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Abstract - Eco-Cycle Model 2.0. for Stockholm Royal Seaport City District

Development of the Eco-Cycle Model 2.0. is one of a total of five sub-projects in the city of Stockholm which have been granted economic support from the Swedish Delegation of Sustainable Cities in order to contribute to making the Royal Seaport in Stockholm a world-class environmental profiling urban area. The purpose of this pre-study is to investigate the options for developing an eco-cycle model that grasps more dimensions than the Hammarby Model, including overall and detailed descriptions of resource flows in different time perspectives. Important starting points for the pre-study are:

- Global and local challenges concerning our use of resources with specific relevance for urban development
- Available models which visualise functions, resource flows and resource synergies in the eco-cycle in a qualitative way
- Available accounts of material, energy and water which quantify functions and resource flows

In order to involve stakeholders in the development process, representatives from different organisations were invited to two workshops where ideas were developed and combined. These workshops are documented in two separate reports (in Swedish).

The primary objective of the eco-cycle model is to contribute to drawing attention to and explaining important connections and synergies between resource flows. Secondary objectives that can be fulfilled after supplementing the development work are: to be a tool for monitoring and follow-up of environmental objectives, to serve as a dynamic tool for analysis of resource flows and to be more comprehensive.

The proposed eco-cycle model 2.0. is not only a general map of functions and flows related to the eco-cycle which characterised the Hammarby Model, but also a line of arguments supported by illustrations on four different levels:

- Level 0 Established theories and concepts for sustainable societal and urban development constituting the basis of the eco-cycle model
- Level 1 Anchoring of the eco-cycle model in a more comprehensive sustainability concept
- Level 2 General Map of functions and flows related to the eco-cycle model including optional systems solutions both within and outside the city district (outside the defined systems boundary). Conceptual future image for 2030 with a perspective towards 2050.

This proposal for a conceptual eco-cycle model 2.0. should be considered as a basis for future R&D work and applications. The presented desirable situation for 2030 with a perspective towards 2050, in line with the applied back-casting methodology, may be used as a basis for defining different stages in a short-term and mid-term perspective. A number of possible development projects which should be initiated as follow-up of the pre-study are defined. One example is the need for developing pedagogical descriptions and presentations supported by visualisation and animation tools. The international perspective is also important, as there is an increasing interest in The Royal Seaport City District in a rapidly urbanising world where many cities are preparing for – or have already started – planning of city districts with high sustainability ambitions.
1. Introduction

Background

The City of Stockholm received a decision from the Swedish Delegation of Sustainable Cities (DHS) to go ahead with five sub-projects that will contribute to making Stockholm Royal Seaport (SRS) a world-leading urban area from an environmental perspective. One of these sub-projects – sub-project 5 – is concerned with development of Eco-Cycle Model 2.0 for the Royal Seaport City District with reference to both the earlier eco-cycle model for Hammarby Sjöstad (Eco-Cycle Model 1.0) and to ongoing development activities within SRS focusing on various sub-segments (energy, waste, water, eco-systems, transports, etc.) that are related to eco-cycle issues.

The City of Stockholm has also been inspired by the VINNOVA-supported development project Visu-City at KTH, which has developed different approaches and tools for visualizing the eco-cycle at multiple scale levels. The project was conducted as a collaboration between the departments for Geoinformatics and Urban Planning and Environment during the period 2008-2010 (Ban and Ranhagen et al., 2010). This contributed to underlining the need for an Eco-Cycle Model 2.0.

In January 2012, KTH Urban Planning and Environment (through Professor Ulf Ranhagen), which had primary responsibility for the sub-project that visualized the eco-cycle, was invited to collaborate with KTH Industrial Ecology (through Professor Björn Frostell) to participate in the city’s development with ideas and solutions that can lead to development of an eco-cycle model which reflects the ambition to make Stockholm Royal Seaport a world-class example of an attractive, sustainable and climate-positive city district.

Purpose and scope

The purpose of the feasibility study can be summed up in the following seven points:

- To contribute to the development of an eco-cycle model that captures the city’s technical systems and eco-cycles with a higher level of detail than in the Hammarby Model (Eco-Cycle Model 1.0).
- To contribute to the development of an eco-cycle model that captures more dimensions than the Hammarby Model.
- To create a model that allows for both conceptual and detailed descriptions of the relevant resource flows and their interplay.
- To enable descriptions of functions and flows associated with different scales and levels of planning.
- To develop a model that can be used as an aid for interdisciplinary triple-helix collaboration between city officials and representatives for the private sector (developers, environmental technology companies, suppliers and consultants), as well as researchers and other experts in the academic sphere.
- With the help of the model, to facilitate cooperation and communication between the City and the public, visitors and others.
- With the support of the model, to facilitate cooperation with other projects such as Smart City SRS and development of follow-up systems.

The purpose was described in more detail in our work program from the spring of 2012 and is presented here with minor revisions based on experiences from the completed study:

a. To create a model that is not static, but that is so dynamic and flexible that it can be adapted to new information and facts over time, as well as to the needs of different actors.

For example, it should be possible to adapt information in the model for a variety of target groups (school children, young people, middle-aged and older individuals active in different workplaces (i.e. private businesses, the public sector, commercial and cultural services), experts from national and international delegations, politicians, etc.

- It should be possible to use in explaining the eco-cycles to users and visitors, for example in the city district’s new information center.
- At the same time, it should be possible to make it more detailed so that it can function in professional contexts, such as inter-sectorial meetings between experts who develop the technical supply systems in the district.
- The model should also function in dialogue between city officials from various departments and politicians, as well as representatives for users and different companies, such as construction companies, housing companies, companies with responsibility for energy, waste, water, etc.
- It should be possible to make the model interactive so that different players can actively change parameters and see how this influences the environmental effects.

b. To create a model that allows for both a conceptual and more detailed description of the separate resource flows for energy, water, materials, food and waste.

The model should describe the resource flows, for example with a division into input-use-output and with feedback loops that make it possible to analyze how the resource flows can interact. It should also be adaptable to time series, i.e. to describe the historical situation, the present and the future. One important aspect here is the connection to the follow-up model so that different types of data can be visualized, such as:

- input data about energy, water, materials/waste, food,
- use of resources for various purposes – housing, work, service, transports, etc.,
- effects and consequences, e.g. emissions of greenhouse gases and other substances into the air and water, health impacts, etc.

