# GIS Modeling as Launchpad for Geodesign of Regional Rural-Urban Nutrient Partnership

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**Abstract:** The article discusses the development and application of a GIS model to support the planning of a rural-urban nutrient partnership. This initiative, funded through the German research program "Agrarsysteme der Zukunft" (Future Agricultural Systems), aims to promote a circular economy by recycling nutrients from household waste and wastewater for agricultural use. The GIS tool assesses the potential for collecting organic raw materials and the utilization potential of produced fertilizers in agrarian areas. The spatial analysis incorporates parameters, such as population density, building age (to estimate the likelihood of retrofitting for new sanitary systems), and agricultural land use. An essential aspect of the tool is its consideration of ecologically sensitive areas and other regulatory factors, such as protected zones, to ensure environmentally responsible implementation. The goal of using the tool is to identify optimal locations for either centralized or decentralized nutrient processing facilities. The model enables spatial prioritization and assists decision-makers in evaluating options for introducing a nutrient community on a regional scale and to promote and substantiating content of the development of a "Sector Plan for a Nutrient Community".

**Keywords:** Geodesign, nutrient recycling, rural-urban collaboration

## 1 Introduction

As part of the "Agrarsysteme der Zukunft" (Future Agricultural Systems) research program of the German Federal Ministry of Education and Research (https://agrarsysteme-der-zukunft.de/), a consortium of engineers, agricultural economists, crop production experts, social scientists, geographers and planners are working comprehensively on the topic "Rural-Urban Nutrient Partnership" (RUN; https://www.run-projekt.de/). In addition to the technical implementation of a new processing technology for the extraction of fertilizers from domestic organic waste and wastewater (see Fig. A1), the project considers social, ecological, economic, geographical, and planning conditions as a framework for the use of the technology.

Our focus is on understanding how a nutrient community can be established between settlements and sub- or peri-urban agriculture to promote the transformation of the spatial urban-rural relationship towards a circular economy (Fig. 1). There are several planning implications associated with this goal. One of these major planning implications concerns the location of processing facilities, which must be close to both the sources of nutrients and to consumers of the nutrients. We report on a GIS model that addresses this challenge. The model supports collaborative decision-making and addresses the spatial aspects that are associated with the implementation of new sanitary systems, the location of a production plant and the inclusion of farmers nearby.

CZIKL et al. (2024) suggest a "Sector Plan for a Nutrient Community" and discuss the necessary components, hurdles that arise, emerging discourses and resulting options for such a plan. They discuss a prototype sectoral plan with stakeholders from various municipalities and municipal associations and networks. The developed GIS tool intends to support the se-

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lection of suitable territories for such a plan and to aid the preparation of its establishment[1]. We present the model and discuss its suitability for a Geodesign process.

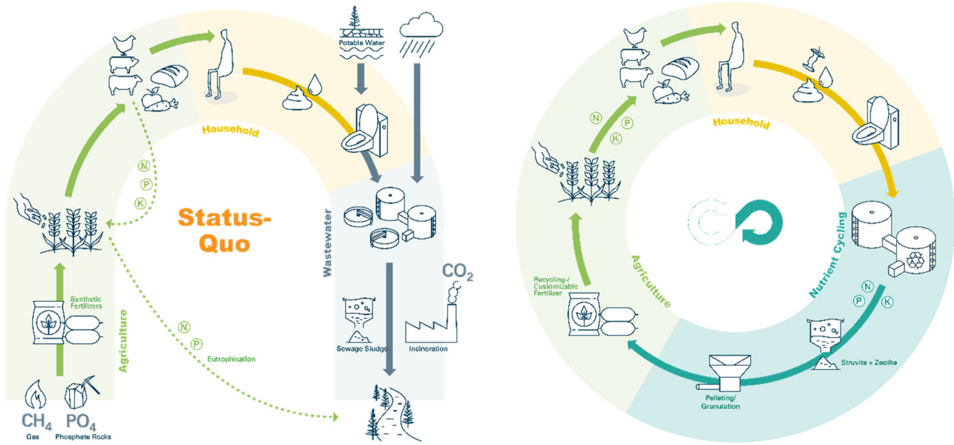


**Fig. 1:** The status-quo as an interrupted urban-rural nutrient cycle in the conventional system (left) compared to the closed loop of nutrient communities based on new recycling system (right CZIKL 2024)

