reviewed paper

Urban Land Use and Food Supply: the Example of Vienna

Lisa Kaufmann, Barbara Smetschka, Sarah Matej, Karl-Heinz Erb, Anna Kozlowska, Ernst Gebetsroither-Geringer

(Mag. Lisa Kaufmann, University of Natural Resources and Life Sciences – BOKU, Institute of Social Ecology; Vienna, AT, lisa.kaufmann@boku.ac.at)
(Dr. Barbara Smetschka, University of Natural Resources and Life Sciences – BOKU, Institute of Social Ecology; Vienna, AT, barbara.smetschka@boku.ac.at)
(Mag. Sarah Matej, University of Natural Resources and Life Sciences – BOKU, Institute of Social Ecology; Vienna, AT, sarah.matej@boku.ac.at)
(Assoc.Prof. Dr. Karl-Heinz Erb, University of Natural Resources and Life Sciences – BOKU, Institute of Social Ecology; Vienna, AT, karlheinz.erb@boku.ac.at)
(Anna Kozlowska, MSc, AIT Austrian Institute of Technology, Digital Resilient Cities; Vienna, AT, anna.kozlowska@ait.ac.at)
(Dr. Ernst Gebetsroither-Geringer, AIT Austrian Institute of Technology, Digital Resilient Cities; Vienna, AT, ernst.gebetsroither@ait.ac.at)

1 ABSTRACT

Since 2008 more than half of the world's population live in cities and in 2050 it will be more than two thirds. Urbanization increases not only the cities themselves, but also their responsibility to provide a 'Good Life for All' within planetary boundaries. Global agreements such as the Paris Climate Agreement, the UN Sustainable Development Goals or the Biodiversity Charter underpin and secure these aspirations. While 55% of the global population live in urban areas, it is estimated that 1-3% of world's land is urbanized. Hence, cities are characterised by land scarcity and urban land use conflicts crystallize around issues such as food production, housing, recreational areas or transport infrastructure. Nevertheless, soil and its biological productivity through photosynthesis is the prerequisite of every life on this planet and urban land use does not end at the city gates: food is just one example of how the city is connected to its hinterland, nation, and to the rest of the world. Their supply with agricultural products is feeding the city, but also connects it with both social and ecological impacts on people (e.g. farmers) and the environment at the place of production resp. processing. From this point of view, the responsibility of urban areas as consumption 'hotspots' does not end at their city borders.

Recently, a broader awareness of environmental impacts by consumed goods could be observed. An important contributor here is the communication and visualization of footprints, which are sustainability indicators that quantify resource use or ecological consequences of certain products. Some well-known examples are probably the ecological footprint, which measures the biologically productive area required, resource footprints for water and land or the carbon footprint, which illustrates the greenhouse gas emissions associated with the consumption of a product or lifestyle. Especially in the context of cities, contrasting consumption and production-based accountings has been proved to provide important insights for options to reduce ecological impacts of cities.

In the course of the IN-SOURCE project, we quantify urban land use intensities both inside and outside of city borders applying the concept of HANPP (Human Appropriation of Net Primary Production) as a further environmental footprint indicator. HANPP measures the depth of human interventions into the biological productivity of ecosystems. Net primary production (NPP) is the amount of biomass produced by the process of photosynthesis minus the plants' own energetic requirements in an ecosystem. Human appropriation of NPP occurs through two distinct processes: first, land cover/use change (e.g., from forest to cropland, HANPPluc) alters ecological patterns and processes, inclduing NPP, and second, via agricultural and forestry harvest, biomass is removed from ecosystems (HANPPharv). HANPP can be calculated for territorial units, e.g. cities or nations, and it also allows to relate the land use intensity of cities within their borders with impacts beyond. In this contribution, we focus on impacts associated with urban food supply in order to contextualize and explore these impacts within the urban food-water-energy nexus (FWE nexus).

In IN-SOURCE, we developed the HANPP Explorer as an interactive web application, which enables stakeholders and other practitioners to access insights from this research and interactively explore the topic. The HANPP Explorer intends to provide knowledge of the manifold dimensions of urban food, thereby gaining new perspectives on urban land use and opening up possible future developments for discussion.

Keywords: environmental footprint, Food-Water-Energy Nexus, sustainable food system, sustainable urban development, land use

2 INTRODUCTION

Fostering sustainability transitions needs interdisciplinary approaches which focus on relations between central resources and their use rather than on separated analysis as well as transdisciplinary research with the aim to co-create new knowledge and policy measures. A rising awareness of trade-offs between a sustainable use of resources such as food, water and energy as well as across disciplinary scales led to calls of a nexus approach from research and policy communities (Newell et al., 2019). As a result, the Food-Water-Energy Nexus (FWE nexus) is and has been discussed prominently by the United Nations (UN), Food and Agriculture Organization (FAO) and the European Union (EU).

Since 2008 more than half of the world's population live in cities and in 2050 it will be more than two thirds. Urbanization increases not only the cities themselves, but also their responsibility to provide a 'Good Life for All' within planetary boundaries. Global agreements such as the Paris Climate Agreement, the UN Sustainable Development Goals or the Biodiversity Charter underpin and secure these aspirations. While 55% of the global population live in urban areas, it is estimated that 1-3% of world's land is urbanized (Liu et al., 2014). Hence, cities are characterised by land scarcity and urban land use conflicts crystallize around issues such as food production, housing, recreational areas or transport infrastructure.