C. To develop a model that illustrates the resource flows at different scale levels: global, national, regional, city and city district, from a human-centered perspective. It should also be possible to further refine a developed model to allocate resource flows at more detailed levels – city block, building, apartment and appliance/equipment.
In addition, the different levels should be interlinked so that it is possible to scalelessly zoom in and out within the model. The division into levels improves the potential to adapt the model for different target groups, not least the users. In a further development of the model, work at multiple scale levels also facilitates reporting of a more detailed visualization and description of the resource flows’ connection to and integration with other urban sub-systems, such as the eco-systems (green spaces/green space factor, storm water, biodiversity, urban farming), energy flows connected to buildings, traffic and transport systems, the functional structure, socio-cultural values, economic factors, etc.

The above purpose outlines the proposed long-term objectives for development of an Eco-Cycle Model 2.0. This feasibility study should be seen as a first step in a longer process that involves more players and goes further in terms of technical design and practical adaptation than has been possible here. This also applies to linkage to other studies and activities, such as a description of socio-cultural, economic and ecological effects and consequences. More specific objectives for the eco-cycle model have been formulated by the City’s representatives, partly based on the joint efforts at workshop 1, see also the chapter on visions and goals for the eco-cycle model.

**Organization**

The report has been written at the KTH School of Architecture and the Built Environment by:

Ulf Ranhagen, Professor at the Department of Urban Planning and Environment, Honorary Professor at Tongji University in Shanghai, Guest Professor at Lulea University and Senior Chief Architect at Sweco architects.

Professor Björn Frostell, the Division of Industrial Ecology at the Department of Sustainable Development, Environmental Science and Engineering.

The formal client of the feasibility study is the Stockholm City Development Administration. The study has been performed by a working group consisting of Ingmarie Ahlberg, Environmental Manager at the City Development Administration, Christina Salmhofer, environmental coordinator for SRS, Maria Lennartsson, environmental expert, Ulf Ranhagen and Björn Frostell.

The study has also been carried out in close ongoing collaboration with the Environmental Coordination Group for the Stockholm Royal Seaport (SRS) and has also been presented to the Environmental Profile Group for SRS, which includes representatives for the six focus groups. In addition, two large workshops have conducted active development efforts that have been of major importance for this work. Since the autumn of 2012, these activities have also been linked to the CESC, the Center for Sustainable Communication at KTH, where Professor Mattias Höjer and Licentiate of Engineering Anna Kramers have acted as contacts.

Architect Jessica Agoes has participated in documentation of the workshops, and Architect Olav Heinmets in presentation of the final draft. Both are active at Sweco Architects.

The development process for the eco-cycle model is described in more detail in the following chapter, in which more of the participating stakeholders are also named.
2. Starting point – environmental challenges

A range of global and local challenges serves as a starting point for our work. Recent studies illuminate the use of resources relevant to urban development.

**Global level**

At the global level there are at least three main concepts that have had relevance in our development of the eco-cycle model: the planetary boundaries concept, the ecological footprint and the carbon footprint (recently further developed in the EU initiative Product Environmental Footprints; cf EU 2013) Planetary Boundaries (the planet’s limits) is a new approach to defining the conditions for human development that was launched in a now well known article in Nature in 2009, see Rockström et al. (2009). Here, it has been found that exceedance of the basic biophysical boundaries will have serious consequences for humanity. Three of the nine thresholds that are presented have already been exceeded to a major extent as a result of human actions and activities that have significantly affected the environment since the industrial revolution. 1

1 The accelerating loss of biodiversity including the reduction of certain species in the wild is estimated to be 100-1,000 times higher than what can be considered natural.

2 Negative impact on the nitrogen and phosphorous cycles, with conversion of more than 120 million tonnes of nitrogen from the atmosphere into reactive forms, mainly due to production of synthetic fertilizers and legumes, as well as a tenfold increase in the amount of phosphorous that flows into the oceans compared to preindustrial levels.

3 The ongoing climate change has attracted even more attention since the article was published, and many people are questioning the viability of limiting the increase in the global temperature to 2 degrees Celsius, which would demand a limitation in the atmospheric CO2 concentration to 350 ppm and a maximum increase in outgoing heat radiation to 1W/m2 compared to pre-industrial levels.

These three factors are closely linked to the six other boundary conditions: global use of freshwater, land use change, the presence of aerosols in the atmosphere, chemical pollution, acidification of the oceans, and reduction in the levels of stratospheric ozone.

The ecological footprint (EF) is an overall measure of the consumption-related fertile land requirement that was first launched by the Canadian scientists Wackernagel & Rees (1996). The WWF’s footprint calculations estimate the amount of biologically productive area that is required to both produce everything we consume and to absorb the waste – including the surface area required for absorption of CO2 emissions. The WWF presents annual statistics on the national ecological footprint of all countries in the world divided into the categories of land for CO2 absorption, cropland, grazing land, forest, fishing grounds and built-up areas. According to the WWF’s Living Planet Report 2012, we Swedes have an average ecological footprint of 5 global hectares 2 and are in 13th place on the list of countries with the largest footprint per person. There are few studies on how to measure the ecological footprint of cities, but it is clearly apparent that cities require a very large surrounding area of productive cropland and forest (which can naturally be spread in several locations) in order to support their consumption and emissions. According to one estimate, it is only possible to meet 1-2% of the local food and energy requirement within the city’s immediate environs, see Berg (2011).

The carbon footprint more specifically shows emissions of climate-affecting gases (CO2, CH4, NOx, halogens), from households, transportation, food and other consumption. This includes emissions driven by consumption within a municipality and whether these emissions occur within or outside the municipal boundaries. Two Swedish studies (WWF, 2008, and the Swedish Environmental Protection Agency (Sida) and the WWF (2010) have estimated Sweden’s total carbon footprint at 8.5 and 9.5 tonnes, respectively, per person and year.