The GIS-tool applies an evaluation methodology for the key question: "Where are activities that trigger a transformation of the waste management system best localized?" It delineates regions with a high transformation potential (i. e., option territories) towards the introduction of a central or decentral organized nutrient community. This potential not only depends on the spatial configuration of settlements and farmland, but also on boundary conditions that influence the decision of implementation. For example, in ecologically sensitive areas fertilization should be generally avoided. This reduces the willingness to accept and adopt the idea of a nutrient community. Here and in general, the method also includes the ability to support decision making for the "Sector Plan for a Nutrient Community" by argumentation scenario maps.

# 2 Data and Methods

## 2.1 Region, Technical Implementation and Data

The evaluation model was implemented using GIS tools for the Baden-Württemberg area of the Rhine-Neckar Metropolitan Region (Fig. A2). The model is programmed as a "geoprocessing tool" in ArcGIS Pro 3.2 and can be run again, if wanted, after adjusting parameters. Processing and results are done on a raster grid with a spatial resolution of 10m as geometry.

Geo-data are compiled from different sources and include ground footprint of buildings, structure of neighborhoods, agricultural land use on crop level, livestock per municipality,

[1] We use Geodesign in a broad definition as any support of GIS in collaborative planning. This is included in https://en.wikipedia.org/wiki/Geodesign and meets the common ground of all the different definitions we can find in specific publications like STEINITZ (2012).

land-suitability for agricultural use, eutrophication sensitive areas and structural biotopes in the agricultural fields (detailed list available from the authors).

## 2.2 Method to Estimate the Potential Volume of Organic Raw Materials

The **potential volume** for organic raw materials at a site considers the residential buildings in a 5 km neighborhood (circular environment) and evaluates the building age and the production of organic source materials (i. e., black water from toilets and organic waste produced in the kitchen). The acquisition potential $A_{Geb}$ of a building (Eq. 1) is determined from the number of inhabitants of a building $INH_{Geb}$, multiplied by the building-typical generation of organic raw materials per inhabitant and $ORGi_{Geb}$, and weighted with a factor $PNEW_{Geb}$. This reflects the fact that new types of sanitary facilities are more likely to be installed in old buildings than in new buildings.

$$A_{Geb} = ORGi_{Geb} * INH_{Geb} * PNEW_{Geb} \qquad \text{(Eq. 1)}$$

The volume of organic raw materials $A_{Geb}$ comes from data for the quantities of organic waste from kitchens and blackwater from the toilet. Data for this is available for single and multi-family homes. The $PNEW_{Geb}$ factor takes into account the required sanitary conversion measures for the collection of organic raw materials. Here, the age of the building is an important consideration – the older the residential building, the more likely it is that there will be a greater willingness or pressure for modernization. This assumption is based on the projected life cycle of a conventional flush toilet and its plumbing of 30-50 years (Baunetz Wissen 2024). After this period the willingness to invest in the refurbishment or modernization of the sanitation system is likely to increase. In this case, the latest technologies can be used, and a separating toilet or a device for collecting kitchen waste can be installed. Building age is divided into three classes: (1) residential buildings that were built before 1977, (2) buildings that were built between 1977 and 2004 and (3) residential buildings that were built from 2004 onwards. The classification of the buildings results from data on historical settlement development in Baden-Württemberg. These three classes are assigned reduction factors in the assessment approach (see Fig. 3), which estimate the potential of renovation.

