

Mapping and managing essential resource flows in airport regions – the case of Amsterdam Airport Schiphol

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Abstract

Metropolitan airports are focal points of large amounts of essential resource flows, such as energy, materials, water and food. These flows are predominantly linear, whilst externalising both the negative and positive impacts associated with them. Moreover, qualitative and quantitative understanding regarding the throughput of these flows is usually incomplete and the related data fragmented i.e. distributed over multiple actors within the system that comprises the airport. To a significant extent these airports can thus be considered black boxes. The aim of this paper is to provide a methodology for analysing and mapping several essential resource flows with their infrastructures, whilst detecting potential for closed and connected cycles. The proposed methodology is part of an integrated effort, addressing technical, spatial and organisational aspects, to secure smart and sustainable development. The case study is the region of Amsterdam Airport Schiphol. The essential resource flows under scrutiny are: energy, plastic packaging materials, wastewater, food and waste. By unravelling supply & demand patterns of the studied resource flows and their infrastructures on the one hand, and local characteristics on the other, potential improvements came to the surface regarding sustainable flow management and regional integration. Limitations of the methodology are characterised by two factors in particular: complex system dynamics and data quality.

Key words: airports, essential flows, energy potential mapping, closed and connected cycles, urban metabolism, systems integration

1. Introduction

Breaking the link between economic growth and environmental degradation is an endeavour at the heart of sustainable development, based on the premise that an economy that extracts resources at an increasing rate without considering the environmental boundaries in which it operates will inevitably expire. For sustainable development, thinking in systems is essential to understand the complexity of the context one operates in [Meadows et al, 1972].

From a systems approach, the performance of large international airports – as *subsystems* of one or more metropolitan areas – can be considered unsustainable concerning the essential resources that drive those airports. Firstly, because airports in general depend greatly on external supply and disposal, in other words they have a disproportionate ecological footprint. Secondly, these resources flow predominantly *linear*, as opposed to *circular*, whilst externalising both the negative and positive impacts associated with them. Airports are inherently part of a bigger system and in multiple ways interwoven with the region they are located in. However, this interdependence between individual entities in a region or system is usually insufficiently anticipated. According to Rotmans [2006], an emphasis on sectorial concerns within individual policies prevails, whereas a multi-dimensional, integrated approach is required for sustainable and mutually beneficial systems. Such an approach demands new paradigms and innovative methods to better understand flows and infrastructures within their spatial, organisational and institutional context.

This paper is part of a set of deliverables within the Better Airport Regions project (BAR). The overarching goal of BAR is to gain insight and skills concerning critical characteristics for integrated sustainable development in airport regions. One of the prerequisites is a better understanding of the dynamic relations between essential resource flows and their infrastructures, which forms the rationale behind this paper. The objectives are twofold: i) analysis of selected essential resource flows and their infrastructures in the region of Amsterdam Airport Schiphol, and ii) identification of potentials to improve the performance of these flows with regards to regional integration and sustainability. The focus is on production, consumption, waste and recycling processes relating to packaging materials, energy, water and food. This paper primarily revolves around technical aspects, whilst establishing input for design patterns, which are further addressed in other BAR modules¹.

In order to sketch the conceptual framework, this paper starts with an overview of existing analysis methods for essential resource flows as well as strategies and tools to manage them. Next, a methodology is presented in which empirical and theoretical data concerning the abovementioned essential resource flows in the region of Amsterdam Airport Schiphol are inventoried, interpreted and synthesized into flow maps and potential maps. Finally, the results are discussed against the backdrop of sustainable transitions in airport regions from the perspective of complex systems.

2. Existing methods and tools to understand and manage essential flows

The methods and tools presented in this chapter all originate in – or are related to – system based endeavours regarding the performance of (urban) resource flows. Common threads are fundamental principles valid in nature, such as homeostasis and the first and second law of thermodynamics. The overview below is not exclusive or hierarchic: it presents a cross section of the concepts that most distinctively paved the way with regard to our research efforts and the discourse around it.

2.1 Urban Metabolism

Urban Metabolism (UM) is a multi-disciplinary and integrated framework for modelling complex urban systems' material and energy flows as if the city were an ecosystem (Nelson, 2010). UM builds

¹ The pattern approach, inspired by Christopher Alexander's *Pattern Language*, incorporates problems (such as unsustainability of a certain status quo), context (topography, technology, space, time and governance variables) and potential solutions (options to substitute or avoid specific products, processes and services)

on a concept from biology, which was at the beginning of the 20th century expanded from living cells to the material construction of buildings and settlements (Tansley, 1935) and in the last decades focused more on the relation between cities and their hinterland, which is in a globalised world the whole planet (Fischer-Kowalski, 2002). UM offers an analytical concept to think about human systems and fluxes of energy, water and materials from the viewpoint of sustainability. Fundamental in the development of UM is the second law of thermodynamics, stating that energy in an isolated system changes from one form to another, always evolving towards maximum entropy; usable energy is thus transformed into unusable energy².

2.2 Industrial ecology

Industrial ecology (IE) emerged in the late 1980s from the awareness that an interdisciplinary scientific approach was required for the multidimensional nature of sustainability-related challenges, comprising environmental, social, technical and economic factors. IE can be seen as the study of the physical, chemical, and biological interactions and interrelationships within and between industrial and ecological systems, accompanied by the identification and implementation of strategies “for industrial systems to more closely emulate harmonious, sustainable, ecological ecosystems” [Frosch 1992]. IE stresses the analogy with natural ecosystems in understanding sustainable systems. The industrial park of Kalundborg in Denmark is often used within the IE discourse as an example of industrial symbiosis. Kalundborg developed over 20 years as an industrial symbiosis network; companies use each other’s waste products or share resources in another way because of economic benefits.

2.3 Cradle to Cradle

Cradle to Cradle is a term that counters Cradle to *Grave* thinking as applied in lifecycle analysis studies [as introduced by Heijungs et al., 1992]. Where Cradle to Grave matches with the rules of a linear economic system, Cradle to Cradle connects with the notion of a holistic, circular system, following the cycles of nature. Within the circular model the focus inherently shifts from product-based to service-based performance, whilst altering traditional ownership structures. Cradle to Cradle (C2C) as popularized and trademarked by Michael Braungart and William McDonough [McDonough & Braungart, 2002], is first and foremost an innovation platform aimed at total quality assurance. Alongside specific conditions for obtaining a C2C® certificate, a series of criteria is formulated to support the implementation of the three basic C2C principles – waste = food; use current solar income; celebrate diversity – in design and operational management.