A reflection of the challenges facing the Stockholm Royal Seaport can be seen in a study on the footprint of Swedish municipalities that has been carried out in collaboration between the Swedish National Development Cooperation Agency (Sida) and the WWF (2010). Looking at the carbon footprint per capita, the variations between municipal groups are not remarkably large. There is a difference of 1.3 tonnes of CO2 between the rural municipalities and the major cities, which are the two extremes. Of the nine municipal groups that were included, the major cities have the second lowest emissions per capita and are on par with the category of other municipalities with a population of more than 25,000. Despite somewhat lower per capita emissions in the major cities, their larger populations are associated with a significant total environmental impact (around 17% of Sweden’s total carbon footprint). The breakdown of the per capita footprint of 6.4 tonnes in the major cities is: 1 tonne for food, 1.4 tonnes for households, 1.7 tonnes for transports and 2.3 tonnes for other consumption. 3

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1 In the Anthropocene epoch, which has followed the more stable pre-industrial Holocene epoch.

2 A global hectare (gha) is a unit used to measure the average productivity of all biologically productive areas on earth.

3 The results of studies on the footprint can vary, partly depending on system boundaries. A study by N. Brandt estimates a total of approx. 8 tonnes per capita in Stockholm with the following breakdown: 2.5 tonnes for food, 1 tonne for households, 2 tonnes for travel and 2.5 tonnes for other consumption.
One established method for reporting the flow of CO₂ equivalents from a life cycle analytical perspective has been developed by the Global Footprint Network (cf GFN 2013). It differs to a certain extent from the ISO’s standardized life cycle analysis method with regard to system boundaries, but provides a life cycle-based estimate of the climate gas emissions of an activity, product or service.

Despite several methodological challenges and still varying results, the trend indicates that the carbon footprint will be developed into a standardized and generally used method for monitoring society’s emissions of climate-affecting substances.

Local level

Stockholm has been successful in combining a decrease in CO₂ emissions with economic growth. According to a recent OECD report (2013), Stockholm reduced its per capita CO₂ emissions by 30% while economic growth (measured as GDP per capita) increased by 76%. This does not include the CO₂ that is embedded in our imports, for example of consumption goods. 4

A few other challenges that are mentioned in the OECD report and are of direct relevance for the eco-cycle model are:

- District heating and cooling, which provide for 80% of the heating and cooling needs in Stockholm, have strongly contributed to low per capita emissions in Stockholm. District heating and district cooling account for 10% of the region’s electricity use. Although district heating is primarily produced using biofuels (37%) and waste incineration (31%), around one third (32%) is based on fossil fuels in the form of oil and coal. The potential to reduce fossil dependency, to raise the share of renewable electricity and to improve the efficiency of the system in general (reduce losses) needs to be utilized to a significantly higher degree. Heat pump technology and geothermal energy can also be developed as an integral part of the district heating and cooling system in order to reduce emissions. 5

- Although waste generation in Stockholm is somewhat lower than the average for the OECD countries (1.43 kg/capita/day compared to the OECD average of 1.48 kg/capita/day), the share of incineration of solid waste is high (69%) and the recycling rate for organic waste and bulky waste is relatively low. Stockholm also has higher generation of waste than the rest of Sweden (average of 1.32 kg/capita/day). The recycling rate for organic waste is around 21% (2010) and has not risen as quickly as in many other European cities. It is notable that of the household waste that is incinerated, 38% consists of organic waste that could be utilized for production of biogas.

- Stockholm enjoys a high quality supply of fresh water. Lake Mälaren provides 90% of Stockholm’s drinking water and in the past 10 years, 96% of the water samples have shown the highest level of water quality according to the EU Water Framework Directive and 4% have shown the second highest level. There are potential risks in the current trends for protection of fresh water reservoirs in the form of increased run-off of polluted storm water into Mälaren. With a projected rise in sea levels by 50 cm by 2050, saltwater penetration into Mälaren may require extensive infrastructure measures.

4 However, new calculation methods are being developed which include both imports and the effects of our foreign exports, see e.g. Kander & Jborn in their DN article from 30 July 2013. Because Sweden is a major net exporter of energy, which is embedded in different products, this decreases our consumption-based emissions from around 9 tonnes to 4 tonnes. The reason is that Sweden has a low carbon energy production system compared to most other countries. Since these calculations have been made for Sweden as a whole, and Stockholm accounts for a limited share of the country’s industrial production, it can be misleading to apply the method at the Stockholm level. It nonetheless illustrates the importance of discussing system boundaries, which we will get back to. There is no room for elaboration of the discussion in this context.

5 The term combined heat and power (CHP) is normally used for plants that generate both electricity and heat. Fortum uses the term district heating with the addition of specifying the allocation between electricity and heat generation.

Figure 2. The Hammarby model is an important starting point for the development of Eco-cycle model 2.0 for SRS (Stockholm Royal Seaport).
3. Starting point – earlier approaches

In particular, there are two main types of earlier approaches that have been useful as a basis for development of the eco-cycle model:

- Models that visualize functions, flows and synergies in the eco-cycle in a qualitative way.
- Material, energy and water accounts that quantify functions and flows in the eco-cycle.

The so-called Hammarby Model (see Figure 2) is naturally an important platform for this work, since for many years it has served as a basis for describing the intentions in terms of the resource cycles for energy, water and waste in Stockholm’s first environmental profiling urban area, Hammarby Sjöstad. The Hammarby Model uses a two-dimensional graphical image to illustrate the main resource flows of energy, water and waste that can be connected to create a resource-efficient district with a focus on housing. The model was developed in 1996 in collaboration between Stockholms Vatten AB (Ltd), the former Birka Energi and SkåfAB in order to achieve the overall goal for “Hammarby Sjöstad to be designed and built as a resource-efficient and environmentally sound city district based on strict eco-cycle thinking”, see also Pandis & Brandt (2009).

Although the model provides only a rough illustration of resource flows without actual quantification of them, it has been of great importance – especially internationally – in describing the eco-systems approach for the city and the district. It shows the importance of visualization in teaching and explaining complex systems solutions. The model allows both a separate description of each of the three sub-systems – energy, water and waste – and an incorporation of these three systems into a greater whole. At the center of the model, there is a symbol for the district that is served by the different flows. There are a number of conceptual, pedagogical descriptions of the model in the information brochures created for the information center in Hammarby Sjöstad, GlasHusEtt, but there do not seem to be any scientifically-based descriptions of the model.