## 2.3 Method to Estimate the Utilization Potential of Produced Fertilizer

The potential of produced **fertilizer utilization** $U_{Cell}$ (Eq. 2) takes into account the agricultural fields in a 5 km neighborhood of a raster cell. It is indicated by the fertilizer requirement of the crops grown in that area. In addition, ecologically sensitive areas, land suitability and substitution conditions (e. g., competition with organic raw materials from livestock farming) are taken into account as factors influencing potential utilization. The utilization potential $U_{Cell}$ indicates spatially the extent to which an area is suitable for the use of the fertilizer produced in the RUN plant. It is measured by the crop specific nitrogen uptake $N_{Cell}^{-}$, multiplied by reduction factors:

$$U_{Cell} = N_{Cell}^{-} * LS_{Cell} * SOF_{Cell} * ESA_{Cell} * RSB_{Cell} \qquad \text{(Eq. 2)}$$

- $LS_{Cell}$: Favourability of cell due to land suitability
- $SOF_{Cell}$: Degree livestock reduces the potential to substitute organic fertilizer
- $ESA_{Cell}$: Cell is in water eutrophication sensitive areas (need to reduce the intensity of the fertilizer use in general).
- $RSB_{Cell}$: Cell is in areas richly structured with protected biotopes (need to reduce the intensity of the fertilizer use in general)

The factors reflect the influence of argumentation chains on the introduction of the technology. The factors enable argumentation scenarios.

The basis for determining the fertilizer uptake comes from land use maps presented by Blickensdörfer et al. (2022) from classified satellite data for the years 2017-2019 available for the territory of the Federal Republic of Germany. The crops were then assigned specific N uptake. To approximately take into account crop rotation, the mean value for the three years 2017-2019 was assigned.

### 2.4 Option Territories for the Location of a Fertilizer Plant

The method now calls for a specification of minimum potentials for volume and utilization potential. An area that meets the requirements is called an "option territory". It includes areas in which a plant should preferably be located. Technically, it is the result of the intersection of a rescaled volume potential raster grid and a rescaled utilization potential raster grid, both restricted by a selection according to the respecting minimum specifications. The final location of a fertilizer production plant inside the option territory is to be determined respecting conditions related to the existing infrastructure, current land use, planning law requirements or so-called "No-Go" areas.

## 3 Results

### 3.1 Mapping the Potentials

Fig. 2 shows the result of summing up $A_{Geb}$ in a 5km radius rescaled to interval [1, 100]. The hot spots of potential organic raw material volume $P_{ORM}$ occur in and around the centers of the two big cities in the study area, Mannheim and Heidelberg. This is expected according to the definition. The map is used as a source map for the potential regional nutrient flow.

Fig. 3 shows the result of summing up $U_{Cell}$ in a 5 km radius rescaled to interval [1, 100]. Here, we identify several potential hot spots for alternatively produced fertilizer utilization $P_{FU}$ according to the amount of agricultural land and the specific nutrient demand of typically cultivated crops. The map is used as a sink map for the potential regional nutrient flow.

### 3.2 Scenarios for Option Territories

Irrespective of specific location criteria for a RUN facility, it is now possible to define optimal option territories. We demonstrate this in two scenarios. The first scenario assumes that there is no restriction on the size of the plant and it implements the strategy for a centralized system. The second scenario assumes a processing capacity of 2,000 tons/year, which is equivalent to the waste of approximately 5,700 inhabitants[2]. This fits to a decentral system. The maps in Figure 4 show a broader option territory and a focus option territory according to specific potentials $P_{URM}$ and $P_{FU}$.

The scenarios lead to distinct regions for option territories. A centralized system preferably should be installed somewhere between the cities of Mannheim and Heidelberg. However,

[2] We estimated and assume 404 kg/person in a single-house neighborhood and 345 kg/person in an apartment neighborhood.

the optimal territory for a decentralized system is located in the more rural areas in the western parts of the Rhein-Neckar metropolitan region near the small cities of Mosbach and Buchen.

# 4 Discussion

## 4.1 Limitations and Role of GIS Support

The demonstrated geoprocessing model can be seen as a rough screening model. Therefore, its use case is restricted to the process of drafting future regional, or even state, development plans. The method increases the understanding of nutrients as a natural resource and their circularity. It can be used to trigger a general discussion, but also a more targeted discussion about geographical relationships when considering preferred implementation areas of a nutrient community.