Growing food demand as well as growing demands on water and energy stemming from a growing population and rising living standards not only result in land use conflicts within a cities boundary. Additionally, these developments initiate a growing pressure on urban hinterland and on national and global resources. Therefore, cities as growing consumption 'hotspots' of resources appear to be decisive in a potentially successful approach to sustainability transitions. In this case study for Vienna, the FWE nexus approach is employed in the context of analysing options for urban sustainability transition. It serves as an entry point of analysing interdependencies, discussing synergies and reduction potentials as well as to foster the co-creation of new knowledge on transformative governance. By integrating an indicator framework for land use intensity (HANPP and Food-eHANPP), we connect urban land use with the necessity of urban resource supply for food in order to stress the accompanying impacts on local ecosystems in the near and far hinterland as one basic key aspect of urban resource use. In this paper, we start with a description of research aims of the underlying research project and more specifically, the characteristics of the case study for Vienna. We then introduce the integrative indicator framework 'Human Appropriation of Net Primary Production' (HANPP) followed by the presentation of the 'HANPP explorer', an interactive and comprehensive web application, which aim to not only show the results of the study, but also to offer an accessible tool to present the results to practitioners. Here, impacts of food supply for Vienna can be investigated and contextualized within urban land use intensity within city boundaries.

3 IN-SOURCE PROJECT AND THE CASE STUDY VIENNA

"Cities, undergoing rapid change throughout the globe, face common metabolic challenges to sustainably provide for energy, water and food supplies under healthy and economically productive conditions. Decision makers, such as governments, utilities, project developers and investors must be able to understand, quantify and visualize multiple interdependent impacts." (project website) The international SUGI project IN-SOURCE aims to model the impact of land use change and renewable energy transition on urban infrastructure with various tools.

Vienna represents a fast-growing city reaching almost 2 million inhabitants in 2021. This poses the major challenge for the urban planning of infrastructure and living space. The city has agreed upon a city development plan (STEP), a climate protection plan and a smart city initiative. In order to reach these goals, land-use change and energy-system change have to be analysed and transformed. The city of Vienna is known for its well-organized city administration in various fields (e.g. community housing, public transport, communal water, etc.). Not least because of the climate crisis, which transforms parts of the city into heat islands, different measures to cool down the city are currently discussed by the city administration. Using a FWE nexus approach in IN-SOURCE, we can ask how green areas, urban food demand and production and local energy and water demand relate to each other. Additionally, we are interested in the role the FWE nexus approach can play within a process to transform Vienna to a climate friendly smart city. The city administration has a strong planning and regulatory role concerning water and energy provision. In IN-SOURCE we aim to cooperate with representatives of the city administration in the endeavour to develop a shared understanding of problems and to co-create ideas and solutions.

The level of food production within Vienna is higher than in comparable cities as a result of a number of farms located within the cities borders. Additionally, initiatives promoting urban farming (e.g. vertical farming) are emerging and getting attention. Urban agriculture is not motivated (yet) by the heat island discourse but rather by the fact, that people aim for producing food (e.g. as in community gardens). Further questions arise around public and private food consumption where the structure of trade and retail services are implied and their availability could be subject to regulations or consumer decisions. Next to social assets, urban agriculture offers a series of co-benefits – such as cooling, less sealing of the soil, a better rainwater management – for the city, which can be analysed with the help of the FWE nexus. However, the agricultural production covers only a small percentage of the food consumption in the city as domestic biomass extraction in Vienna represents mere 2% of all biomass consumption for food, energy and material (Plank et al., subm). Thus, the lion's share of urban food supply grows on regional, national as well as remote areas. It therefore connects urban regions with land and biomass production in their regional and global hinterland embedded in a global supply network of international trade connections. Land use on these areas imply the human intervention into ecosystem processes, aiming at increasing the output of biomass products. We quantify the degree of these interventions using the HANPP framework ('human appropriation of net primary production'), a footprint indicator that measures land-use intensity, while considering spatial differences in productivity.

Moreover, one key aspect of the FWE nexus approach is the integration of transdisciplinary research. Building on several workshops conducted within the presented research project, we show how introducing the concept into discussion between city administration, civil society and scientists can help to start a process of joint problem framing and how analysing the FWE nexus links and visualization of results can be useful to develop future scenarios and policy measures for an urban sustainability transition.

4 ENVIRONMENTAL FOOTPRINT: HANPP AND EMBODIED HANPP

Recently, a broader awareness of the 'teleconnections' between producing and consuming regions (Seto 2016) and the ensuing environmental impacts by consumed goods can be observed. An important contributor here is the communication and visualization of footprints, which are sustainability indicators that quantify the resource use or ecological consequences of certain products respectively consumption patterns. Since the introduction of the ecological footprint in 1996, a large number of environmental footprint indicators emerged. The ecological footprint assesses the required biolgically productive global average area required to sustain a nation's consumption. Another popular example is the carbon footprint which quantifies the greenhouse gas emissions associated with the consumption of a product or lifestyle. These as well as other footprints covering resources such as water, land, nitrogen, phosphorus, material, biodiversity or energy are summarized and referred to as the 'footprint family' (Vanham et al., 2019). In the context of cities and their characteristic of resource supply from outside of their city boundaries, footprint indicators are from particular value due to their ability to capture the environmental impacts associated with urban resource consumption along the supply chain despite intricacies of congruent system boundaries. Moreover, if contrasted with production-based accountings, the consumption perspective has been proved to provide important insights for options to reduce ecological impacts of cities (Athanassiadis et al. 2018).

In the course of the IN-SOURCE project, we add a further environmental footprint built upon an established and acknowledged socio-ecological framework for material- and energy flow accountings (MEFA) (Haberl et al 2004, Haberl et al 2016). We quantify the impacts of human society on ecosystem productivity and further develop this framework to be able to quantify the extent of impacts associated with urban land use and food consumption. By doing that, we are able not only to contrast impacts occurring within and outside city boundaries in the same 'currency' but also to improve the comprehensibility of the framework as a basis of transferring a scientific concept into the applied realms of (city) practitioners. The quantification of environmental impacts by urban land use and food consumption follows the concept of Human Appropriation of Net Primary Production (HANPP). It measures the depth of human interventions into the biological productivity of ecosystems. Net primary production (NPP) is the amount of biomass produced by the process of photosynthesis minus the plants' own requirements in an ecosystem. Human appropriation of this energy occurs through two distinct processes: first, land cover/use change (e.g., from forest to cropland, HANPPluc) and second, product removal (e.g., agricultural harvest, HANPPharv) (see Fig. 1a).