A booklet from 2006, see GlasHusEtt (2006), describes the Hammarby Model as a unique eco-cycle where the integrated environmental solutions can be monitored. The eco-cycle handles energy, waste, water and wastewater for housing, offices and other activities in Hammarby Sjöstad. Planning for the eco-cycle is seen as an important aspect of the integrated planning with a focus on the environment. The booklet describes the environmental goals that form the basis of the model and presents several examples of integrated solutions – developed in collaboration between city administrations, public authorities, architects, engineers and building contractors.

The model has come to function as an archetype for development of similar technical systems in major cities, partly because it has been a central aspect in the presentation of Hammarby Sjöstad for a large number of delegations over the past 15 years. Integrated planning of the Hammarby Model and the eco-cycle model has also been one important starting point for development of the Swedish SymbioCity concept. It serves as a platform for knowledge transfer and export of Swedish solutions for sustainable urban development.

The conceptual model for urban sustainability presented in the SymbioCity Approach builds on established theories of sustainability and is centered on humans and their interactions with environmental, sociocultural and economic aspects. The necessity of synergies between all urban systems is emphasized, see Figure 3. Here, the eco-cycle model’s central systems of energy, water and materials/waste are also related to the eco-system, urban functions like housing, workplaces and services, etc., transports, the built environment, public spaces and ICT (Information and Communication Technology). The spatial dimension is given great weight alongside institutional factors, see Figure 3. In connection with application of the SymbioCity Approach around the world, a number of practical, site-adapted examples of spatial eco-cycle models have been developed in different countries, including Ireland, Russia, Canada and China:

- A sustainability program for South Docklands in Ireland formulated an eco-cycle proposal at different scale levels that also illustrates the system boundaries and interdependence between the levels (Sweco 2007).
- In the development of a proposal for a new city in China (Tangshan Bay Eco-City), an eco-cycle model was created in the form of a flow diagram at several planning levels and includes a proposed eco-cycle center for coordination of all central facilities for energy, materials/waste and water, separation of grey water and black water, and production of nutrients for the surrounding agriculture as a replacement for synthetic fertilizers (Sweco 2009).
- In connection with a conceptual proposal for a new “innovation city” – Skolkovo in Moscow – an eco-cycle model was developed with an emphasis on locally produced renewable energy in combination with established large-scale systems for combined heat and power, as well as waste management and smart electric grids (Sweco 2011).
The VisuCity project, inspired by examples such as international applications of the SymbioCity concept, developed ideas for how visualization of the eco-cycle systems can contribute to highlighting eco-cycle issues in physical planning of a city district, with SRS as the foremost application example. In the early stages of the program, visualization of systems such as those for water and wastewater connected to the urban structure can facilitate selection of the optimal system – compared to the use of flow diagrams alone. Description of proposals at different system levels facilitates decisions in the design phase. Visualization can also support follow-up of goal attainment in implementation and in the finished environment.

There are also other examples of eco-cycle models created to describe how the systems function, such as illustration of eco-cycles that can be of relevance for the development of an eco-cycle model for SRS:

- In a pedagogical manner, Borås Eco-Cycle City shows the energy, waste and water systems for a mid-sized Swedish city (Source: Tekniska Verken i Borås Stad)
- Smart City is an international concept that has gained widespread attention, and that shows different ways in which ICT solutions can be integrated into the design of city districts (Source: A Japanese Smart City Project)
- An interactive system diagram created by the Ellen McArthur Foundation to illustrate how organic and non-organic materials can be recycled at different system levels (Source: www.ellenmcarthurfoundation)

The eco-cycles for energy, materials/waste and water are closely related to the eco-system in general, and also to that which is known as eco-system services. According to Wikipedia, these are functions of eco-systems that in some way benefit mankind. Eco-system services are commonly grouped into four categories:

- Supporting services are necessary for the production of all other eco-system services, such as nutrient and water cycling.
- Regulating services consist of somewhat more specific functions such as pollination, purification of air and water, as well as attenuation of storm water flows (our addition).
- Cultural services include everything that we use for our more emotional well-being, such as aesthetic and recreational experiences
- Provisioning services refer to food and materials that we can obtain and use more or less directly.

The VisuCity project was a source of inspiration for work on Eco-Cycle Model 2.0. It indicated far-reaching potential in visualization that can be of interest when Eco-Cycle Model 2.0. is further developed and concretized.
In today’s economy we use formal accounts primarily for financial transactions. These represent a major simplification of the real economy, which also encompasses other activities – so-called externalities such as housework, volunteer work, emissions of climate-affecting substances and social processes. In the rapidly expanding global economy, the externalities of emissions and their subsequent environmental impacts have gained fast-growing importance.

A recently published book (Laestadius 2013) discusses this accelerating environmental load in the global economy and it is increasingly clear that accounts for physical resources like energy and materials must be included to meet the need for achieving ecologically sustainable development. When introducing energy and material accounts, it becomes increasingly important to apply life cycle thinking and report the total energy and material flows for a particular product, service or process, whether used/provided in the SRS, Sweden or elsewhere in the world.

One analytical approach for creating accounts in an economic system with many sectors is to use a so-called input-output analysis. It is based on the idea that goods flow from one sector to one or several other sectors and that a balance is thus created between producers/sellers and purchasers/buyers in the system. For a more in-depth description of input-output analysis, see e.g. Miller and Blair (2009).

As highlighted above, it has been shown that visual models are very useful in conveying a message and/or communicating complex interactions effectively. One example of how accounts based on parameters such as input-output analysis can be converted into effective communication is the use of so-called Sankey diagrams. These diagrams are based on illustrating flows, for example of goods or resources, with arrows where the thickness of the arrow is directly proportional to the flow magnitude.

An early Swedish approach to creating material accounts for municipalities was development of the so-called ComBox Model (Frostell et al. 1994). In the model, annual flows of different materials are followed through different economic sectors in society. Inflows to the system take place through the air, through human-controlled transports and through water. Outflows take place in the same manner. Within the ComBox, a certain amount of the substance is metabolized and emitted into the environment (air, soil and water) or is transported by humans to other systems (municipalities). The first application of ComBox was for nitrogen in the Municipality of Varberg (Figure 5, cf Brandt et al. 1996).

