnes of food are wasted annually in the European Union (Stenmarck et al. 2016). Wasting food is not only an ethical and economic issue but it also depletes the environment of limited natural resources. Cities are one of the biggest consumers and generators of food waste. Usually, food is discarded as waste into the waste bins, and taken by waste management actors to landfills or incinerators outside the cities. In line with circular economy principles, one way to deal with this issue would be to use the food scraps for composting/creating fertile soil for agricultural use, or to use

fried oil for biodiesel production. Whatever the choice and technical possibilities, the main idea is to maintain it within the economic circuit instead of discarding it as waste. Figure 33 illustrates other ways to deal with food waste based on circular economy principles.

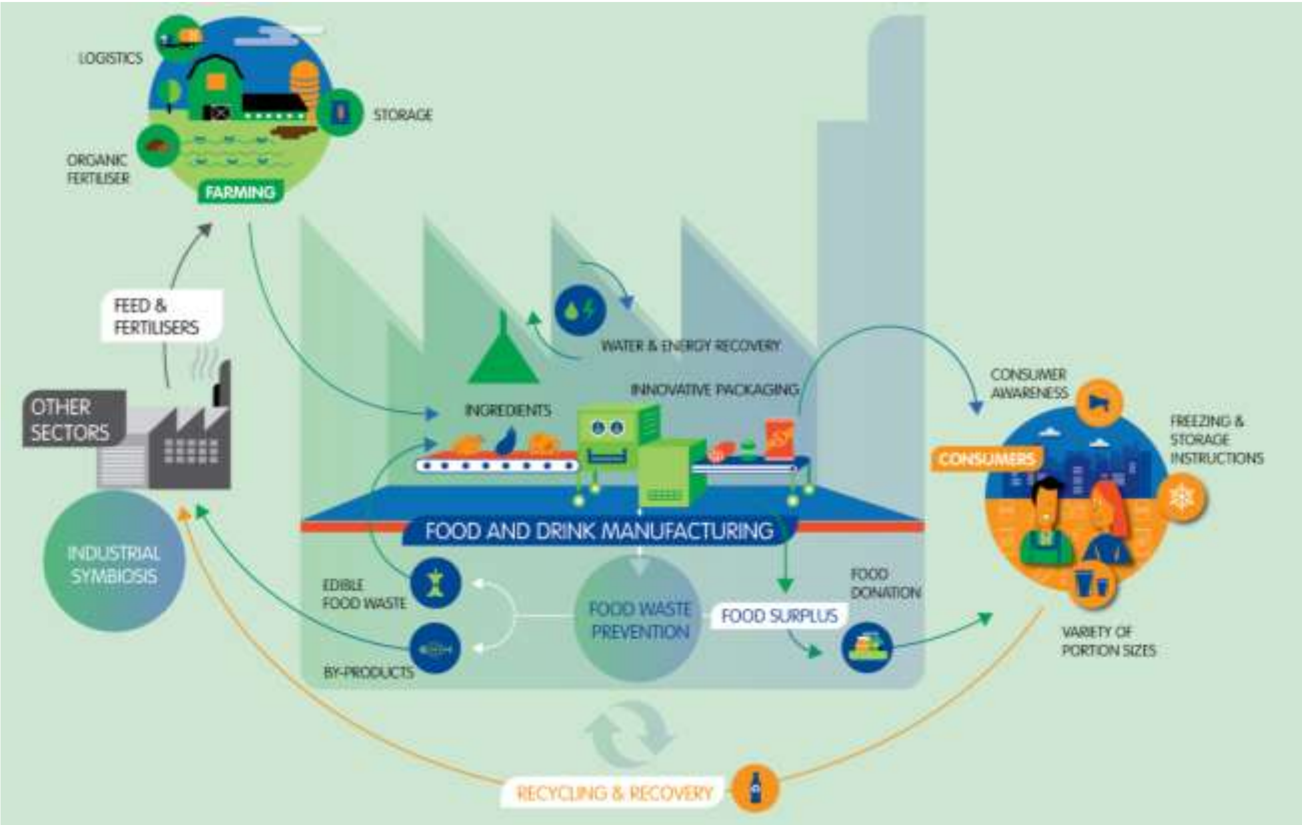


Figure 34. Enhancing a resource-efficient, circular economy in the food and drink industry. *Image source:* *FoodDrinkEurope*