2.4 Energy Potential Mapping

The rationale behind Energy Potential Mapping (EPM), developed at the TU Delft in 2006 [Dobbelsteen et al., 2011a], lies in the synergy of energy considerations and spatial planning. EPM is a systematic approach to sustainable regional planning based on climate change, local potentials and exergy³. Energy potential maps indicate in which places which energy resources are available. They also point out the locations that are most logical for certain developments if these should be directed by energy supply and if transport of energy over long distances should be avoided. In order to draw energy potential maps, an extensive analysis of the local characteristics is necessary, as well as a survey of regional functions with their characteristics, such as location, processes and energy supply and demand. Similar mapping can be undertaken for the demand for different forms of energy. EPMs are performed within a variety of projects and on different spatial levels.

2.5 REAP

The Rotterdam Energy Approach & Planning (REAP) [Tillie et al., 2009] method, developed for the Hart van Zuid area in Rotterdam, the Netherlands, is based on the premise that urban areas can be

² An isolated system is a hypothetical concept – as the only isolated system may be the universe itself – that can be used as a model for real-world situations

³ A measure that indicates to what degree energy is convertible to other forms of energy

transformed into energy-neutrality by means of a structured approach. REAP draws attention to the alignment of energy supply and demand patterns of different urban functions, for instance through heat cascading and exchange between buildings. Within REAP, the local context is addressed in an iterative way on multiple spatial scales. The options concerning step 1 of the New Stepped Strategy (NSS) [Dobbelsteen, 2008] – reduce the energy demand – are first explored on the highest spatial scale relevant to the specific project, say the city scale, and gradually on the lower scales: district, neighbourhood, building. The second step – reuse energy flows – is then anticipated on the building scale and subsequently on the neighbourhood scale, district scale, etc. Finally, in step 3 – produce sustainably – the options are explored to fulfil the remaining energy demand on all scales, informed by the best scale for a specific measure.

2.6 REAP+

Linkages with other flows already become apparent in both EPM and REAP, but their main focus is on energy. REAP+ [Geldermans et al., 2011] puts the emphasis on two other essential resource flows: materials and water. REAP+ centres around effective (re-)utilization of resources and connections between flows, anticipating an integrated approach towards resource flow management. The accent is on integration or relocation of processes within a – production/consumption – system, whilst seeking commitment from the industry and other stakeholders. By means of qualitative and quantitative analyses of a designated area, the (business) potentials are explored. REAP+ was developed by performing three explorative case studies in the Merwe-Vierhavens, a sub-area in the Stadshavens (Cityports) of Rotterdam. The three case studies revolved around: sugar-containing waste flows, brine water, and copper stocks.

All these described methods and tools share a system based approach to sustainable development, aiming at the creation of synergies between components in a designated area. However, an implementation gap can be detected between such concepts' envisioned solutions on the one hand, and today's reality on the other [Vernay, 2013]. Vernay argues this is due to the largely technocratic nature of developed ideas, whilst there still being a poor understanding of how these ideas can come into being. In other words, the emphasis in the described concepts is predominantly on the *why* and *what*, but less so on the *how* and *where* question.

3. Methodology for essential flows in airport regions

3.1 Introduction

The methodology introduced in this paper was part of an integrated endeavour that addresses technical and spatial characteristics of essential resource flows in the airport region on the one hand, and the related organisational and institutional context on the other. Central to this paper study was the analysis and mapping of flows, infrastructures and potentials.

Figure 1 visualises the methodical steps for analysing and mapping the essential resource flows relevant to the performed case study of Amsterdam Airport Schiphol (AAS or Schiphol). We applied an iterative method, in line with the dynamics around acquiring knowledge necessary for advancing in the research. In the first stage the context of the study was laid out, area boundaries were set and resource flows determined. The inventory stage subsequently comprised: i) system analysis, ii) initial flow charts, and iii) data collection. In a parallel track the quality of data was assessed and monitored to find whether the findings were in line with the goal and scope or adjustments were required. An interpretation and evaluation stage, in turn, induced a reiteration of specific process steps. The data generated were input for flow maps and potential maps. Moreover, these data contributed to an indication of ways in which the various flows are – or could be – interconnected. Several geographic and thematic areas were detected with specific opportunities. These '*hotspot zones*' dictated a tailor-made analysis, of which the results are precursors for generic lessons, potentially applicable in other regions as well. In subsequent steps, not part of this paper, the analyses and maps from this case

study are used to develop design patterns that distinctively represent the opportunities, and specific attention is given to the governmental dynamics under which such patterns could be realised. Moreover, this case study feeds and is fed by best practice studies in a variety of airport regions, as performed within other modules of the BAR project.