In 2010, a master’s thesis at KTH reintroduced the ideas from ComBox but applied them at the regional level – the County of Stockholm (Sörenby 2010). Here, the phosphorous flows in the regional economy were followed from the inflow to Stockholm County and to their final resting place during 2010. Two clear conclusions of this work were (i) that the phosphorous flow through the County is largely linear and shows a lack of eco-cycle thinking, and (ii) that accounts of this nature are an effective tool for monitoring how a material flows through a society and is metabolized in different social processes (cf Figure 6).

Figure 5. The ComBox model for nitrogen – Municipality of Varberg 1995; Numbers refer to flows of nitrogen (t/yr). Source: Brandt et al (1996)

Figure 6. Phosphorus flows in Stockholm County 2009. Source: Sörenby (2010)
4. Development process

In order to become a useful tool in the City’s sustainability and environmental efforts, it was imperative to involve relevant stakeholders in the development of Eco-Cycle Model 2.0. There was no single obvious solution for how the model should be designed, rather it was a question of creating an interactive process for further development and modification. In a later process, it can also be useful to develop a series of interrelated sub-models that can be adapted to the needs of different target groups in various phases of the planning and implementation process, in different types of applications, etc.

In order to involve different local stakeholders, two workshops were organized in collaboration with the City, both of which were documented in separate reports.

Two basic premises for the entire feasibility study and the workshops were to apply a relatively long-term perspective (2030) and to use a back-casting approach. In short, this means that possible ideas and solutions for the year 2030 were the main focus and that steps or stages along the way were outlined based on a future vision for 2030. Given the limited amount of time available for the workshops, a strict application of this methodology has not been possible.

Workshop 1 – which was held on 31 May 2012 – was attended by 17 people representing different departments within the SRS project organization from the Municipality of Stockholm (the City Development Administration, the Environmental Administration), the Stockholm Water Company, and representatives from the Ports of Stockholm and the energy company Fortum. The participants were also active the SRS focus groups and in the environmental coordination group. The main purpose of this workshop was:

- To present and discuss different goals and motives for development of an Eco-Cycle Model 2.0.
- To describe and test a few approaches that can serve as a starting point or energy and waste.
- To describe and discuss how to structure the process of developing the eco-cycle model.

Following an introduction by Environmental Manager Ingrid Ahlberg, Björn Frostell presented examples of metabolic approaches and Ulf Ranhagen presented different ways of describing eco-cycles and resource flows also with relevance for urban and regional planning and urban design. In the first stage of the workshop, the participants were divided into four smaller groups that used structured brainstorming to formulate ideas for objectives/motives for Eco-Cycle Model 2.0, see Figure 7. This work resulted in each group agreeing on five key objectives/motives and also exploring a possible overall vision. The results of the four groups’ work have been compiled and further processed within the City into a coherent picture of the targets, see also Chapter 5.

In the second part of the workshop, the four groups were asked to develop ideas about resource flows to provide input for the flow analyses to be included in the eco-cycle model. As a basis for the workshop, a classic flow model was used with empty fields for resource extraction, production/distribution, use and reuse. Each of the four groups worked with a specific area: water, energy, materials/waste and transports. Ideas were formulated by the groups and were written down on Post-It notes that were placed in the different stages of the flow model.

In the third part of the workshop, the idea was for the groups to brainstorm ideas for an integrated model in which the working group had developed a graphical image that allows allocation of ideas related to all types of resource flows – energy, materials/waste and water – at different system levels. In the basic model, all of the activities and operations that will be conducted in SRS in interplay with the physical structure for the built environment, transports and green areas are found in the middle of the image. The different resource types can be described as sectors in the image, which creates opportunities to discuss ideas at different levels – both outside SRS (in the rest of the world) and within SRS. In this way, the model enables description of both functions and flows in the chain of resource extraction – production – distribution – recycling/reuse for the different resource types. It is also possible to illustrate interconnections and synergies between different resource types, such as energy and water or energy and waste.

There was not enough time at workshop 1 to use the graphical image practically to generate ideas from the groups. At the same time, this image proved to be an important tool for discussion, documentation and visualization in subsequent work during the feasibility study.

Workshop 2 – held on 23 October 2012 – was attended by 18 people, of whom 12 had also participated in workshop 1. The participants represented all of the organizations that took part in workshop 1. In addition to KTH, the speakers included Hanna Eklof from the Swedish Transport Administration on the theme of “Energy-efficient transports to increase the share of renewable energy”.

The first step at workshop 2 was to continue the process of formulating ideas regarding resource flows in a 2030 perspective using the same material as in workshop 1. The ideas generated for the different steps in the flow model (resource extraction/production – distribution/treatment – use – reuse/recycling) have been documented in two separate workshop reports. They form an idea bank that has been partially used in the design of the flow models in the final proposal for Eco-Cycle Model 2.0.

In the second stage of workshop 2, the groups practically applied the draft integrated model that is described above to consolidate ideas for activities and flows for the different resource flows into an overall picture. The basic model has been inspired by the Hammarby Model’s way of presenting resource flows. The difference is that the Hammarby Model is presented as a finished solution rather than a platform for creative development. Because the groups were able to work creatively by placing ideas for functions, flows and synergies on a “blank slate”, they were able to develop the embryo for alternative models. The short amount of time available meant that this resulted only in preliminary approaches.
Two types of platforms served as a starting point for the groups’ work:

- A platform that focuses on functions and flows to and from SRS linked to different planning levels: the city, the region, Sweden and the world.
- A platform that focuses on functions and flows within the city district.

Certain groups chose to organize their work at these two levels, while other found it practical to use a platform for discussion of both the global and city district perspective.

When processing the results from work on the integrated model from workshop 2, we chose KTH’s working group to structure the ideas from the groups into two different scenarios for Eco-Cycle Model 2.0:

- Scenario A – A high degree of self-sufficiency with small-scale solutions.
- Scenario B – A high degree of large-scale/centralized solutions.

In connection with this revision, the KTH working group also supplemented the scenarios with other ideas that had not been put forward at the workshops. The scenarios showed that the applied methodology holds the potential to develop complex future scenarios for the eco-cycle model. At the same time, it became clear that within the available time and resource framework for the feasibility study, it would be difficult to develop future scenarios as far as necessary to perform an evaluation and impact assessment.

In January 2013, a decision was made to develop a comprehensive future scenario for 2030 (looking ahead to 2050) to reflect the ongoing planning within SRS, where a combination of large-scale/centralized and small-scale solutions was sought.