We must state that data availability is limited. For instance, matching farm registries at the municipal level with the used remote sensing data is rarely possible due to confidentiality reasons. A second challenge rises from the lack of precise data on high nature value farmland and on the location and state of existing sewerage. Both substantially determine utilization opportunities of the alternative fertilizer, opportunities to introduce new sanitary systems in buildings, as well as opportunities to build new sewage pipes. Better data would allow network analyses to support inter-municipal sewerage planning (e. g., for efficient extension or retrofitting by vacuum-based systems).

Nevertheless, the current status of the GIS model can serve certain planning objectives despite the limited data coherence and availability. The resulting option areas and the variability of the minimum requirements provided important information for planning communication.

Aside from the addressed planning scenario for the regional level, the GIS model could also contribute to planning at a municipal level. For instance, municipalities seeking inter-municipal cooperation for the realization of infrastructure projects like sewage sludge incineration plants to comply with the sewage sludge ordinance, would benefit from a spatial prioritization at the regional level during the initial stages of exploratory inquiries and potential analyses.

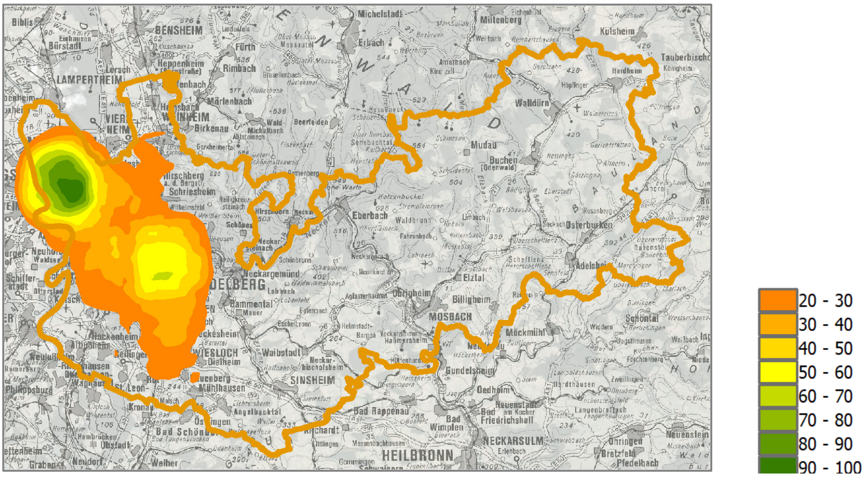


**Fig. 2:** Organic raw material volume potential $P_{ORM}$ (100 = highest) calculated for the Rhein-Neckar metropolitan region

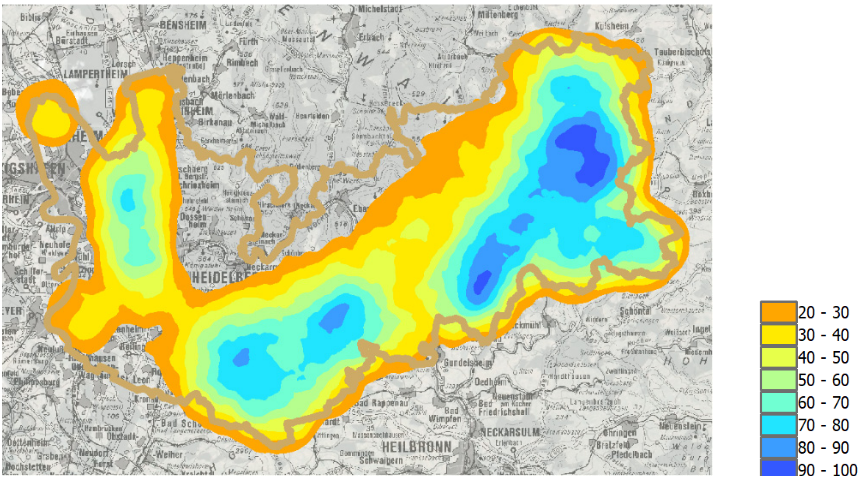


**Fig. 3:** Potential for alternatively produced fertilizer utilization $P_{FU}$ (100 = highest) calculated for the Rhein-Neckar metropolitan region

## 4.2 Perspectives for the Concept of Nutrient Communities

Pertaining to the concept of nutrient communities in general, other planning instruments should be simultaneously considered to achieve holistic and cohesive geodesign at the regional level. These can be broadly categorized into formal and informal instruments. Some examples of legally binding formal instruments include: regional and state development plans, sectoral plans and relevant legislation like the state water act and the circular economy law. Informal instruments with a binding or non-binding nature include: strategic concepts like village and city development plans, expert procedures, concept papers and guidelines and the corresponding designable and problem-driven procedures (PAHL-WEBER & HENCKEL 2008). A planning scenario that demonstrates the interplay of these instruments -- together with the proposed and additional GIS models – could be the foundation of the geodesign of regional nutrient communities.