More good practice examples of various circular economy projects throughout Europe can be found on European Circular Economy Stakeholder Platform:
https://circulareconomy.europa.eu/platform/en/good-practices?key_area=All&sector=All&country=PL&title=

More on circular economy is available in these interesting and useful resources:
https://www.ellenmacarthurfoundation.org/circular-economy
http://www.wrap.org.uk/about-us/about/wrap-and-circular-economy
https://circulareconomy.europa.eu/platform/en/good-practices/stories-circular-economy-italian-atlas-and-competition

2.9 Sustainable urban mobility

Sustainable urban mobility refers to a large pool of measures and solutions able to tackle urban mobility challenges linked to the uncontrolled growth of vehicles. Broad dimensions of sustainable mobility planning include promotion of Public Transport modes, alternative modes (walking, cycling) and alternative fuel-driven vehicles (e.g. electric), while in order to achieve the desired modal shift, strong emphasis is given on multimodality enhancement (e.g. development of fully interconnected and accessible terminals), Intelligent Transport Systems development and services integration. The Transportation Sustainability chapter, of this course is entirely dedicated to exploring and understanding in more depth urban mobility - what makes it sustainable or not.

3. Connecting the Societal Metabolism approach to real life examples.

In this section, the terminology defined in the previous sections is illustrated by using examples from real life.

3.1. Example of unsustainable practices

Fossil fuel transport

Why is it an unsustainable practice? Because all modes and means of transportation that consume petroleum based fuels contribute to the pollution of air and water, and the capabilities to neutralize this pollution are limited. This happens both through burning the fuel, and through the process of refuelling. A scan through this source will give students an idea on the complexity of the problem: https://www.aps.org/policy/reports/popa-reports/energy/transportation.cfm

Terminology:	**How to apply the key concepts when analyzing the practice?**
Urban metabolism	Fossil fuel is metabolized into air pollutants, including greenhouse gases (GHG) (carbon monoxide, nitrogen oxides, volatile organic compounds including hydrocarbons). To identify where we can inter look at what the fossil fuel is used for, when it is being used, what is it decomposed into (e.g. cars burn the fuel and generate emissions), etc.
Stock	Fossil fuel accumulates in the city as substance (petrol, gas for cars) and/or energy (kCal, KJ, etc.)
Flow of materials (Material flow)	To understand what are the sources of pollution, it is needed to investigate how fossil fuel is brought into the city, how much of it is

	brought in per month/year. Then, one looks at what goes out from the city as a result of its urban metabolism (e.g. tones/year of emissions).
Flow of energy	It is needed to take a look at how much energy the amount of fossil fuel brought into the city can generate, and then look at how that energy goes out from the city as a result of its urban metabolism (e.g. tones/year of thermal energy/ heat that warms up the environment).
Environmental Impact	This is a qualitative metric, defined by looking at what are the negative and positive impacts of the use of fossil-fuel based transport. E.g. CO_2 emissions contribute to climate change. Thermal energy (heat) can create "heat islands" in the cities. Particulate matters (e.g. PM5, PM10) contribute to air pollution.
Sustainability	This characteristic of the practice of using fossil fuel in transportation is defined by analyzing if the use of fossil fuel based transport can be sustained into the future. Can it be carried on indefinitely? Or is there a limitation for its use (e.g. time, resources)?
Systems thinking	When analyzing urban metabolism and sustainability of fossil-fuel based transport, a systems way of thinking looks at the means of transport that use fossil fuel, people that use personal cars or public transport, etc. as components of a system. At the same time, this requires looking at the linkages and interactions between the components. Some examples include: decisions that people take to use cars or transport; what increases the attractivity of fossil-fuel based cars compared to electric cars or public transport, how the price of fuel and the regulations of city councils influences the amount of fossil fuel consumed by city inhabitants, etc.
Circular economy	In contrast to the common, linear economy (i.e. materials in - waste out), by adopting this perspective, one looks into what can be done to reduce the amount of fossil fuel consumed and the waste generated, as well as how to reintroduce the waste into the economy of the city as a reusable material/resource. For example, one way to reduce resource consumption and waste would be to share rides. However, the waste generated by burning fossil fuel (PMs and CO_2) cannot be reintroduced in the economy. This is one of the reasons why fossil fuel based transport is considered unsustainable.
Sustainable urban mobility	From this standpoint, one needs to look at what are the more sustainable alternatives to fossil-fuel based transport. Some examples may include: electric public transport (tramways, trolley buses, trains, etc), bicycles, or

	walking.