During the period from February to May, the draft model was gradually refined to create the proposed Eco-Cycle Model 2.0 as further described in the Chapter “Overview of the model’s different levels” below. The overview of functions and flows, which illustrates the connections between different systems, has been developed parallel to flow models that enable quantifications. One central part of this process has been to conjoin all of the different approaches and ideas among both the KTH researchers and the City’s representatives about what is important to demonstrate with Eco-Cycle Model 2.0.

In the final phase of the project, a non-formalized Delphi process was used in which researchers together with a core project team from SRS successively revised parts of the proposed model in several stages until a common understanding was reached. The critical but constructive discussion that took place in this part of the project contributed significantly to the proposed Eco-Cycle Model 2.0 and gave it considerably more depth relative to the provisionally produced proposals.
5. Visions and goals for the eco-cycle model

The synthesis of conceptualized visions and goals for the eco-cycle model that was conducted by the City following the workshops is presented in Figure 8. Four main goals have crystalized. The primary goal is to inform and elucidate, i.e. for the model to contribute to knowledge and insight and assist in illustrating and explaining significant connections between resource flows. The secondary main goals that can be met after further study are:

- To serve as a tool for environmental monitoring
- To serve as a dynamic analysis tool
- To be comprehensive

As shown in the figure, each of the main goals has then been divided into sub-goals. A few particularly important sub-goals for the main goal to inform and elucidate are:

- To provide knowledge and create the conditions to meet the eco-cycle targets.
- To communicate to different audiences and target groups in order to increase understanding of and knowledge about the SRS objectives.
- To provide insight about system boundaries and the limitations of the ecosystem.
- To show different geographical scales – to illustrate flows from the local to the global level.
- To inspire – to create a desire to explore and develop.

The secondary main goal – to serve as a tool for monitoring of environmental targets, should be interpreted as meaning that the model can be linked to specific monitoring models and tools that have been developed in other projects, not that the feasibility study includes models or tools of this type.

The secondary goal – to serve as a dynamic analysis tool, is a high ambition that cannot be fully attained in the feasibility study, but which has provided inspiration for creating a concept that can be developed in a direction that allows more advanced tools to be added. Our workshops demonstrate the potential to also utilize materials produced in the feasibility study as qualitative tools in collaboration between a number of different stakeholders.

The proposed visions and goals can be seen as a living document that can be modified and further developed over time.

With regard to the secondary goal to be comprehensive, the focus of this work has been on energy, material/waste and water flows, but with a view to enabling description of the eco-cycle in a holistic manner on different system scales, i.e. in both a global and a local perspective. Furthermore, the aim is to relate the model to different sustainability dimensions and urban systems, such as transports and eco-system services.

![Figure 8. The City’s compilation of visions and goals for the eco-cycle model based on the results of workshop 1. Colors show main goals (blue), secondary goals (grey), tertiary goals (green) and boundary conditions (yellow).](image-url)
6. Overview of the model’s different levels

Eco-Cycle Model 2.0 is designed to be much more than an overview of the functions and flows that characterized the Hammarby Model. The model is seen as a series of arguments and illustrations at the following levels:

- Level 0: Established theories and models for sustainable social and urban development.
- Level 1: Eco-Cycle Model 2.0 rooted in a broader sustainability context.
- Level 2: Overview of functions, flows and fractions in the model.
- Level 3: Flow analyses linked to accounting systems for the energy, material/waste and water eco-cycles.

Level 0: Established theories and concepts for sustainable social and urban development

Eco-Cycle Model 2.0 is designed based on an ideology towards sustainable development that is in line with the Brundtland Commission’s proposal in the report Our Common Future for division into ecological, social and economic aspects of sustainability, but also with its so-called generation principle. The basic definition of sustainability in the Brundtland report has stimulated the development of a number of different ways of looking at sustainability, that which research describes as discourses.

There are compelling reasons for setting the ecological aspects in focus, since to our current knowledge, eco-system functioning and capacity set the limits for demographic and economic growth. The discourse can be illustrated by three circles, where the eco-system as the largest circle in which the social system is enclosed. The economic system is dependent on the existence and functioning of the two other systems and is consequently illustrated by the smallest circle.

The discourse of ecological modernization focuses primarily on the limitations of human, social, organizational and technological creativity as a threat to our survival, and not the lack of natural resources. It is assumed that environmental problems will be solved by scientific achievements and innovation linked to techno-economic measures without the need for sacrificing economic growth.

The discourse global justice is the most important starting point for Eco-Cycle Model 2.0, but in combination with ecological modernization, which is also consistent with the ambitions to create advanced technical solutions in the SRS as part of a larger global whole and with great consideration to eco-system functioning and well-being.

The SymbioCity Approach is a Swedish concept for the internationalization of Swedish urban development which introduces a conceptual model that is also based on Our common future but also clarifies the different sub-systems, institutional and spatial factors of a sustainable city. Concern for human beings and their interaction with the eco-system in general as well as socio-cultural and economic factors represent the model’s main focus. The timeframe is highlighted, i.e. all sustainability aspects need to be considered from both a historical and a future perspective, see Ranhagen & Groth (2012).

Level 1: Eco-Cycle Model 2.0 rooted in a broader sustainability context

Based on the global discourses and concepts that were presented at level 0, we deepened the discussion on how to anchor Eco-Cycle Model 2.0 in a more fundamental sustainability context. This resulted in an explanatory model as seen in Figure 10. Figure 10 shows that we illustrate the reality with a number of concentric rings in a hypothetical cross-section of the earth and next to this section we cut out a magnified cone representing the ecosphere. In order to be very complete, we would also need to include the space outside the ecosphere since it includes the sun, which is essential for life on earth. Our entire existence is naturally dependent on how the earth has been formed by materials from space over billions of years. Although there is a central dimension to an overall discussion of the cycles, we will leave it now.

Here, the ecosphere is subdivided into four partial spheres:

- The lithosphere, which consists of the bedrock and the top 10 km of the earth’s crust.
- The hydrosphere, which consists of water in bedrock, seas, lakes, rivers, glaciers and the atmosphere.
- The biosphere, which is made up of living organisms in the form of animals and plants on earth.
- The atmosphere, which consists of the air we breathe and its connection to the earth’s other metabolism.
Eco-Cycle Model 2.0 is based on the fundamental material, energy and water flows that make up nature’s own metabolism. These flows move between the four spheres, which is also conceptually illustrated as three rings with arrows in Figure 10. One such example is mining of materials in the lithosphere or hydrosphere, which are then transported to and converted in the biosphere and eventually results in emissions of different types into the atmosphere.