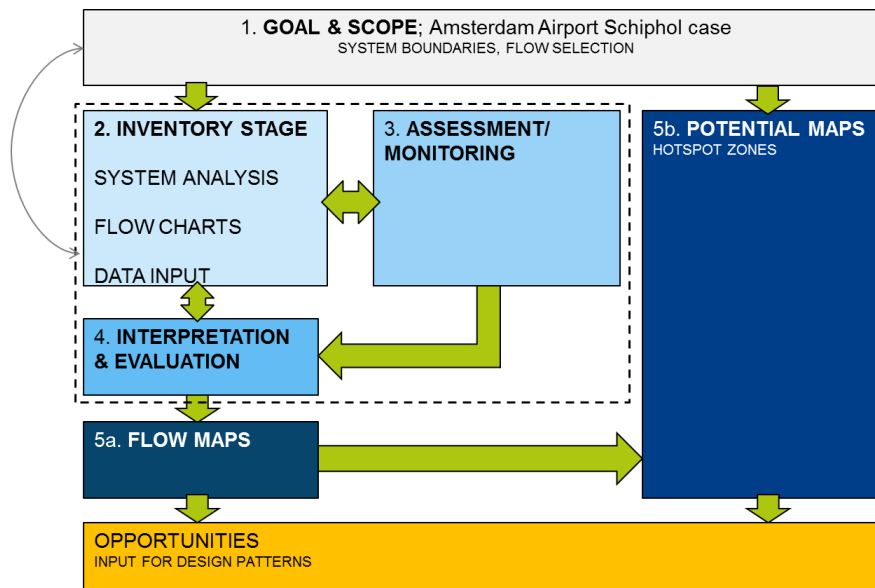


Figure 1: Research methodology

3.2 Goal and Scope

Flow selection

A preliminary selection focused on the following critical flows: energy, materials, water, food, waste. The energy flow has been divided in electricity, thermal energy and transport energy, leading to a focus on the energy carriers of electricity, gas, and combustion fuels. Associated indicators are related to the annual use. To measure and compare the energy involved in the different carriers this use was indicated in Joules (J). The term materials is actually an overarching label for a large, heterogeneous array of categories and subcategories. Context and time restrictions considered, the selection was narrowed down to the packaging materials that constantly flow through the airport. Primary packaging materials are paper/cardboard, glass, and plastics. Recycling rates for paper/cardboard and glass packaging – in Europe – are currently around 70% [FEVE, 2013; ERPC, 2013], whereas the European Association of Plastics Recycling and Recovery Organisations indicated the following breakdown for packaging plastics: 33% recycling, 33% energy recovery, 33% landfill [EPRO 2013]. Various studies show that significant improvements can be made regarding the recycling of plastics [e.g. Morris, 1996; CE, 2011]. Moreover, plastic packaging materials is a high-potential group for biobased economy endeavours. For these reasons we focused primarily on plastic packaging materials. The unit used was kg/year. With regard to water, the emphasis was on wastewater, as this flow indicates to an important extent the consumption of water in the given system. This was measured in litres and annual pollution units. Furthermore, waste water is a medium that carries a myriad of substances, whilst bearing multiple cross references with other flows. Food consumption was measured in kg per year, and divided in six food groups: carbohydrates, vegetables, fruits & nuts, meat products, fish products, and dairy products. Regarding the waste flow, the following main categories were discerned: packaging material fractions in solid waste, organic waste and mixed waste. The unit used was kg/year.

Soft spaces and area boundaries

Given Schiphol's action radius and the manifoldness of interactions with its surroundings on multiple levels, the airport region cannot not be a well-defined area with clear borders. As one of Europe's most important air travel hubs the flows in and out of Schiphol do have a global span. The different

companies, branch organisations, GIS based software and map material, and statistical bureaus. Via interviews, desk research, expert judgment, best estimates and hands-on knowledge critical data were collected that helped gain insight in qualitative and quantitative aspects of the various flow patterns. This stage also included an analysis of the local characteristics. Basic information has been collected of matters such as climate, topography, landscape, land use, infrastructure, and governance. For example, the local climate was essential for the determination of solar and wind energy potentials, land use gave a clue to the possibilities of harvesting this solar and wind energy, and information on governance provided a grasp of the dynamics regarding policy and decision makers that play a key role in resource flow management and sustainable development transitions. Furthermore, a survey of regional functions was required to get a picture of potential exchange of flows. In order to keep the inventory manageable, generic values of demand and supply were used where possible. However, for some functions the specific processes and characteristics were studied in greater detail. The most recent data available were used.

3.4 Mapping

Mapping evolved through the process of data sourcing, deduction and association. The generated GIS maps visualise areas with specific flows or buffers, for example, and evoke measures to be taken for closing cycles or connecting chains. Via these maps data of quantity, quality and location of demand and supply, as well related routes and infrastructure, has been made accessible and visible. This gave more insight in the spatial characteristics of the current flows and their infrastructures, and of potential interventions. Mapping the different supply and demand patterns generated a catalogue of the area to help anticipating or designing more healthy, robust and integrated regions with. The maps were made at the different scales, depending on their primary focus. Special attention is given to the designated hotspot zones, where specific opportunities or characteristics were detected.

4. Results

In this section, the results of underlying research are presented. Firstly, an indication is given concerning current use patterns of Schiphol, as well as the related resource flows and their infrastructures, through flow maps and supply and demand data. Secondly, the designated hotspot zones are briefly introduced. Finally, interrelations between flows are highlighted by means of a matrix that links flows, sources and functions.

4.1 Flows & consumption patterns of Amsterdam Airport Schiphol

The people 'inhabiting' Schiphol can be divided in three categories: passengers, workforce and visitors. Approximately 50 million passengers passed through Schiphol in 2011 [Schiphol Group, 2012]. The workforce at Schiphol contains around 60,000 employees, working for 500 companies. The category of visitors adds up to 13 million visitors in total. Furthermore, about 1.5 million ton of freight passed through the airport in 2011 [Schiphol Media, 2011]. All these people and processes make use of resources.

Energy

The energy flows through the airport are divided into electricity, thermal energy and transport energy, leading to a focus on the following energy carriers: electricity, gas, and combustion fuels. Virtually all of the required energy is directly or indirectly (i.e. combustion fuels for local generation of electricity and/or heat and cooling) imported into the airport system. 1.25% of electricity is generated renewably at the airport itself. Figure 3 shows the main current and planned energy infrastructure as well as energy network components in the airport region. Figure 4 shows a breakdown of the energy use at Schiphol – incorporating *Control*, *Guide*, and *Influence* levels – in terajoule (TJ) and percentages. It becomes apparent that most of the energy demand is related to fuels for air traffic, even if this only includes the landing and take-off cycle. Furthermore, Table 1 displays the energy use of the 12 municipalities in the airport region.