3.2. Examples of practices that contribute to sustainable urban metabolism

Example 1:Ecopixel - Recycled and Recyclable Plastic

Organization or Company: ECOPIXEL®
Country: Italy
Description: ECOPIXEL is a recycled, recyclable, circular, sustainable plastic material that melts at minimum temperatures so to have the minimum ecological impact also during its transformation.
Scan through the details of this practice here: https://circulareconomy.europa.eu/platform/en/good-practices/ecopixel-recycled-and-recyclable-plasticand here: http://www.ecopixel.eu/index.html

Terminology:	How to apply the key concepts when analyzing the practice?
Urban metabolism	Human society consumes/metabolizes the Low-Density Polyethylene (LDPE) waste-material to obtain a new recycled and recyclable material that can be used for different products. The raw material used for ECOPIXEL comes from industrial waste or from any other field including household-waste. The waste material is shredded, melted at a low temperature and re-transformed into products used by the urban community.
Stock	The accumulation (stock) of plastic waste in a city is increased through generation of waste by urban population, and is decreased by disposal, incineration or recycling of plastic waste. In this example, the stock of plastic waste is significantly reduced because the waste material is recycled, and the generated product is still recyclable at the end of its life.
Flow of materials (Material flow)	When looking at the dynamic of plastic waste in a city, one can identify the input of goods (plastic goods, packaged non-plastic goods) into the shops and markets of a town as inflow of plastic material. Once consumed, the generated material can be considered as an outflow of waste from households. Within the manufacturing process of ECOPIXEL production, the flow of material can be visualised as follows: Inflow: ‘raw’ waste material; Outflow: products manufactured from recycled plastic.

Flow of energy	One way of looking at flows of energy in this example is by considering that to recycle the plastic material product, manufacturers consume energy. For example, there is an inflow of electric energy to the recycling and manufacturing machines to keep them functioning. There is also an inflow of heat to melt the plastic. Depending on the production process, the outflow can be either as heat, as well, or/and as chemical energy binded into the recycled plastic product.
Environmental Impact	Some non-exhaustive examples of analysing the environmental impact of ECOPIXEL during its lifecycle include: ● Using material composed of 100% recycled Low-Density Polyethylene (LDPE) reduces the need to generate new raw material from petrol → minimizes impact on finite natural resources; ● Recyclable material that can be re-melted multiple number of times without altering its properties → minimizes generated waste; ● Using waste as raw material for production of consumer goods provides an alternative for plastic incineration or storage → minimizes pollution of the environment with plastic materials.
Sustainability	Plastic waste recycling into new plastic objects answers the needs of consumer society without needing new, finite raw material resources to be extracted. It also provides a solution for waste management that can be repeated multiple times into the future. In addition, the resulted products can be further recycled at the end of their lifetime, which makes this practice a sustainable one.
Systems thinking	Systems thinking means that one looks at the connections and the implications of plastic waste materials and the changes that ECOPIXEL is bringing. What causes and consequences are there for generation of plastic waste? What are the stocks and flows of materials in this process? What are the factors that influence the generation and recycling rates of plastic waste? Are there “side-effects” of plastic generation and recycling process that have an unexpected effect on the system? - these are some of the questions a systems thinker would look at.
Circular economy:	ECOPIXEL collects, separates, chips into pieces and re-transforms into products what others throw away. It is made from ‘raw’ waste material that can be reintroduced into the economy nearly infinite number of times, thus creating a continuous cycle in material-use.