Through our social and economic activities, humans have started to affect nature’s metabolism to an increasing extent. Humans have created a sociosphere that consists of mankind’s activities to feed and warm themselves, find shelter, establish contacts and networks and build shared institutions and rules. Closely linked to the sociosphere is the econosphere, which encompasses the monetary-steered formal economy on earth but also includes informal economic activities in the form of barter trade, which is found in certain developing nations.

In the magnified cut-out cone that represents the ecosphere, we enclose two smaller but congruent cones that represent the sociosphere and the econosphere. In accordance with the global justice discourse that is presented at level 0, the econosphere is the smallest truncated cone, since its development is dependent on the conditions that are dictated by the ecosphere and the sociosphere. All social and economic activities interfere with the ecosphere, i.e. humans interact with nature through the exchange of materials, water and energy. The three rings that symbolize the fundamental material, energy and water flows are thus strongly related to this interaction between mankind and nature, i.e. the interplay between the three spheres.

With reference to a magnified image of the biosphere in Figure 10, we also choose to describe the closely interconnected sub-systems that make up the Stockholm Royal Seaport city district:

- The built environment and all of the urban functions (activities) in the form of work, living and services conducted by humans in the city district.
- The transport system is an infrastructure system that naturally serves the above-mentioned urban functions by enabling movement.
- The eco-cycle system is an infrastructure system that provides the district’s activities, the built environment and the transport system with energy, materials and water.
- Eco-system services that can be supporting, provisioning, regulating and cultural.

The double-headed arrows represent how resources from the different parts of the ecosphere – the lithosphere, hydrosphere, biosphere and atmosphere – are processed in energy, materials and water systems and introduced into the built environment, urban functions and the transport system.

Figure 10. The eco-cycle model is rooted in a broader sustainability context (level 1).
Level 2: Overview of functions, flows and fractions in the eco-cycle model

Level 1 gives us a basis from which to go further in concretization of the eco-cycle model by presenting its construction in a series of explanatory pictures. We started by placing the SRS as a whole with all of the support systems – aside from the eco-system that serves the city district – centrally in an overview, see Figure 11a.

The eco-cycles that were shown as vertical double-headed arrows at level 1 are shown here as three overlapping circles for materials, energy and water to symbolize the fact that the flows are highly interdependent and overlapping. ICT will play an increasingly important role in providing efficient and relevant information and communication between people and organizations and contribute to the effective use of resources.¹

This is also illustrated as a connective glue between the systems and as a link between man/urban functions and systems. In this two-dimensional image, the enveloping circle represents the ecosphere – which in Figure 10 was shown as a cut-out cone. This makes it possible to conduct discussions on a detailed level about interaction between the eco-cycle systems (materials, energy and water) and the eco-system.

This picture lacks the system scales that allow description of the flows at different levels in the environment on which the SRS is dependent and the flows within the city district. Figure 11b shows a simplified view of the SRS’s metabolic connection to different system scales. By combining the images in Figures 11a and 11b, a picture is created that allows description of materials, energy and water on different system scales. For the sake of clarity, Figure 11c defines only the most important system boundary, i.e. that between the SRS as a whole and the outside world. In continued work, there are opportunities to also allocate functions and flows more precisely to the levels described in Figure 11b.

Figure 11c shows a sub-division of the materials system into two main parts:

- Non-renewable resources for example in the form of coal, oil, gas and minerals – can also be called “technical materials and products”.
- Renewable resources – can also be called organic materials.

The inspiration for testing this sub-division has come partly from the interactive system diagram that we have referred to earlier, see http://www.ellenmacarthurfoundation.org/cecdiagram/index.html.

There is also reason to consider sub-division of energy and water in the same manner, although there may be a risk of becoming locked into ideas, for example about how to organize efficient eco-cycles for water.

Figure 11c shows a structure in which all of the three main systems have been divided into sub-systems:

- Materials – non-renewable and renewable resources, see above.
- Water – rainfall, storm water, drinking water and wastewater (alternatively, rainwater and tap water).
- Energy in the form of the supply of electricity, heating and cooling, as well as different fuels for these purposes and for transport. For this reason, fossil fuels that include undesirable use of non-renewable resources from the materials system are marked with distinctive narrow arrows.

Finally, Figure 11d also illustrates both the local and global dependency cycle for these six sub-systems, which is the most detailed resolution that we see as possible at the fundamental level.

Based on these conceptual images and reasoning, we developed the detailed Eco-Cycle Model 2.0, see Figure 12. This picture shows flows and synergies in the cycle at the local, regional and global levels. The people and systems that the cycle will serve and are contained in the center of Figure 12 – the users, urban functions in the form of housing, work and services, resource-efficient buildings and transports – are shown enlarged in Figure 13.

One basic idea is to show the importance of minimizing the resource requirements of the built environment and transportation in order to maximize the supply of renewable resources. In practical application of Eco-Cycle Model 2.0, it will be necessary to work on this interplay between minimizing resource requirements and trying to maximize a resource-efficient and renewable supply of materials, energy and water.

A slideshow that has been created in connection with the feasibility study illustrates how the detailed eco-cycle model in Figure 12 can be used as a starting point for discussing the different parts in more detail, see Figure 14:

Focus on both the local and global eco-cycles for materials, water and energy, see Figure 14c – Figure 14e.

The slideshow indicates – albeit roughly – the potential in more advanced digital technology to illustrate the eco-cycles as a whole or in their different parts for the various purposes that may arise during planning, design, implementation and monitoring of the SRS.

¹ ICT in the eco-cycle is a technology to facilitate collection and analysis of data. This has previously been done manually and has therefore not been very effective. Although ICT is primarily an automation of existing systems, increasingly advanced systems also provide new opportunities in a social perspective, for example in promoting interaction with and participation by the users. In other words, the systems create dynamic social effects that the manual systems lacked.
Eco-cycle model 2.0 for Stockholm Royal Seaport

Figure 11. Incremental development of principles for the concrete eco-cycle model at level 2, 11a-11d.
Figure 12. Final draft Eco-cycle model with overview of functions, flows and synergies.
Figure 13. Enlargement of the central part of the eco-cycle model to emphasize the need to minimize resource requirements through measures that are tied to the users (e.g., lifestyle), resource-efficient buildings and transportation, and resource-efficient operations – housing, work and service.