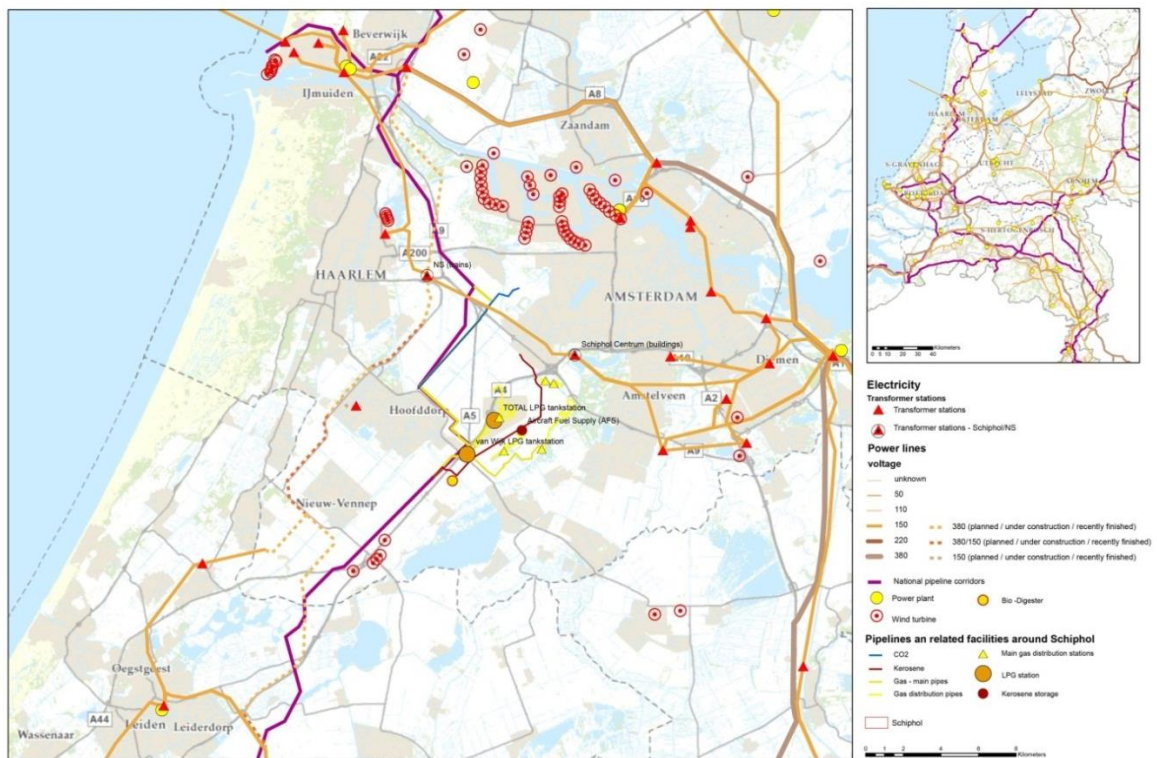


Figure 3: Main energy network and components in the Schiphol region

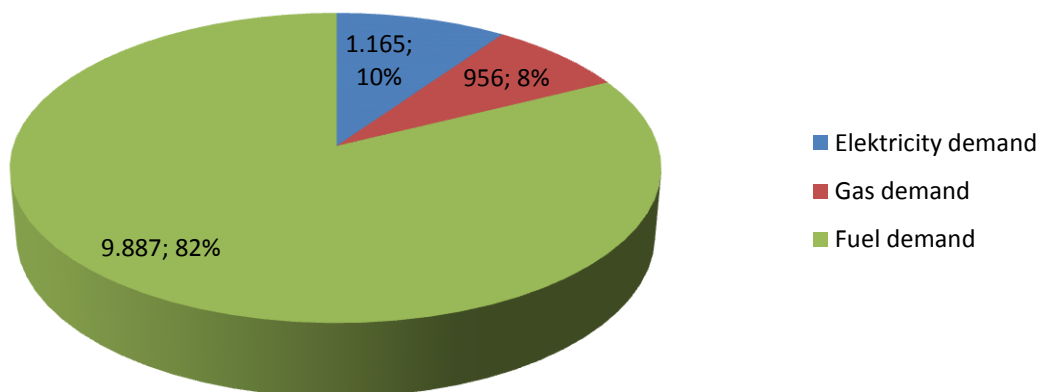


Figure 4: Energy use at Amsterdam Airport Schiphol, in terajoule (TJ) and percentages

Table 1: Energy use of the 12 municipalities surrounding Amsterdam Airport Schiphol

	el. (TJ)	gas (TJ)	fuels (TJ)
Aalsmeer	962	3,207	745
Amstelveen	1,505	3,845	1,557
Amsterdam	15,748	34,703	10,671
Bloemendaal	191	741	509
Haarlem	1,926	4,975	2,970
Haarlemmerliede	43	128	138
Haarlemmermeer	6,693	14,168	4,756
Heemstede	252	881	566
Hillegom	594	2,120	507
Kaag & Braassem	930	3,561	655
Lisse	516	1,619	515
Teylingen	568	1,759	778
<i>Total</i>	29,927	71,708	24,366

Waste

The current throughput of specific flows can to a significant extent be unravelled by analysing the waste associated with Schiphol. Figure 5 visualises selected waste flows and their destinations for treatment: food waste to bio digesters, packaging materials – glass, paper/cardboard, plastics, and separated PET – to recycling facilities, Category 1 airplane waste and rest – mixed – waste to incinerators with energy recovery facilities. Furthermore, the waste flow ‘tissues’ is included because of its specific significance and relation with both packaging materials and food. This flow is separately collected and distributed to a bio digester. The larger map shows the volumes (in ton) and transport routes by truck, following the shortest distances over road (in km). The smaller maps show the directions per waste flow in straight lines.