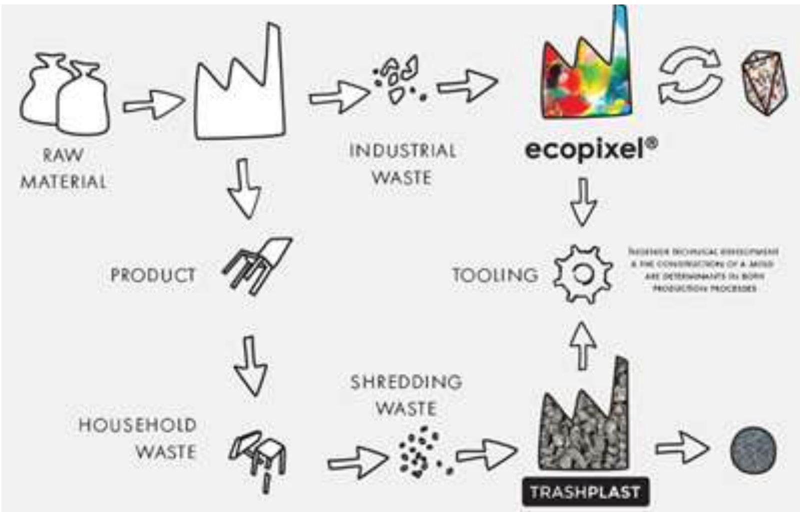


Figure 35. Ecopixel technology. Image source: Ecopixel

Example 2:Every Can Counts

Organization or Company: AluPro
Country: 12 European countries (UK, France, Austria, Hungary, Romania, Ireland, Greece, Spain, Montenegro, Serbia, Poland, Belgium).
Description: The "Every Can Counts" programme works to improve recycling by enabling and encouraging people to recycle beverage cans used outside the home (e.g. workplaces, festivals, tourist locations, etc.)
Learn about this practice here https://circulareconomy.europa.eu/platform/en/good-practices/when-it-comes-recycling-aluminium-every-can-counts and here https://www.everycancounts.eu/

Terminology:	How to apply the key concepts when analyzing the practice?
Urban metabolism	The beverage cans are introduced in urban societies as packages for various sorts of drinks and foods. As the packed goods are consumed, the cans are discarded as waste. AluPro is an initiative to transform this waste into new recycled cans.
Stock	There are several accumulations in this process, for example: stock of canned beverage, stock of cans discarded as waste, stock of recycled cans, and others. The stock of aluminium waste is increased by the consumption of aluminium-packed beverage, and decreased by incineration or recycling.

Flow of materials (Material flow)	Inflowing can-packed beverages determine how much potential aluminium waste will be generated after product consumption. Similarly, once generated, the discarded cans enter the recycling process. At this stage, discarded cans are both outflow from the consumers, as well as inflow for the recycling process. It takes only 60 days for a single aluminium can to be produced, filled, distributed, consumed and recycled into a new can.
Flow of energy	Recycling aluminium uses only 5% of the energy needed to produce it from virgin materials, reducing greenhouse gas emissions by 95%. By recycling the aluminium, we reduce the need for additional energy to produce new cans. Thus, the required inflow of energy with in process is reduced.
Environmental Impact	Aluminium is valuable at every stage of a product's life cycle - from production to end of use. It can be repeatedly recycled while keeping the properties of the recycled material. Using recycled aluminium reduces the need for primary aluminium and therefore minimizes need for mining for aluminium ores and avoids finite resource depletion, minimizes waste, and lowers greenhouse gas emissions across a product's life cycle.
Sustainability	This program is trying to provide a more environmentally and economically-friendly alternative to the depletion of natural resources and mining that has often caused ecological damage by exploiting raw aluminium ores. If pre-treated and/or sorted, aluminium products can be recycled for use in almost all aluminium applications since the metal's atomic structure is not altered during melting. Aluminium recycling benefits present and future generations by conserving energy and other natural resources[1].
Systems thinking	A systems thinker would look not only at what generates the waste and what is the output of waste generation directly and try to tackle the problem of excessive waste from this perspective solely. Instead, looking at aluminium waste from beverage products in a systemic way, one would seek to understand what is the pathway of aluminium throughout the urban system. For example (but not exhaustively): Who generates it and how much of it is generated? What is the capacity to generate aluminium from raw materials/mining? What could be alternative uses? How much of it can be potential input for a recycling process? What would be a reasonable recycling rate given the waste generation rate? How would aluminium be best reintroduced in the economy?

[1]Source: http://www.world-aluminium.org/media/filer_public/2013/01/15/fl0000181.pdf

Circular economy:	Aluminium is a material that can be melted and remoulded (i.e. recycled) multiple times. In this way, its inherent properties do not change during use and following repeated recycling into new products. Encouraging recycling of aluminium cans is thus one way to achieve a circular economy, whereby waste is regenerated as new products.