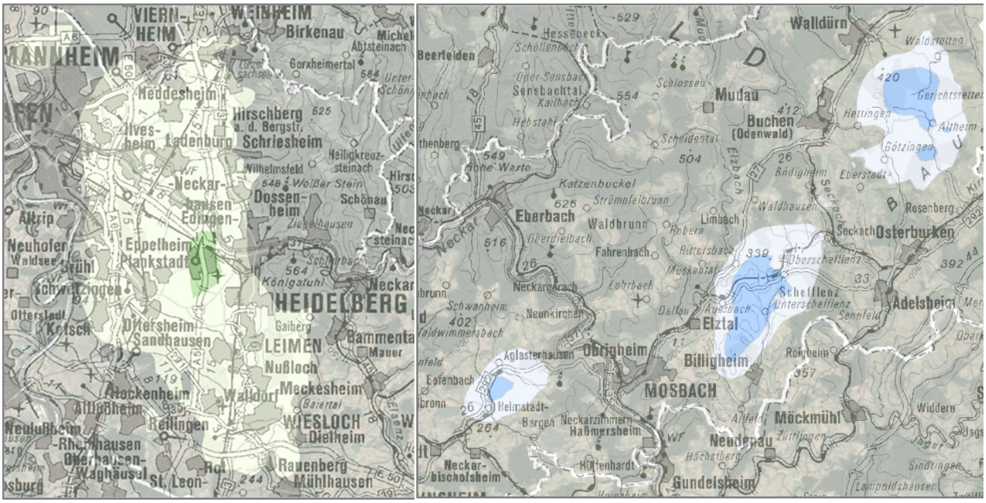


**Fig. 4:** Option territories calculated for the Rhein-Neckar metropolitan region. Left: for high-capacity nutrient recycling plant, $P_{ORM}$, $P_{FU} \geq 20$. Right: for low-capacity nutrient recycling plant, $P_{ORM}$, $P_{FU} \geq 80$. Dark color: focus for location ($P_{ORM}$, $P_{FU} \geq 50$ / $P_{ORM}$, $P_{FU} \geq 90$).

Drawing a perspective for nutrient communities *per se*, will have their starting point at the local scale and will likely span decades of transformative actions, setbacks and adaptations. It is imperative that local nutrient communities be integrated into formal planning at the municipal and district levels. This is evidenced from similar research projects that focus on suggesting practical tools and transition knowledge to support pilot projects within the municipal planning framework (e. g., policy briefs and planning guidelines; JANSSEN 2024, JUNG et al. 2023, PARFITT 2023).

## 4.3 Perspectives for Further Development

In order to ensure broad transferability of the geoprocessing tool not only regarding the consideration of spatial conditions, but also local economic and social conditions, additional parameters can, and should be, developed. The specifics of these parameters are then to be set in collaboration with stakeholders from the agricultural industries, local associations and public initiatives, such as food security councils, among many other stakeholders and actors.

It is important to stress the inherent potentials of the proposed GIS-model to integrate and engage stakeholders and actors as part of a geodesign for nutrient communities. The ability to quantify potentials, anchor them spatially and apply minimum requirements to meet specific planning parameters can resonate with a broad range of planning intentions and objectives. We therefore recommend that the approach outlined in this article be applied, adapted and extended to other specific geographical contexts. Additional hypothetical studies like ours would contribute insights regarding co-productive processes in planning, and the transformative challenges regional nutrient partnerships and communities demand.