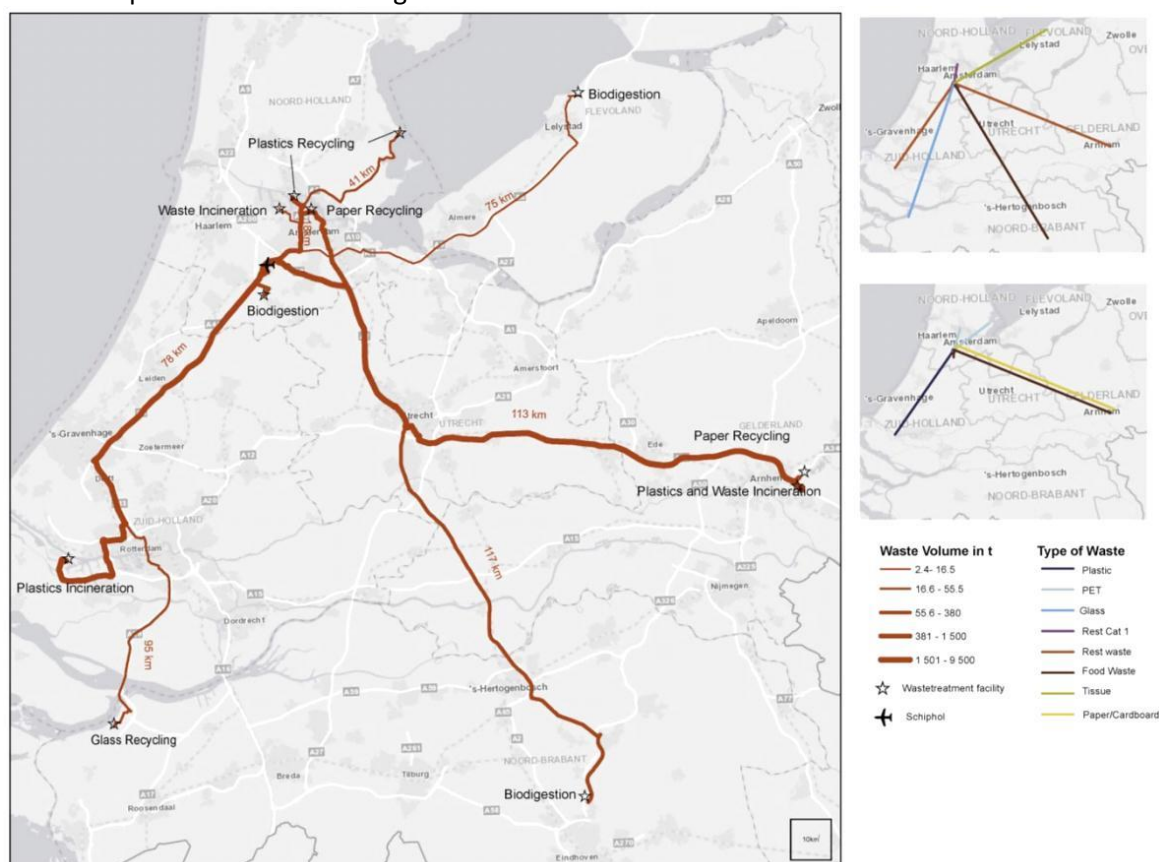


Figure 5: Waste flows and routes associated with Amsterdam Airport Schiphol

Plastic packaging materials

Due to the lack of transparency on the input side, we looked at the output side for an analysis of the plastic packaging materials throughput. More specifically, the solid waste handled under the control of Schiphol Group⁴. Based on information from Van Gansewinkel, the main waste contractor at Schiphol, plastic fractions in waste at the airport are divided in PET and other mixed plastics. PET (100 ton) is separately handled, whereas the other mix of plastics (2 ton) is not separated yet; 50% of these plastics is recycled and 50% ends up in incinerators for production of electricity and heat.

Waste from airplanes consists to a large extent of so called *Category 1* waste, which implies it has to be incinerated within 24 hours, in accordance with safety regulations. In total, this waste flow adds up to 2,400 ton/year, which is incinerated at the waste energy company (AEB, Afval Energie Bedrijf) in Amsterdam. Random samples by waste-research agency Eureco indicate that those plastics comprises 40% of PET (288 ton) and 60% of unspecified synthetics (432 ton). *Unspecified* synthetics is a mixture of polymers, such as polyethylene, polypropylene, polyvinyl chloride and polystyrene, most of which can be recycled, particularly when collected separately.

Based on generic data from Nedvang [2010] and Jetten et al. [2011], the municipal solid waste flow in the surrounding municipalities can be used to estimate the throughput associated with various packaging plastics in households⁵. This concerns approximately 25 kg annually per capita, of which the lion's share is currently incinerated. In Figure 6 the estimated annual plastic packaging waste per type of polymer is displayed for each municipality. Schiphol is included in the Figure, discerning only the categories PET and Other/Unspecified.

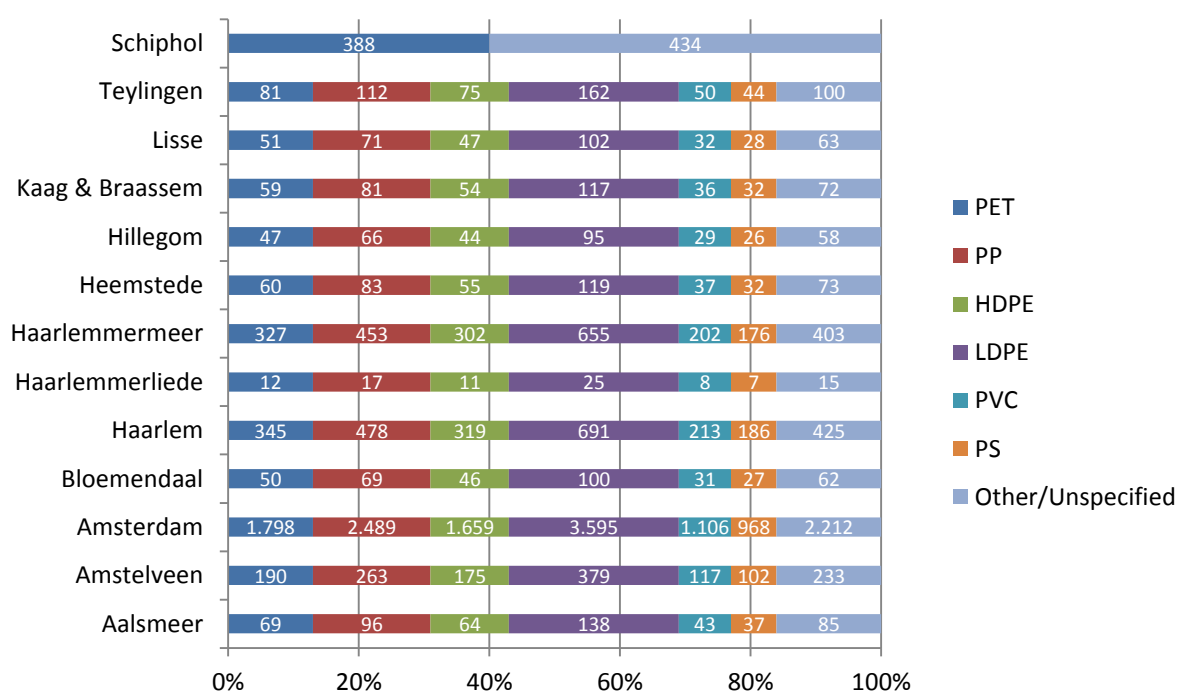


Figure 6: Estimated plastics throughput in the Schiphol region in 2011, per polymer in t/year and percentages

⁴ Although this comprises most of the waste at the airport, a significant part falls outside of the direct control of Schiphol Group, for instance specific waste flows of the main airline company at Schiphol: KLM

⁵ Industrial use is not included here

Food

At Schiphol, the various food & beverages companies have their own logistical scheme to get the food products in place, at the airport or in the airplanes. A small selection of large organisations is at the top of these chains. Data regarding consumption patterns and food waste flows associated with Schiphol is gathered from the two most prominent companies in the food & beverages segment at the airport: KLM Catering Services and HMS Host⁶. We also received data from Van Gansewinkel and Evides; the company responsible for the waste water treatment at Schiphol. Supplementary aspects, such as travel patterns, dwell times and nutrition were studied in order to paint a more complete picture of the air traffic related food chain. Statistics were used as much as possible; where these were not available data were sourced from literature and interviews. Figure 7 gives an overview of the results for passengers, workforce and visitors, both in weight and energy content, in total and per selected food group.