Example 3:No Food Waste Aiud

Organization or Company: Society for Responsible Consumption
Country:Romania
Description: A group of young volunteers from the small town of Aiud in Romania decided to tackle the issue of increasing food waste through grass-root level actions in their local market. In September 2016 they started a food waste prevention project, and just in the first year of activity they collected over 1300 kilograms of "ugly" but quality vegetables. These were later donated to more than 80 people in the local community. The project is a seasonal, but ongoing one. Find out more about it here https://www.youtube.com/watch?v=Zj7qt_9ZaVM and here https://www.romania-insider.com/pumping-life-small-romanian-town-reducing-food-waste/

Terminology:	How to apply the key concepts when analyzing the practice?
Urban metabolism	Food is perhaps one of the products that is the easiest to visualize as something that is metabolised by a society. That is because any human and any society needs food for survival. It comes into the urban communities through imports from other countries, or nearby farms and factories. It exits the urban community as waste (wastewater, solid waste) after being consumed, or compostable material: food remains that were not edible, or unused and discarded fresh food. About a third of the food produced globally is lost or wasted[2]. This initiative seeks to reduce the wasted food by reintroducing "unattractive" and thus potentially wasted food into the food consumption circuit of the urban community.
Stock	The stock of fresh food waste increases with food being thrown away, and decreases as it is either discarded for compost, or deposited on landfills, or by recovering the good fruits and vegetables and reintroducing them into the metabolic circuit.
Flow of materials (Material flow)	Food comes into the town of Aiud as an inflow of raw or processed products from other countries, or nearby farms and factories. The outflows can be multiple: sewerage, biodegradable/compostable solid waste. To reduce the solid waste, this initiative recovers the food and reintroduces it as inflow into the food supply of the town.

[2]Source: https://www.sciencedirect.com/science/article/pii/S0956053X18301740

Environmental Impact	Producing food requires the use of arable land, energy, water, chemicals and other valuable materials, as well as often - contamination of environment with pesticides, artificial fertilisers, and greenhouse gasses. The food from the local market that is considered "ugly" or not fresh enough to be sold to customers is recovered by the volunteers and reused as good food to help the people in need. This is translated in a reduced waste of resources, reduced landfill stock and reduced greenhouse gases.
Sustainability	Discarding food that could have been eaten by humans, except for the case when it is spoiled, is a total lost for the environment, society and economics. The "No Waste Aiud" program is a sustainable practice because it contributes to reducing the waste of resources (food and resources used to produce food). This results in environmental and economic benefits. Simultaneously, by providing people in need with food, it also has a social benefit. This initiative can be carried out into the future to address the above-mentioned environmental, economic and social issues.
Systems thinking	Thinking in terms of multiple casualties and benefits of a single activity is a feature of a systems thinking. Almost a third of food products in Romania are wasted annually[3]. This reality collides with the fact that poverty and social exclusion in the country is among the highest in the European Union: 40.2%[4]. Reducing food waste is among one of the most at-hand measures to tackle multiple, yet connected environmental and social problems.
Circular economy	Volunteers, who are members of the local community, are reintroducing the food that is safe for human consumption back into the value chain.

More on urban metabolism and resource efficient cities is available here:
https://resourceefficientcities.org/wp-content/uploads/2017/09/Urban-Metabolism-for-Resource-Efficient-Cities.pdf

[3]Source: http://foodwaste.ro/ce-este-risipa-de-hrana/#1481708895048-d86bc495-8bd3
[4]Source:https://ccir.ro/2016/11/03/food-waste-a-major-social-problem-in-romania-discussed-at-ccir-business-center/

4. Homework - Individual and group Exercise

4.1 Explaining the terminology and definitions

Exercise type: individual work
Task: Watch the fragments of the video materials mentioned in the tables below (1) - (8).
In each of the video fragments, try to identify and briefly describe examples that fit with the concepts listed in the column "Concepts". To understand how the concepts, relate to the examples in the videos, look back at the definitions. You may also wish to consult the examples presented in the previous chapter.