Figure 14a-e: Suite of pictures that show the opportunities to further develop and deepen the various parts of the detailed model in Figure 12.

Figure 14a. Focusing on external systems that SRS is dependent of.
Figure 14b. Focusing on the local resource flows within SRS.

Figure 14c. Focusing on both local and global energy flows.

Figure 14d. Focusing on both local and global water flows.

Figure 14e. Focusing on both local and global material flows.
Level 3: Flow analyses related to accounting systems for the energy, materials/waste and water eco-cycles

Level 3 of the proposed Eco-Cycle Model 2.0 includes annual accounts for key parameters for ecological sustainability. As a first step, it is proposed that accounts be prepared for at least three different parameters, namely energy, CO2 equivalents and water. In the longer term, it will be necessary to establish accounts for additional parameters such as nitrogen, phosphorus, sulfur, key metals and possibly POPs (Priority Organic Pollutants). The pace of introduction must be discussed in further development of Eco-Cycle Model 2.0 and must be based on experience from a first pilot demonstration of accounts and their effectiveness in environmental work.

The reason to start introducing accounts for energy, CO2 and water is: energy is a critical resource for all social and economic progress and will probably be limiting for future development. This is true regardless of the degree to which the global community is able to make the transition to a climate-neutral energy system. Consequently, there is a very strong incentive to monitor both total energy consumption and different types of specific consumption, for example that can be measured per service unit or energy use per person and year.

CO2 equivalents: The most discussed environmental aspect in a global context is our global society’s impact on the climate. The main impact comes from four different substance groups: carbon dioxide, methane, nitrogen oxides (NOx), and halogens. The environmental impact from these four substances/substance groups is normally converted into CO2 equivalents in order to quantify climate-affecting emissions. The most important contributions come from CO2 and methane emissions, and these are in turn linked mainly to the following human activities:

- Use of fossil fuels, coal, oil, natural gas and peat in the global energy system.
- Deforestation and changes in land use.
- Emissions from food production, particularly beef cattle and poultry.

The implementation of parallel accounts for energy and carbon (dioxide equivalents) provides a unique opportunity to better monitor both the necessary energy efficiency improvements and the effectiveness of climate work.

Water is a vital resource for all life, and in many parts of the world it is an even more basic resource than energy (at least with the current level of material standards). In Sweden – with its abundant water resources in an international perspective – it could be argued that water is not among the most limited physical resources and therefore does not need to be recorded.

Seen from an international perspective, however, access to water is a crucial limitation for continued social and economic development and due to globalization of the economy, consumption in Sweden also has an influence on the global water cycle. This means that it is justified, even in a Swedish and SRS context, to include water as a decisive parameter to accompany the accounts.

Figures 15-17 illustrate the draft annual accounts for energy, carbon and water.

It is important to note that the accounts have been prepared in a global context that shows whether the resource (energy, carbon, water) is consumed/metabolized locally, regionally or globally. To facilitate communication and improve visualization, the principle of Sankey diagrams is used to clarify the origins and destinations of the major flows.

One key issue to discuss in practical implementation of these accounts is how they will be linked to the physical and administrative reality. In the above described ComBox Model, it was proposed that administrative boundaries (or city district in the case of the SRS) be used as a basis. This was done because in our Western democratic system, influence over decisions is tied to the representative democracy as a system boundary.

However, it is not entirely certain that this is always the best system boundary. For instance, water management in Europe is linked to watersheds and not to administrative boundaries (an example of a physical basis for system boundary division). It may be noted that with modern ICT it would be possible to overcome such challenges, for example by using a physical system boundary for water and then, in the computer environment, converting the results into administrative boundaries through appropriate allocations.
Figure 16. Schematic diagram showing approach to energy accountings in a Sankey diagram.

Figure 17. Schematic diagram showing approach to water accountings in a Sankey diagram.
Continued development work

The feasibility study has resulted in a conceptual proposal for Eco-Cycle Model 2.0 as a basis for continued development and application. The proposal requires further work and gradual updating in collaboration with various stakeholders in order to be consistent with the stated intentions and the stringent environmental targets for the district.

According to the back-casting methodology, Eco-Cycle Model 2.0 can be related to different periods, see Figure 18. The idea in the feasibility study is that a proposal for the desirable situation in 2030 with an outlook to 2050 be first developed as a basis for then describing where we stand today and different stages along the way.

Listed below are various possible activities for continued development:

- Based on a future scenario for 2030 for Eco-Cycle Model 2.0, to create a detailed description of the starting point and different stages for the SRS from a stakeholder perspective.
- In-depth description of both the overall model and sub-models for materials, energy and water, among other things linked to eco-system services.
- Integration of the eco-cycle model in urban planning through development of pedagogical descriptions with the help of technology for 3D/4D/5D visualization and animation in which it is possible to move freely between the various parts of the model, etc.
- Development of eco-cycle models for other existing and upcoming city districts based on Eco-Cycle Model 2.0.
- Definition of linkages and collaborations with other parallel ongoing projects such as Smart Cities SRS, CESC (Center for Sustainable Communication at KTH), etc.
- Use of the model to produce a map of completed, ongoing and potential future R&D projects.
- Further development of the eco-cycle model’s ICT component – in collaboration with CESC – as part of the question of how to develop knowledge and ideas about the importance of lifestyle, behaviors and attitudes in achieving a sustainable district. The ways in which this can take place must, of course, be further clarified.
- Development of pilot accounts for energy, carbon dioxide equivalents and water.
- Development of a dynamic analysis tool where simulations of various substance flows can be carried out to test and evaluate different proposals and scenarios. The tool should be connected to the visualizations and animations described above.

Development efforts must naturally be formulated for different stakeholders – city officials, politicians, academics and experts, residents and visitors, etc. The international perspective is important because there is widespread interest in the SRS in a rapidly urbanizing world where many cities are preparing for or are in the process of planning city districts with high sustainability ambitions.
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