# 5 Conclusion

The GIS model discussed in this article contributes to the geodesign of regional nutrient communities, a concept proposed by the research project RUN (CZIKL 2024). The demonstrated application and its discussion represent a blueprint not only for the urban-rural nutrient flow system under consideration but also for the role of GIS models in the context of integrated and cooperative planning.

# Acknowledgements

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# References

BAUNETZ WISSEN (2024), Lebensdauer von Haustechnikkomponenten – Bestandsaufnahme von Heizungs-, Wasser- und Elektroleitungen. Baunetz Wissen (101.2025).

BLICKENSDÖRFER, L., SCHWIEDER, M., PFLUGMACHER, D., NENDEL, C., ERASMI, S. & HOSTERT, P. (2022), Mapping of crop types and crop sequences with combined time series of Sentinel-1, Sentinel-2 and Landsat 8 data for Germany. Remote Sensing of Environment, 269, 112831c.

DEUTSCHE VEREINIGUNG FÜR WASSERWIRTSCHAFT, ABWASSER UND ABFALL (DWA) (2015), Zustand der Kanalisation in Deutschland: Ergebnisse der DWA-Umfrage 2015.

CZIKL (2024), Planning “Urban-Rural Nutrient Communities”: a Concept. In: EGERER, M., GRĂDINARU, S. R., ROLF, W. (2025): Productive Urban and Peri-urban Landscapes – Benefits, Co-benefits, and New Modes for Planning. Springer (in perp.).

JANSSEN, L. (2024), Understanding end-user acceptance of ‘new sanitation’: the path towards a circular urban water system. Utrecht University. 12 July 2024.

JUNG, E. M., ROTTER, V. S., KIRSTEN, C., MÜHLENBERG, J. & KRAUSE, A. (2023), Dry toilets offer a sustainable solution for communal waste management and regional economies by enabling nutrient recycling. https://doi.org/10.31030/3213808.

PAHL-WEBER, E. & HENCKEL, D. (2008), Studies in spatial development: Bd. 7. The Planning System and Planning Terms in Germany: A glossary. Akad. für Raumforschung und Landesplanung, Hannover.

PARFITT, N. (2023), Centering Farmer Perspectives on a Dry-Fertiliser Made from Human Urine. Centre for Sustainable Studies, Lund University. May 2023.