ISBN 978-3-9504945-0-1. Editors: M. SCHRENK, V. V: POPOVICH, P. ZEILE, P. ELISEI, C.BEYER, J. RYSER, G. STÖGLEHNER

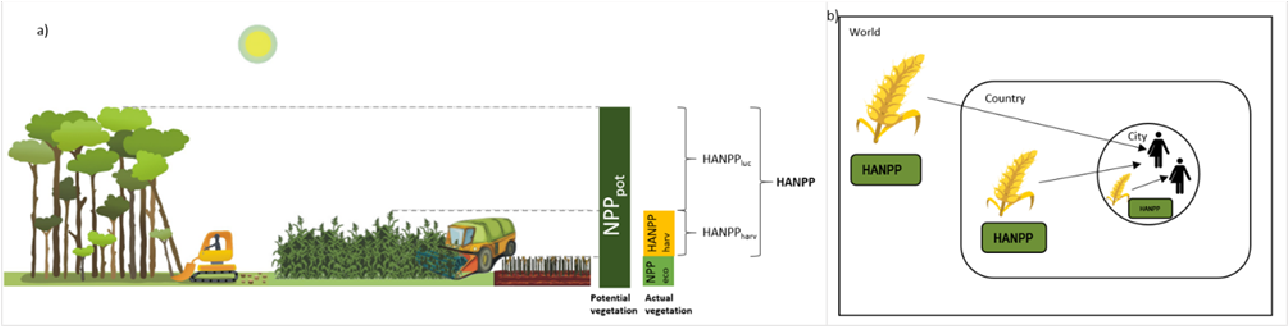

Fig. 1: Conceptualization of a) the Human Appropriation of Net Primary Production (HANPP) framework as a quantification of society's impact on the productivity of ecosystems (illustration by Plutzar, 2010, own adaption); b) the analysis of urban impacts on ecosystems associated with food consumption (=Food-eHANPP; own illustration).

Originating from the quantification of 'Human Impacts on Energy Flow through Natural Ecosystems and the Implications for Species Endangement' in 1990 (Wright, 1990), the concept has proved its applicability and ability to enable a better understanding of interactions between humans and nature and as a measure of human domination of the biosphere. For example, while Haberl et al. (2007) found a global HANPP value of 24% of the potential net primary productivity caused by humans, Krausmann et al. (2013) demonstrate the doubling of global HANPP in the course of the 20th century. Various national HANPP analysis (for example Kastner, 2009; Niedertscheider and Erb 2014) allow a better understanding of country-specific socio-economic pressures on terrestrial ecosystems. Against the background of increasing trade volumes since the 1960ies and resulting teleconnections (i.e. links between the place of production and consumption despite growing spatial disconnection), a land system analysis which assesses the impacts from a consumption perspective gained of growing importance, implemented by the quantification of the embodied HANPP (Erb et al. 2009). Akin to other footprint indicators, eHANPP allows to account for the HANPP resulting from the consumption of defined entities, here the city of Vienna (Haberl et al., 2014). Subsequently, for the application of the HANPP framework in the context of a transdisciplinary FWE nexus approach, we quantify urban land use (intensity) as the impacts of humans on ecosystem's productivity both inside and outside of city borders. For the latter, we focus on impacts associated with urban food supply (see Fig. 1b). The results are visualized in an interactive web-application with maps displaying the HANPP embodied in food differentiated by its origin ('HANPP Explorer').

5 HANPP EXPLORER: VISUALISATION AND INTERACTIVE LEARNING

The HANPP explorer is developed as an easy accessible online tool to transfer knowledge from the scientific community into practitioner's realm. In the following subsections, we first describe the approach of visualisation followed by data and method used for the application of the HANPP framework as well the conceptualization of the stakeholder workshops, which served as the basis of scenario development. Second, we show the results and information, which can be gained from the HANPP explorer differentiating between the land use impacts within (HANPP Vienna) and those occurring outside of city boundaries (Food-eHANPP Vienna) as well the insights and scenarios gained from the workshops.

5.1 Visualisation

HANPP Explorer is an interactive web application built within IN-SOURCE. The intention of creating this online tool was to present the HANPP framework within the context of the urban FWE concept in a straightforward and easy to understand way so that people who do not know the topic very well can easily assimilate this knowledge and use it in the future. The interface of the app is rather minimalistic with only necessary information displayed on the screen which makes it easy to navigate between the functions of the application. The navigation bar presents six sections: Home, About, Methods, Food-eHANPP, HANPP, and Scenarios (see Fig. 2). The Home tab welcomes to the explorer, second and third tabs are intended to familiarise the user with both the subject matter (the HANPP methodology) and the functionality of the application. While About is focused more on the purpose of the explorer with a short introduction to the topic and other sections, Methods dive into methodology of the analyses, description of the data and information on how to understand the results in further sections. After overall description, the focus lies separately on each topic, i.e. HANPP, Food-eHANPP, Scenarios. If a user is interested in the methods

behind the results or wants to know more about the data, they are invited to use this section to find necessary information. The aim is to enrich text with illustrations, diagrams and maps. Additionally, in this section the user will find a video tutorial explaining the functionality of the application. The next three tabs (HANPP, Food-eHANPP, Scenarios) show the results of the topics respectively to their titles. HANPP and Food-eHANPP are interactive maps with the possibility to zoom in and out, rotate and click to show more information. Result values are represented by colours which are part of colour scale adapted to the range of input data. Next to the map, additional control widgets and graphs are placed (Fig. 2-4). These control widgets, like radio buttons, select boxes and sliders, are used to change parameters (e.g. different products) of the input data. Once the user selects the values, the updated information will immediately be shown on the map (Fig. 2-4). Another functionality is the possibility to display information depending on the specific area of the map (e.g. based on administrative or functional boundaries) by clicking on a chosen area (Fig. 4a). Next to each map an information 'I' button is placed. Once the user clicks on it, a short text shows up. The purpose of it is to give a quick overview of that page and how to change the parameters of the map.