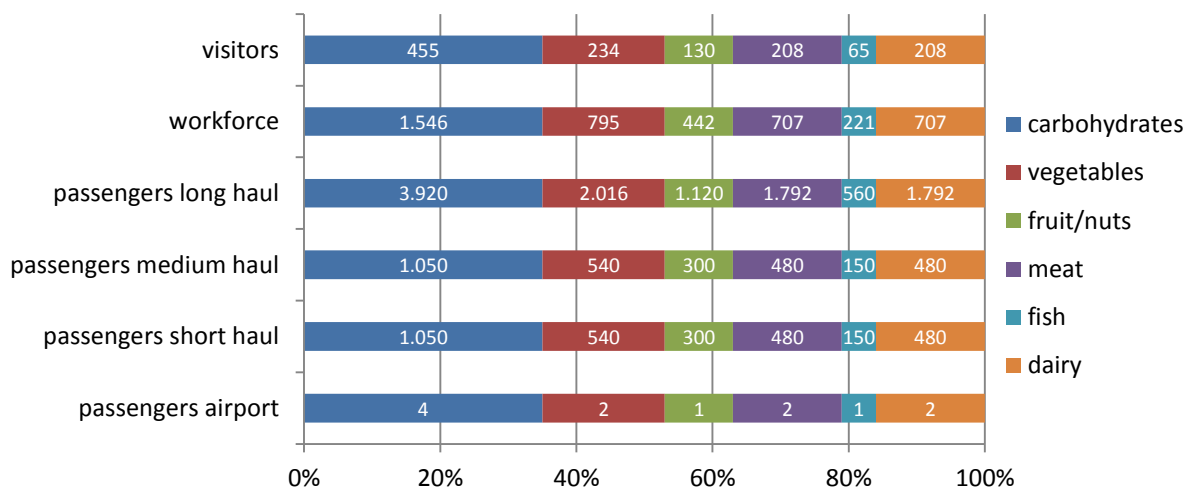


Figure 7: Food consumption at Amsterdam Airport Schiphol in 2011, per food group in tonnes and percentages

Concerning food waste, just less than 380 ton was collected by Van Gansewinkel at the airport in 2011. This is distributed to a bio digester near Eindhoven. Furthermore, food waste from airplanes adds up to an estimated – at least – 600 ton annually. Approximately 25% of this ends up in a local bio digester, the rest is incinerated. Moreover, organic waste fractions end up in the black water flow, see the section below.

Water

Drinking water is centrally supplied by – predominantly – water company Waternet, who use water from the river Rhine and rainwater that is transported to and purified in the dunes. In the year 2011, the water use at the airport was 14 l per passenger, excluding bottled water. Furthermore, Schiphol has a waste water treatment plant within its borders that is exclusively allocated to processing waste water flows from the airport. The water treated here therefore is an appropriate indicator for the water throughput. This waste water is associated with a variety of functions, predominantly fed by the drinking water supply network. Water Company Evides owns and operates the waste water treatment plant. Approximately 4 million l is processed per day, corresponding to 45,000 pollution units. The treated water is fed back onto the surface water, whilst sludge is reused as fuel in factories of Dutch cement producer ENCI.

⁶ HMS Host operates more than 70 food and beverage venues at Schiphol, holding about 65% of the total share at the airport before customs and 90% beyond customs, and KCS is the largest airline caterer at Schiphol

De-icing of aircraft implies a specific water flow at Schiphol leading to a significant waste water flow with volumes depending on winter conditions. This de-icing water is collected separately. Pilots with algae to metabolize this glycol containing water were as yet unsuccessful, due to the mismatch between supply timing (winter) and algae growth optimum (summer) on the one hand and heavy metal content in the algal product on the other. Currently this wastewater stream is divided in a high and a low concentrate; the former is recycled, the latter landfilled. Figure 8 displays the water and wastewater network of the Schiphol area.

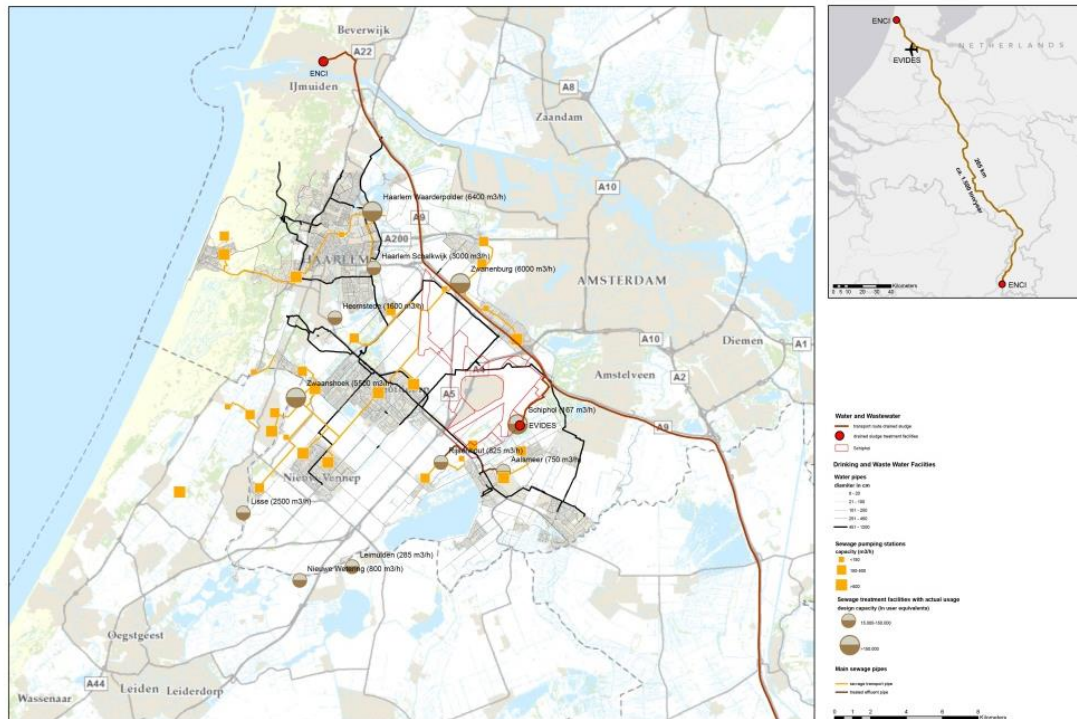


Figure 8: Water and wastewater network of the Schiphol region

Table 2 is an overview of the volumes through Schiphol in 2011 concerning the flows people (passengers, workforce, visitors), energy (electricity, gas, fuels), drinking water, plastic packaging materials (divided in PET and unspecified), food (divided in six foodgroups) and total waste.