# Appendix

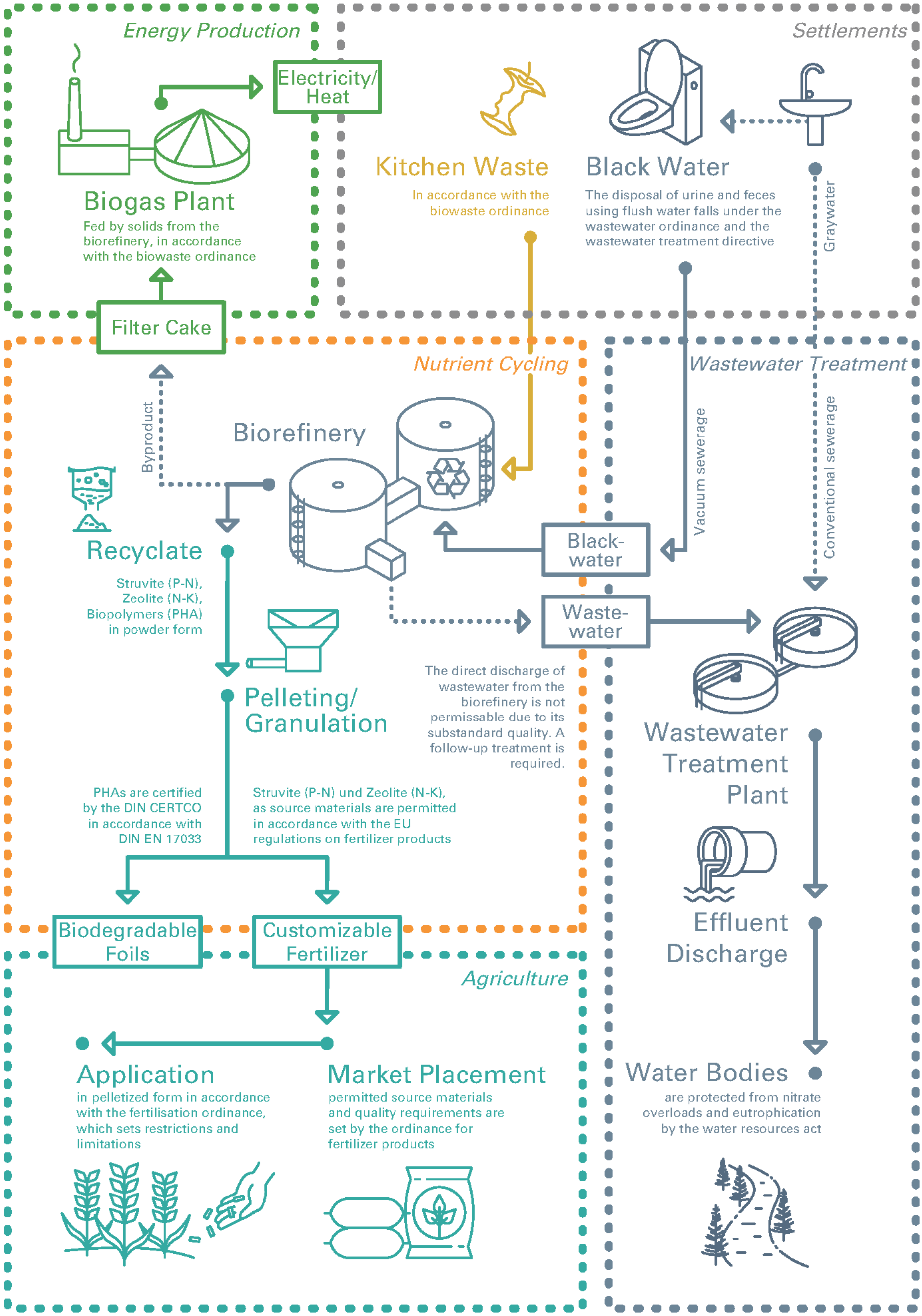


**Fig. A1:** The regulatory framework for nutrient communities across legislative fields (CZIKL 2024)

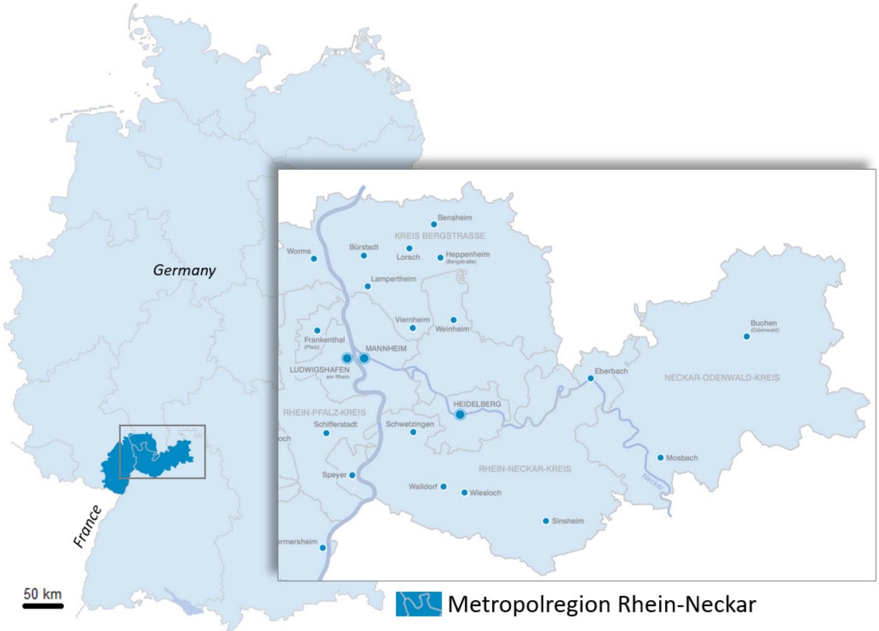


**Fig. A2:** Metropolregion Rhein-Neckar located in FRG and study area (https://www.m-r-n.com/meta/medien-und-publikationen/karte, modified by the authors)