HANPP Explorer is built with R programming language and the Shiny R package developed by R Studio, which allow to build an interactive web app (Gebetsroither-Geringer et al., 2018). The code in R is extended by CSS, HTML and JavaScript scripts which allows for a more unique and customised look and functionality of the application. Once the code is uploaded on a specific shiny server, the web application is available to public here: https://cities.ait.ac.at/uilab/udb/home/dev/HANPP_Explorer/.

5.2 Data and Methods

5.2.1 HANPP Vienna

Land use data sets are the basis of HANPP calculations. We use factual land use data ('Realnutzungs-kartierung') provided by the city administration, which is freely available online and is based on air photo interpretation complemented by factual data (OGD, 2020). We aggregate all 32 land-use and -cover categories into 6 land use classes: Cropland comprises of agricultural land used for crops like cereals or vegetables as well as intensively used grassland, while meadows are aggregated as grassland. We specify vineyards as separate land use class as they represent 90% of land with permanent crops and is from extraordinary cultural importance in the city of Vienna. Forestry activities are subsumed within the land use class 'forest'. We further distinguish between sealed settlement (i.e. transport infrastructure) and green settlements, the latter includes parks and other green areas. Additionally, water bodies are identified, but not further processed due to the focus of the HANPP framework on terrestrial ecosystems (see above). For each land use class, we quantify the entity of biomass flows on a given area in terms of net primary production (NPP) starting from the actual production (NPPact), the amounts of harvested biomass (HANPPharv) as well as the amounts of biomass, which would have been produced in the absence of human activities (HANPPluc) and are considered as human appropriation of ecosystem productivity due to land use changes. HANPP is the sum of HANPPharv and HANPPluc (see Fig. 1). The calculation of flows follows the method described in Krausmann et al. (2013) and is based on an extrapolation of available statistics and standardized factors. Agricultural harvest statistics serve as basis for the HANPP calculation on cropland (Statistik Austria, 2020). In vineyards, the main entry point stems from wine production data and has been converted into grape matter assuming a standard output of 69% according to reports from winegrower. Biomass extraction from forest areas is provided by the municipal department for forestry and urban agriculture (MA49) in the form of harvest statistics and reported in solid cubic meters. Similar to cropland, we extrapolate HANPPharv from harvest data using multipliers for wood density by differentiating both deciduous and coniferous species as well as wood fuel and industrial roundwood. We assume zero HANPPharv for sealed settlement, but estimate harvested biomass from parks, house gardens and roadside greenery for green settlement. Harvest data provided by the municipal department for Waste Management, Street Cleaning and Vehicle Fleet (MA48) include biomass flows from organic waste and other biomass not grown in within city boundaries. Therefore, we assume 5% of biomass recycled in Vienna to actually be grown in Vienna. The potential ecosystem productivity (NPPpot), which represents the biomass production in absence of human activities is based on vegetation modelling, here from LPJ-Guess (Smith et al., 2014). HANPPluc, the appropriation associated with land use change, is the difference between NPPpot and NPPact. All values are expressed on the basis of tonnes in dry matter as annual average for the years 2009-2011.

ISBN 978-3-9504945-0-1. Editors: M. SCHRENK, V. V: POPOVICH, P. ZEILE, P. ELISEI, C.BEYER, J. RYSER, G. STÖGLEHNER

5.2.2 Food-eHANPP Vienna

The Food-eHANPP Vienna, which can also be interpreted as the HANPP footprint of food consumed in Vienna is based on a quantification of Viennese biomass metabolism (Kalt et al., 2021). The concept of the socio-economic metabolism is a systems approach to study society-nature interactions by linking socio-economic with biophysical processes. The reliance of social systems on the supply of biophysical resources and the determination of environmental pressures and impacts by their composition, magnitude and patterns are the key basic assumptions of this concept (Haberl et al., 2019). For the quantification of urban biomass metabolism, two research strands namely urban metabolism and material-flow accounting (MEFA) have been connected. The Viennese biomass metabolism provide data on Vienna's food supply, the embodied biomass as well as its origin (for further details on the methods see Kalt et al., 2021). The data comprise of 108 agricultural primary products aggregated into 8 main categories (cereals, oil crops, sugar crops, roots and tubers, pulses, fruits and nuts, vegetables and stimulants and spices) produced in 148 countries. Six livestock products are considered (milk, beef, pork, eggs, poultry and sheep and goat meat) and expressed in amounts of supplied product as well as in the amount of agricultural primary product required for their production (= embodied feed/biomass). We connect Vienna's biomass footprint for food with values of HANPP associated with the production of one unit of product for a given country. The so-called 'HANPP rucksack' is based on a crop-specific calculation of global HANPP for the year 2010. It is building upon the latest global spatially explicit dataset on agricultural production (Yu et al., 2020) and follows likewise the standard procedure to apply the HANPP framework (see above and Krausmann et al., 2013; Haberl et al., 2007). Methods and outcomes are explained in detail in Semenchuk et al. (subm.). As a result, we obtain the amount and location of HANPP related to food consumed in Vienna, which can be explored within the online toolbox.

5.2.3 Scenario development in stakeholder workshops

HANPP Explorer was developed as an interactive web application, which enables stakeholders, experts and students to learn from our research and interactively explore the topic. In order to achieve a goal of science communication and cooperation with stakeholders it is necessary to listen and organize exchange with stakeholders (Smetschka and Gaube, 2020). Based on the specificity of the case of Vienna we opted to invite stakeholders from city administration responsible for energy and water topics, from private and public food production and consumption bodies including civil society and NGOs to cooperate with scientists from the fields of FWE nexus. We invited a group of stakeholders to a series of workshops. Albeit, in the first workshop we learned that the systemic and complex concept of the FWE nexus is neither known or used by city administration. Stakeholders view the nexus as a promising but overly demanding approach. In the VisToolBox of IN-SOURCE we therefore offer tools addressing food, energy and water separately along with elements where systemic analysis is demonstrated.