Table 2: Schiphol throughput overview of selected flows in 2011

PEOPLE	Passengers	Workforce	Visitors			
	5,00E+07	6,00E+04	1,30E+07			
ENERGY	Electricity TJ	Gas TJ	Fuels TJ			
	1,18E+03	9,75E+02	1,19E+04			
WATER	Drinking Water Liters					
	1,22E+09					
MATERIALS	Plastics: PET kg	Plastics: Unspecified kg				
	3,88E+05	4,34E+05				
FOOD	Carbohydrates kg	Vegetables kg	Fruits/nuts kg	Meat products kg	Fish products kg	Dairy products kg
	1,15E+07	5,93E+06	3,29E+06	5,27E+06	1,65E+06	5,27E+06
WASTE	Total waste kg					
	1,39E+07					

4.2 Hotspot zones

Specific characteristics and associations that emerged from the flow analyses were listed in order to identify zones with specific interest to explore in greater detail. During internal workshops researchers with various backgrounds – notably engineering, industrial ecology and urban planning and design – further discussed this and developed a shortlist of six hotspot zones. Determination of the shortlist was done by four main criteria⁷:

- Presence of specific flow potentials, for example large volumes of excess heat
- Spatial relevance; the area's morphology and its spatial potential for interventions in resource management (production, storage, infrastructure)
- Strategic relevance; the area's identity regarding the organisational and regulatory status
- Current or planned regional developments.

Each of the six hotspot zones, localised in Figure 9, revolves around one or more coinciding specific main themes rooted in –but not exclusive to– that specific context; generic lessons can be drawn through the specific examples. One example is depicted in Figure 10; *Route du Soleil* (no. 4 in Figure 9), which centres around solar, wind and biomass potential, addressing: PV on noise barriers, thermal buffering in roads, wind turbine locations, crop cultivation, roadside grass harvesting, saline algae culture. The six hotspot zones are further elaborated in a second paper called *Airport Region Metabolisms; An exploration of essential resource flow potentials and their infrastructures in airport regions – the case of Amsterdam Airport Schiphol* [Geldermans et al., forthcoming].

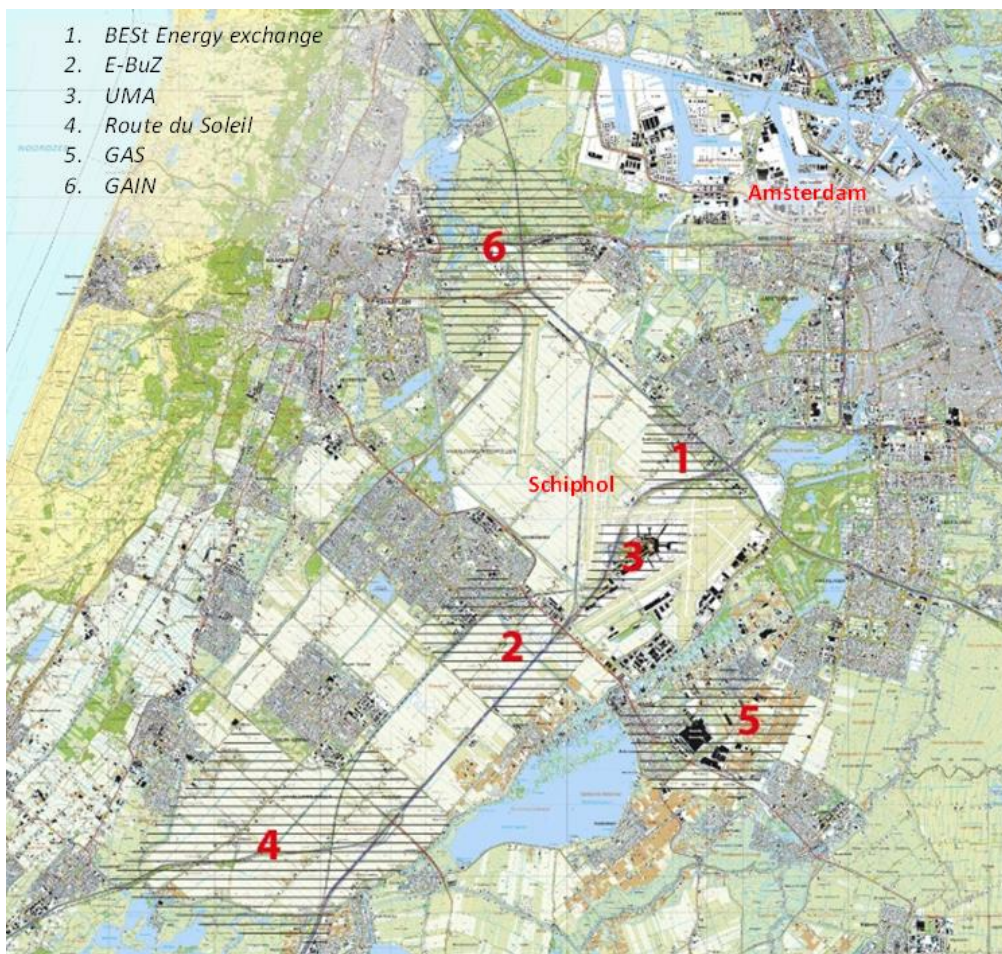


Figure 9: Six designated Hotspot zones in the Schiphol region

⁷ A 5th criterion 'spatial and thematic dispersion' was added to secure the scope required for the BAR context