(1) Documentary: From Farm to Fork[5]		
Fragments:	**Concepts:**	**Examples:**
Min 1:10 – 14:15	Flow of materials (Material flow)	

(2) Documentary: From Farm to Table[6]		
Fragments:	**Concepts:**	**Examples:**
Min 1:15 – 15:00	Urban metabolism	
Min 1:15 – 15:00	Flow of materials	
Min 1:15 – 15:00	Flow of energy	
Min 1:15 – 15:00	Environmental Impact	

[5] Link video: https://www.youtube.com/watch?v=u9lU7GOPWAw
[6] Link video: https://www.youtube.com/watch?v=f1b1YWwF3_I

(3) Documentary: The Rise of Sustainability[7]		
Fragments:	**Concepts:**	**Examples:**
Min 14:00-19:09	Sustainability	
Min 27:50 – 34:00	Circular economy:	

(4) Documentary: The Urban Green[8]		
Fragments:	**Concepts:**	**Examples:**
Min 3:40 – 11:05	Flow of energy	
Min 15:55 – 20:55	Urban metabolism	
Min 21:00-23:40	Sustainable urban mobility	

(5) Documentary: Introduction to SD overview[9]		
Fragments:	**Concepts:**	**Examples:**
Min 2:43- 14:00	Systems thinking	

[7] Link video: https://www.youtube.com/watch?v=0UZjCSBdyzM
[8] Link video: https://www.youtube.com/watch?v=o86Ut6kAEMQ
[9] Link video: https://www.youtube.com/watch?v=AnTwZVviXyY

(6) Documentary: System Dynamics[10]		
Fragments:	**Concepts:**	**Examples:**
Min 4:00-5:00	Stock	
Min 0:00-6:07	Systems thinking	

(7) Documentary: The Last Call[11]		
Fragments:	**Concepts:**	**Examples:**
Min 0:00-6:30	Sustainability	
Min 0:00-6:30	Systems thinking	

(8) Documentary: The Future of Cities[12]		
Fragments:	**Concepts:**	**Examples:**
Min 0:00 - 5:50	Urban metabolism	
Min 5:50 – 9:45	Sustainable urban mobility	
Min 9:45 – 13:15	Circular economy:	
Min 13:15-16:40	Environmental Impact	

[10] Link video: https://www.youtube.com/watch?v=nxlHUW3jZeY
[11] Link video: https://www.youtube.com/watch?v=SzUKVqD-xKs&list=PLp2sSyTWaut1rxZbRAZUfVxQDrQu5nk42
[12] Link video: https://youtu.be/xOOWk5yCMMs

4.2 Understanding the topic by connecting with real life examples

Exercise type: individual work
Task: Watch the news/media reports mentioned below (Case A & Case B). In each case, answer to the listed set of questions.

CASE A - Polish City of Lodz: The Water Paradox - Metropolitans (NEWS - 8'03'')[13]

Questions Case A:

1. The flow of which "material" is presented in the news?
2. Flow of material presented in the video: from where is the respective material flowing into the city?
3. Flow of material presented in the video: How it was used in the past? How is it used now in the city?
4. Flow of material presented in the video: what can you say about how it was flowing out of the city in the past? How is it flowing out now?
5. What were the measures taken to improve the way this material is metabolised by/in the city?

CASE B - Woodlands in the City: Green Space at Penn (MEDIA REPORT - 2' 24'')[14]

Questions Case B:

1. The stock of which "material" has changed over time?
2. If the stock of this material increases, the stock of which material decreases?
3. What are the benefits of the increase of this stock of material?
4. What are the trades-offs of the increase of this this material?

4.2 Looking at examples around us - case study from our local reality

Exercise type: group work.
Task: In teams of 4-5 people, identify an example from your local community or country that exemplifies a sustainable/ less sustainable case of urban metabolism. Explain why is a good/bad practice. In your arguments make use of:

- The definitions used in the course;
- Data from official sources (e.g. UNEP; website of environmental agency; reports from WHO, country statistics, etc.).

Output: Prepare a minimum 1 page - maximum 5-page team report and share the findings in the class in a 5 minutes presentation.

[13] Case A: **Link Video** https://www.youtube.com/watch?v=R5U5gBu
[14] Case B **Link Video** https://www.youtube.com/watch?v=-suEYEPZpRc

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