In a first stakeholder workshop we explained the HANPP framework as an environmental indicator, discussing data availability and questions arising from stakeholders. In a second workshop we developed scenarios for food, energy and water separately. The HANPP Explorer, as part of the VisToolBox, intends to provide knowledge of the manifold dimensions of urban food, thereby gaining new perspectives on urban land use and opening up possible future developments for discussion.

5.3 Results

For an inter- and transdisciplinary approach of the urban FWE nexus, the 'HANPP Explorer' seeks to facilitate the understanding of urban impacts on terrestrial ecosystems which can be gained through the lens of the HANPP framework. It aims to easily explore the degree of human appropriation of ecosystem productivity associated with Vienna's land use activities – both within the city ('HANPP Vienna') as well as those in the local and global hinterland, which occurs by Vienna's food consumption (Food-eHANPP). As such, the 'HANPP explorer' not only supports a better understanding of the ecological consequences of urban land use and food supply, but also to make the HANPP framework more accessible outside of research communities.

5.3.1 HANPP Vienna

The tab 'HANPP Vienna' allows to explore the depth of intervention into natural ecosystem productivity as well as the differences among six different terrestrial land use classes in terms of HANPP per ha per year

within Vienna. The lowest values of HANPP per ha per year can be found on forests and meadows (2.6 resp. 3.1 t dm/ha/yr and 18% resp. 22% of NPPpot), whereas green settlement and vineyards (5.2 resp. 6.3 t dm/ha/yr and 38% resp. 44% of NPPpot) show medium values. Highest values in terms of HANPP/ha/yr show cropland and sealed infrastructure (12.5 resp. 13.9 t dm/ha/yr and 92% resp. 100% of NPPpot). Altogether, the Human appropriation of Net Primary Production (HANPP) in Vienna amounts to 70% of potential net primary production (NPPpot). Fig. 2 shows a spatial presentation of described results for all land use classes within the HANPP Explorer.

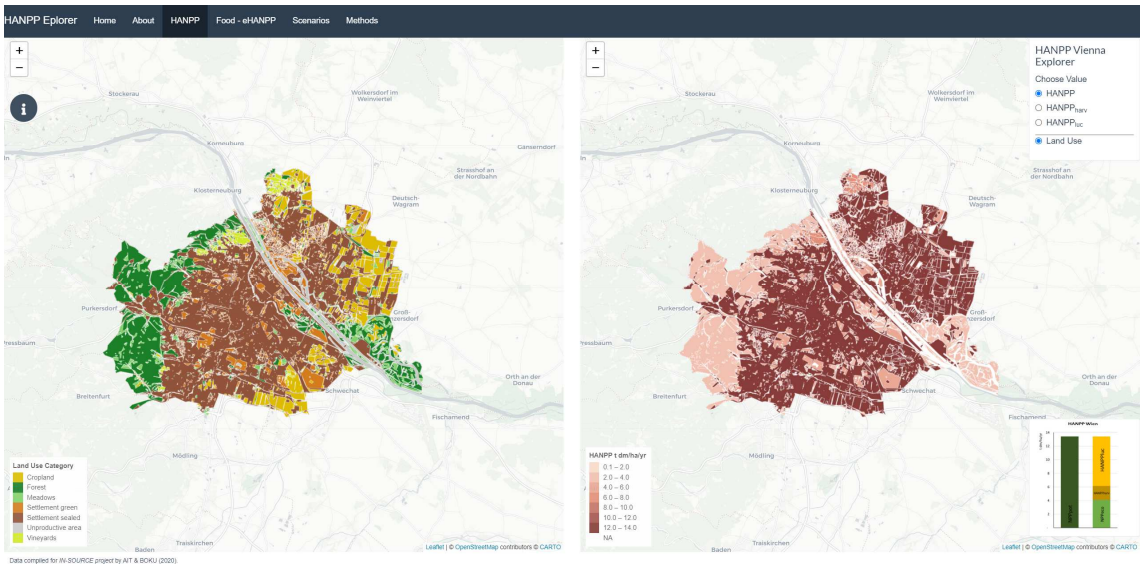

Fig. 2: Screenshots of 'HANPP Vienna' tab in 'HANPP Explorer'. left: shows the extend of 6 terrestrial land-use classes considered within the application of the HANPP framework. right: indicates the depth of intervention into natural ecosystem productivity in terms of HANPP per ha per year. Higher impacts are displayed in darker colours. (https://cities.ait.ac.at/uilab/udb/home/dev/HANPP_Explorer/ - accessed 06-17-2021