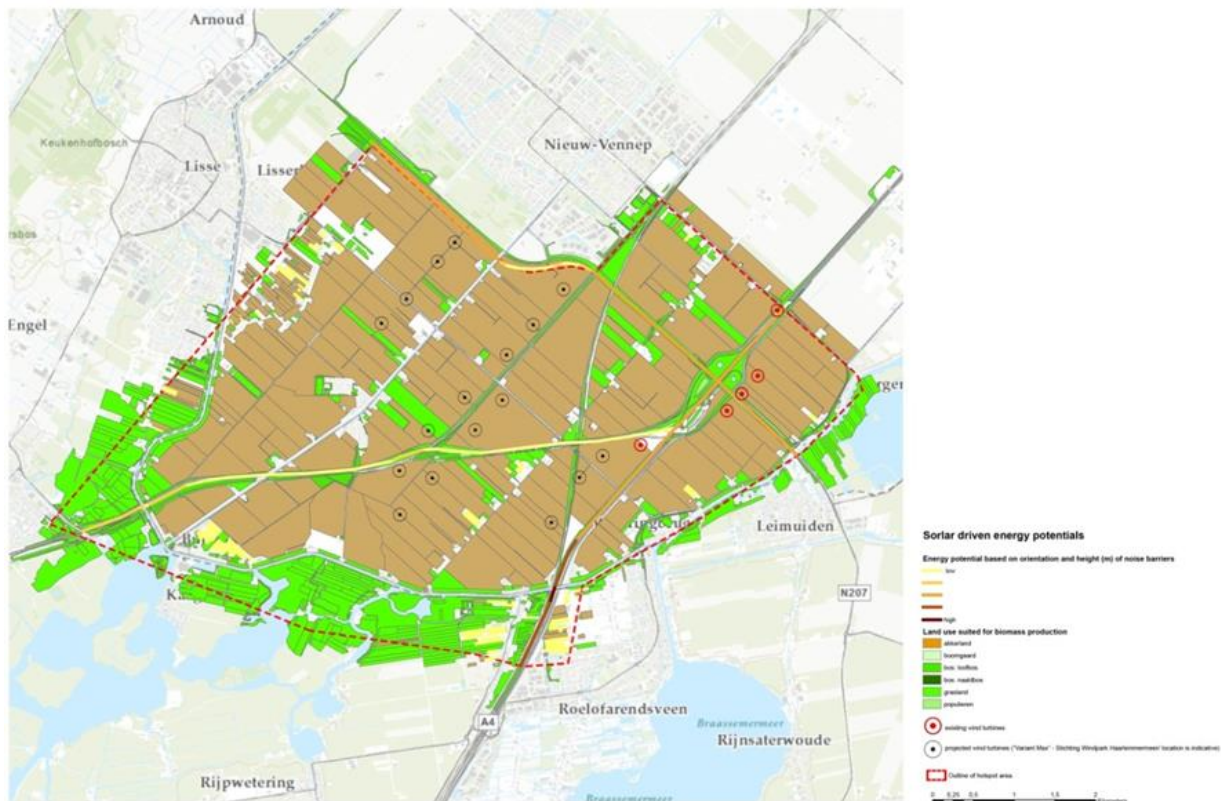


Figure 10: Hotspot zone Route du Soleil

Discussion and Conclusions

The described approach to analyse essential resource flows in airport regions has led to a better comprehension of current flow management at the airport. Moreover, unravelling the supply and demand patterns concerning the studied resource flows and their related infrastructures on the one hand, and an analysis of the local characteristics on the other, provided ample leads for potential improvements with regard to sustainability and regional integration. Two – interrelated – aspects in particular have come to the surface as critical factors that determine the value of the proposed methodology and its results: complex system dynamics and data quality. Below, those aspects are further discussed. Moreover, an outlook is provided with regard to the potential of this methodology.

Complex system dynamics

Airports, being complex systems in their own right, interact with their direct surroundings in complex and multifaceted ways. Reciprocal relationships with those surroundings imply surplus value rather than nuisance in the form of noise, pollution and traffic congestion; associations that currently seem to prevail. This reciprocal relationship relates to new paradigms in dealing with essential resources. Reciprocity not only implies a symbiotic relationship but also a degree of mutual obligation that comes with it. These are properties of systems thinking and underline the non-linearity in complex systems. The proposed methodology results in identified potentials that are largely of a technical nature. But technology is often not the limiting factor with regard to breakthroughs of sustainable innovations. In that respect, the methodology contains a paradox; a *reductionist* approach to ultimately understand a *holistic* system. However, this methodology is part of an integrated effort to understand complex systems, whilst yielding *sub*-results as input for design patterns. Those patterns are subsequently coupled with spatial design, planning and governance. In this way the opportunities detected in the case study area of the Schiphol airport region obtain systems based value.

Data quality

During the research, we have strived for the highest data quality possible within the restrictions dealt with. However, due to the complexity and size of the study area, as well as the amount of data owners and stakeholders, a certain asymmetry in data has to be taken into account. In those cases the emphasis is more on qualitative than on quantitative results. Despite the cooperation of several key players, data – if existent at all – are in many cases not readily available. Lack of transparency is an issue here in two ways: firstly, actors may not want to – or be allowed to – share certain information. Secondly, actors may not share the piece of information that is valuable for us, and/or they may not be aware what the significance of specific information is. In the first case it is clear that confidentiality renders data out of reach. The latter case, however, is more ambiguous and seems closely connected with individual sectorial concerns, as referred to in the introduction. During the research we have explicitly operated from a systems approach towards sustainability; data are assembled to anticipate non-sectorial solutions. It is not self-evident that this approach coincides with the interests of individual actors. However, outlines of specific projects become discernible in the hotspot zones, which may appeal to individual actors as much as the society. This appeal is thought to create the required incentives for individual actors to take next steps in generating and sharing data. This aspect is further addressed in other modules of the BAR project, in particular the module dealing with governance.

Outlook

In the presented methodology qualitative and quantitative flow analyses on the one hand and local characteristics on the other are coupled, whilst revealing synergetic potential between resource flow considerations and spatial planning directions. These synergies derive from the case study region, containing specific potential as feedstock for local projects and generic lessons applicable to other airport regions. Contextualization of the detected flow potential is facilitated by zooming into designated hotspot zones. The four main criteria to determine these zones – presence of specific flow potentials, spatial relevance, strategic relevance and current or planned regional developments – will arguably lead to an integrated, region-specific selection procedure⁸. This is valid provided that an optimal blend of disciplines and stakeholders takes part in the selection process⁹. Studying the hotspots reveals – the contours of – patterns, linking problems and context to potential solutions. The methodology thus helps to better understand the fabric that complex challenges, such as sustainable development, are made of. The following example, related to hotspot zone Route du Soleil (see also Figure 9 and 10), illustrates this:

The municipality of Haarlemmermeer consists of land reclaimed from water, initially aimed at an agricultural function. Rising brackish water is an increasing threat for agricultural activities. Under the pressure of climate change, the freshwater supply in Haarlemmermeer becomes less secure, especially in dry summers. The Southeast part of Haarlemmermeer is one of the problem zones in that respect. This part is designated for 'innovative agriculture' in the strategic vision of the municipality. Considering these facts, this Southeast part seems an appropriate location for applying innovative saline agriculture, whilst working *with* the inevitably increasing salinity level of the groundwater in this region instead of keep fighting the costly and unsustainable battle *against* it. Algae types capable of utilizing saline water are an opportunity here. Saline alga-culture could subsequently play a role in multiple applications, following a value hierarchy; from fine chemicals, food, feed, bulk chemicals to energy. In cold periods, low temperature excess heat from local buffers could be used to keep conditions optimal. In this zone, heat buffered in road surfaces or greenhouses

⁸ The fifth criterion – spatial and thematic dispersion – added for developing the methodology is not necessarily critical in other contexts

⁹ Which was not possible within underlying case study due to time restrictions and compliance with the overall scope of the BAR project

and stored in aquifers could fulfil that role. This aspect is also interesting with regard to an algae pilot project at Schiphol – aimed at metabolizing glycol containing de-icing water – which failed due to, among others, suboptimal temperature conditions in winter. The municipality, local agrarians and horticulturists, and Schiphol may all find significant incentives to collaborate in fleshing out the opportunities; an observation that requires further exploration from a technical and, maybe even more so, an organisational and institutional point of view.

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