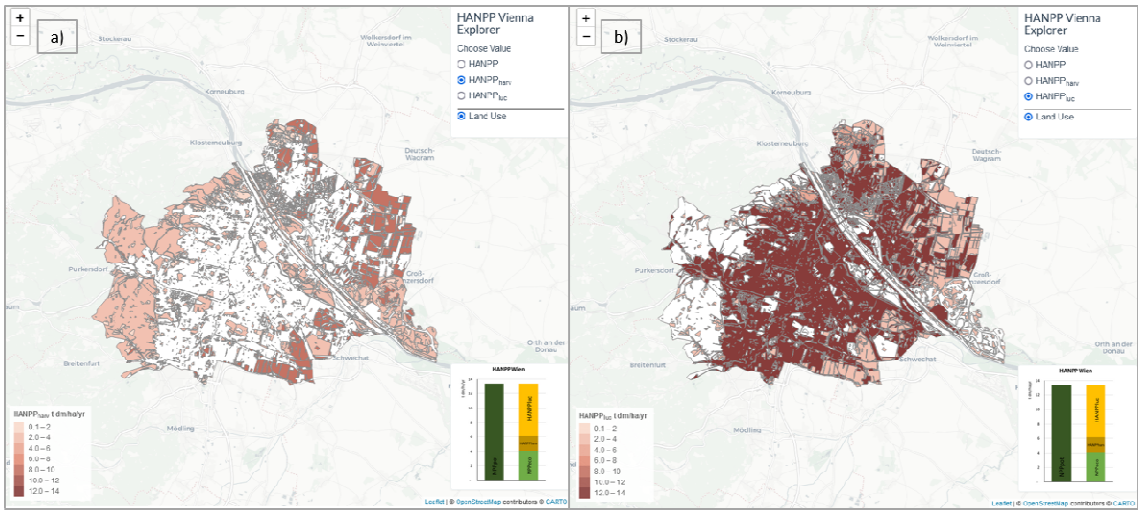

Fig. 3: Screenshot of 'HANPP Vienna' tab in 'HANPP Explorer' a) HANPPharv per ha per year; b) HANPPluc per ha per year for six land-use classes in Vienna. Higher impacts are displayed in darker colours. (https://cities.ait.ac.at/uilab/udb/home/dev/HANPP_Explorer/ - accessed 06-17-2021).

Further, the analysis along the HANPP framework allows for the differentiation of two different processes through which humans appropriate natural ecosystem productivity: while HANPPharv is characterised by biomass extraction mainly for harvest purposes, HANPPluc is induced by the change of land use/cover. This differentiation can be explored by explicit maps of HANPPharv per ha per year resp. HANPPluc per ha per year (see top right in Fig. 2 and Fig. 3). HANPPharv predominantly occurs on land use classes which are characterised by agricultural (cropland and vineyards) resp. forestry activities (forest) (see Fig. 3a). Agricultural areas in the Northeast as well as in the South of the city are coloured in rusty red as well as forest areas in the west (Wiener Wald). The average HANPPharv on cropland in Vienna is 9.4 t dm/ha/yr and in forests 2.6 t dm/ha/yr. Moreover, HANPPharv on green settlement is 3.8 t dm/ha/yr, where plants and

ISBN 978-3-9504945-0-1. Editors: M. SCHRENK, V. V: POPOVICH, P. ZEILE, P. ELISEI, C.BEYER, J. RYSER, G. STÖGLEHNER

trees are trimmed for regrowth or safety reasons. On the contrary, 90% of all HANPPluc occurring in Vienna is associated with sealed settlement (13.9 t dm/ha/yr), which is the largest land use class and characterise in particular central urban areas as can be seen in Fig. 3b).

5.3.2 Food-eHANPP Vienna

The tab 'Food-eHANPP' allows to explore the impacts of global agricultural activities on ecosystem productivity associated with Viennese food supply. It shows the relative distribution of HANPP from cropland and grassland on a country-resolution for the European Union and a regional-resolution for the rest of the world. Over all products, 51% of HANPP embodied in food products consumed in Vienna occurs in Austria, 25 % in other countries of the European Union and 24 % from non-EU-countries. In total, the supply of 0.3 t dm of food products per capita per year requires the production of 1.1 t dm biomass from cropland and grassland, which is associated with 3.0 t dm of HANPP. The difference between the final amounts of products available in Vienna and the biomass which is necessary to produce those is predominantly caused by the conversion efficiency of livestock. It represents the feed for animals for both to maintain their basic metabolism and to produce products such as meat, milk or eggs. Moreover, HANPP embodied in food products indicate further impacts on natural ecosystem productivity next to the harvest of products (=extraction), e.g. changes induced by land use change from the potential vegetation cover to cropland. By doing so, the analysis of Food-eHANPP reveals the disproportional impacts of imports from highly productive world regions such as Latin America and South East Asia.

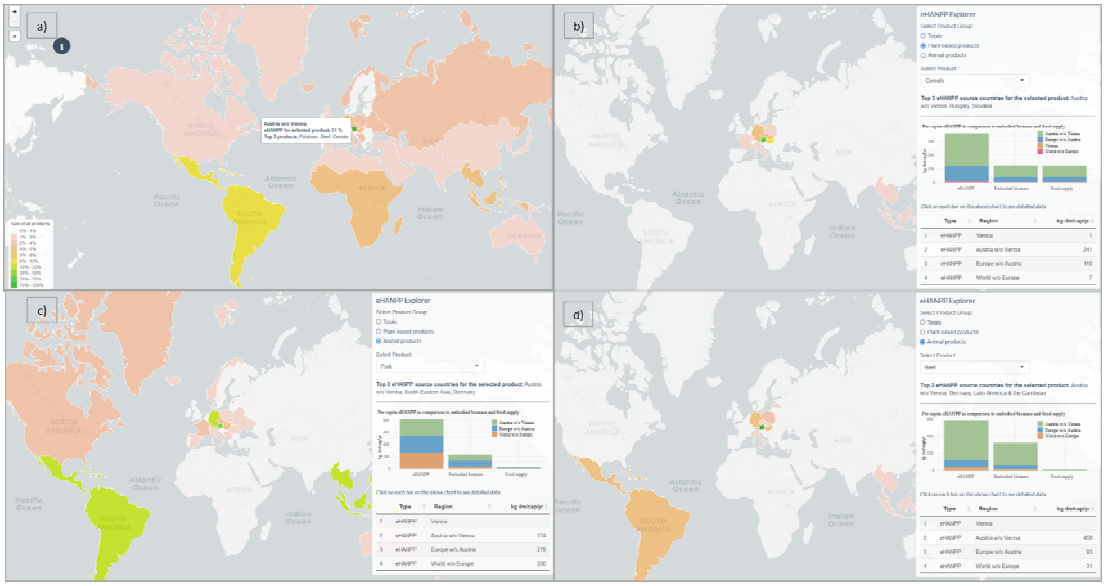

Fig 4: Screenshots of 'Food-eHANPP tab in 'HANPP Explorer' a) Total Food-eHANPP and relative origin; b) Embodied HANPP for cereals consumed in Vienna; c) eHANPP for pork c) eHANPP for beef.
(https://cities.ait.ac.at/uilab/udb/home/dev/HANPP_Explorer/ - accessed 06-17-2021).

Next to the sum of embodied HANPP associated with food supply in Vienna, the origin and the respective contribution of eight groups of plant and six animal products can be explored. For example, the supply of 122 kg dm cereals per capita is associated with 359 kg dm of HANPP of which 67% occurs in Austria and 30% in the rest of the European Union. As a comparison, the supply of 26 kg dm pork per capity per year is associated with 812 kg dm of HANPP. Here, only about 35% of embodied HANPP occurs in Austria, 33% in the rest of the European Union and 33% on Non-EU-regions of which Southeast Asia and Latin America are on top. In contrary, 70% of embodied HANPP in beef (10 kg dm supply per capita with an embodied HANPP of 583 kg dm) originates in Austria, demonstrating the importance of domestic grasslands in the feed supply of ruminants. Overall, the Food-eHANPP map within the HANPP explorer informs about the global ecological impacts of food products consumed in Vienna.

5.3.3 Scenarios

The last tab of the HANPP explorer will show first explorations on scenarios for changes in food production and consumption in Vienna. In IN-SOURCE we cooperated with a group of stakeholders from city administration and NGOs in order to co-create questions arising from a systemic view on the FWE nexus of

the city. Scenario ideas elicited in stakeholder workshops range from urban agriculture to multi-purpose uses of roofs and facades of buildings for food production, energy production and lowering energy demands; from wastewater management in order to produce energy and greywater to changes in diets reducing food with high footprints and long-distance transportation.

The aim of the HANPP explorer in terms of scenarios is to inform on the potentials of urban agriculture on the one hand. On the other hand, the focus on food production and consumption of the HANPP footprint indicator can help analysing land-use conflicts in a growing city as well as the impact of diets on the city, but mostly on the urban hinterland and national and global ecosystems. We will provide calculations and explanations on these single issues and invite further questions from users.

6 DISCUSSION AND OUTLOOK

A FWE nexus approach offers an integrative systemic path for an analysis and evaluation of solutions in the context of urban sustainabilty transistions. Yet, to work with it often makes it necessary to focus on specific questions where data can be gathered and analysed. We approach this challenge on the basis of the application, analysis and presentation of the HANPP framework accompanied by stakeholder discussions.

The key questions derived from these stakeholder discussions - posed in a comprehensible language – aim to guide through the HANPP explorer:

- In comparison to other cities, Vienna has a lot of green areas and agriculture - can this contribute to nutrition?
- Vienna is growing fast – what does this mean in terms of conflicts / competition for land use?
- Nutrition has a big impact on ecosystems – (how) can we reduce the impact?

With the help of these questions, users can stroll in the HANPP explorer according to their own interest. The explorer serves three purposes, as it provides an easy introduction to 1) the FWE nexus approach offering links to other FWE tools as part of a bigger VisToolBox and 2) the environmental footprint of HANPP/eHANPP with interactive maps and explanatory texts and graphs. HANPP footprint shows the human appropriation of biomass, whereas eHANPP footprint shows the depth of interventions into ecosystems required for the food supply of the City of Vienna. Further, the HANPP explorer seeks to offer an opportunity for users to explore and learn on topics of sustainable urban development and sustainable resource use in contexts of food consumption. They can deepen their knowledge via in-depth explanations and literature links as well as learning on scenarios potentials and calculated results for example for dietary changes.

As cities can be considered as consumption hotspots, urban green areas and agriculture only can contribute little to urban food demands. Notwithstanding these results, urban food production can be promoted and enlarged in light of its many co-benefits, ranging from greening and cooling the city, providing better air quality and water management to social community aspects. Moreover, it is beneficial for both health and sustainability purposes, to rise knowledge and awareness of food production and its impacts.

Growing cities face conflicts on land use between the functions of living, working, transport and areas for recreation and experience of green environments (plants, good air quality, low noise, …). Though, they are mainly focused on urban land use within city boundaries, despite the prevailing teleconnections induced by food supply from the close and distant hinterland. The eHANPP footprint of food reveals that cities cannot focus merely on the environment within their boundaries but have to seriously consider their impacts, the depth and size of their footprint on the urban hinterland, on the national and global ecosystems. Our analysis revealed that, per capita, the total HANPP within city boundaries over all land use classes is 0.2 t dm/yr, whereas the eHANPP footprint for food supply in Vienna is 3.0 t dm/yr. Therefore, urban land use impacts outside city boundaries surpass those inside by a factor of 13. Discussing urban land use, in particular in the context of the FWE nexus, where sustainable urban resource supply under constrained land availability is explored, needs to adequately take this imbalance into consideration. Hence, the promotion and support of less resource intensive dietary habits such a diets low in animals products or vegetarian diets is inevitable in the urban context. Finally, we hope the HANPP explorer can be used for discussing FWE nexus questions with scientists, experts, administrators and planners in order to further systemic ideas on urban sustainability transitions.

ISBN 978-3-9504945-0-1. Editors: M. SCHRENK, V. V: POPOVICH, P. ZEILE, P. ELISEI, C.BEYER, J. RYSER, G. STÖGLEHNER

7 REFERENCES

ATHANASSIADIS, A., Christis, M., Bouillard, P., Vercalsteren, A., Crawford, R.H., Khan, A.Z.: Comparing a territorial-based and a consumption-based approach to assess the local and global environmental performance of cities. In: Journal of Cleaner Production. Vol. 173, pp. 112–123. 2018.

ERB, K.-H., Krausmann, F., Lucht, W., Haberl, H.: Embodied HANPP: Mapping the spatial disconnect between global biomass production and consumption. In: Ecological Economics, Special Section: Analysing the global human appropriation of net primary production - processes, trajectories, implications, Vol. 69, pp. 328–334, 2009.

GEBETSROITHER-GERINGER, E.; Stollnberger, R.; Peters-Anders, J.: 'Interactive Spatial Web-Applications as a New Means of Support for Urban Decision-Making Processes'. In: ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences IV-4/W7 (September): 59–66. 2018.

HABERL, H., Erb, K.H., Krausmann, F., Gaube, V., Bondeau, A., Plutzar, C., Gingrich, S., Lucht, W., Fischer-Kowalski, M.: Quantifying and mapping the human appropriation of net primary production in earth's terrestrial ecosystems. In: Proceedings of the National Academy of Sciences, Vol. 104, pp. 12942–12947. 2007.

HABERL, H., Erb, K.-H., Krausmann, F.: Human Appropriation of Net Primary Production: Patterns, Trends, and Planetary Boundaries. In: Annual Review of Environment and Resources. Vol. 39, 363–391. 2014.

HABERL, H., Fischer-Kowalski, M., Krausmann, F., & Winiwarter, V. (Eds.). Social Ecology. Society-Nature Relations across Time and Space (Vol. 5). Springer International Publishing. 2016.

HABERL, H., Fischer-Kowalski, M., Krausmann, F., Weisz, H., Winiwarter, V., Progress towards sustainability? What the conceptual framework of material and energy flow accounting (MEFA) can offer. Land Use Policy 21, 199–213. 2004.

HABERL, H., Wiedenhofer, D., Pauliuk, S., Krausmann, F., Müller, D.B., Fischer-Kowalski, M.: Contributions of sociometabolic research to sustainability science. In: Nature Sustainability, Vol. 2, pp. 173–184. 2019.

KALT, G., Kaufmann, L., Kastner T., Krausmann F.: Tracing Austria's biomass consumption to source countries: A product-level comparison between bioenergy, food and material. In: Ecological Economics, Vol. 188, pp. 107129. 2021

KASTNER, T.: Trajectories in human domination of ecosystems: Human appropriation of net primary production in the Philippines during the 20th century. In: Ecological Economics, Special Section: Analyzing the global human appropriation of net primary production - processes, trajectories, implications. Vol. 69, pp. 260–269. 2009.

KRAUSMANN, F., Erb, K.-H., Gingrich, S., Haberl, H., Bondeau, A., Gaube, V., Lauk, C., Plutzar, C., Searchinger, T.D.: Global human appropriation of net primary production doubled in the 20th century. In: Proceedings of the National Academy of Sciences, Vol. 110, pp. 10324–10329. 2013.

LIU, Z., He, C., Zhou, Y., Wu, J.: How much of the world's land has been urbanized, really? A hierarchical framework for avoiding confusion. In: Landscape Ecology, Vol. 29, pp. 763–771. 2014.

NEWELL, J.P., Goldstein, B., Foster, A.: A 40-year review of food–energy–water nexus literature and its application to the urban scale. In: Environmental Research Letters, Vol. 14, pp. 073003. 2019.

NIEDERTSCHEIDER, M., Erb, K.H.: Land system change in Italy from 1884 to 2007: Analysing the North–South divergence on the basis of an integrated indicator framework. In: Land use policy, Vol. 39, 366–375. 2014.

OGD: Realnutzungskartierung ab 2007/08, Open Government Data Vienna, Wien, 2020

PLANK, C.; Görg, C.; Kalt, G.; Kaufmann, L.; Dullinger, S.; Krausmann, F.: "Biomass from somewhere": Governing the spatial mismatch of Viennese biomass consumption and its impact on biodiversity. [submitted]

PLUTZAR, C.: Biodiversität und Gesellschaft: Mensch-Natur-Interaktionen auf unterschiedlichen maßstäblichen Ebenen. Dissertation Alpen-Adria-Universität Klagenfurt, Klagenfurt. 2010.

SEMENCHUK, P.; Plutzar, C.; Kastner, T.; Matej, S.; Bidoglio, G.; Erb, K.-H.; Essl, F.; Haberl, H.; Wessely, J.; Krausmann, F.; Dullinger, S.: Relative effects of land conversion and land-use intensity on terrestrial vertebrate diversity. [submitted]

SETO, K.C., Ramankutty, N., 2016. Hidden linkages between urbanization and food systems. Science 352, 943–945

SMETSCHKA, B., Gaube, V.: Co-creating formalized models: Participatory modelling as method and process in transdisciplinary research and its impact potentials. In: Environmental Science & Policy 103, 41–49. 2020.

SMITH, B., Wårlind, D., Arneth, A., Hickler, T., Leadley, P., Siltberg, J., Zaehle, S.: Implications of incorporating N cycling and N limitations on primary production in an individual-based dynamic vegetation model. In: Biogeosciences 11, pp. 2027–2054. 2014.

VANHAM, D., Leip, A., Galli, A., Kastner, T., Bruckner, M., Uwizeye, A., van Dijk, K., Ercin, E., Dalin, C., Brandão, M., Bastianoni, S., Fang, K., Leach, A., Chapagain, A., Van der Velde, M., Sala, S., Pant, R., Mancini, L., Monforti-Ferrario, F., Carmona-Garcia, G., Marques, A., Weiss, F., Hoekstra, A.Y.: Environmental footprint family to address local to planetary sustainability and deliver on the SDGs. In: Science of The Total Environment, Vol. 693, pp. 133642. 2019.

WRIGHT, D.H.: Human Impacts on Energy Flow through Natural Ecosystems, and Implications for Species Endangerment. In: Ambio Vol 19, pp. 189–194. 1990

YU, Q., You, L., Wood-Sichra, U., Ru, Y., Joglekar, A.K.B., Fritz, S., Xiong, W., Lu, M., Wu, W., Yang, P.: A cultivated planet in 2010 – Part 2: The global gridded agricultural-production maps. In: Earth Syst. Sci. Data Vol. 12, pp. 3545–3572. 2020

8 ACKNOWLEDGEMENTS

Research was supported by Belmont Forum Sustainable Urbanisation Global Initiative (SUGI)/Food-Water-Energy Nexus theme within the JPI Urban Europe programme via the Austrian Federal Ministry of Climate Action and the European Commission (project No. 869027IN-SOURCE). We further acknowledge funding from the Vienna Science and Technology Fund (WWTF, projects No. ESR17-014 and ESR17-042) for supporting these research activities.