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Developing network phenotypes considering the holistic dimension of sustainability

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Topic: Developing network phenotypes considering the holistic dimension of sustainability

Ever-increasing sustainability requirements from customers, investors and politicians are changing business strategies and models for manufacturing companies. Global manufacturing companies are often organised in production networks with globally distributed locations. The reasons for this include access to resources, markets or technologies, as well as the realisation of economies of scale or economies of scope. These structures, which have often evolved over time, represent a considerable environmental burden due to long transport routes and their consumption of resources. In the strategic orientation of their production networks, companies often orientate themselves on so-called network phenotypes, whose model is based on an ideal-typical orientation of networks. Existing models of these reference architectures are based in their description on conventional economically characterised production networks without integrating the holistic sustainability dimensions and thus the social and ecological dimensions.

Against this background, network phenotypes are to be developed in the context of this work, taking into account the holistic sustainability dimensions. To this end, the theoretical foundations with regard to sustainability, network phenotypes and the categorisation of these in the strategy process of global production networks are first elaborated. Subsequently, existing approaches for the development of network phenotypes are to be identified and evaluated with regard to their transferability to the sustainability context. In order to develop sustainable network phenotypes, the requirements of the sustainability dimensions in this context must be worked out based on the literature. In addition, the constituent elements for modelling network phenotypes must be worked out on the basis of existing approaches. By combining these results, the procedure for developing network phenotypes is finalised, taking into account the holistic sustainability dimension. The resulting network phenotypes need to be analysed from the perspective of applicability by identifying and applying strategic target dimensions for their evaluation. The development of a procedure for using the network phenotypes concludes the methodological part of the work. Finally, the sustainable network phenotypes developed are to be validated on the basis of a practical example.

In detail, the following subtasks are to be solved:

- Elaboration of the theoretical foundations of sustainability, network phenotypes and the strategy process of global production networks
- Research into existing approaches to the development of network phenotypes and evaluation taking into account the holistic sustainability dimensions
- Literature-based derivation of requirements for network phenotypes under sustainability aspects
- Development of the constituent elements for modelling network phenotypes
- Definition of network phenotypes taking into account the holistic sustainability dimensions
- Development of a procedure for the application of the developed network phenotypes within the strategy process of global production networks
- Validation of the developed network phenotypes and the procedure using a practical example

The results of the work are to be derived in scientific form.

Prof. Dr.-Ing. Dipl.-Wirt. Ing. Günther Schuh

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II Formula symbols and abbreviations

Formula symbol	Unit	Description
$N_{Circular\ economy}$		Number of possible combinations of characteristics in the circular economy
$N_{Linear\ economy}$		Number of possible combinations of characteristics in the linear economy
$N_{Extension}$		Number of possible combinations of characteristics for the expansion from linear to circular economy

Abbreviation	Description
resp.	respectively
CO_2	Carbon dioxide
CSR	Corporate Social Responsibility
ESG	Environment, Social, Governance
EU	European Union
GPN	Global production network
GRI	Global Reporting Initiative
OEM	Original Equipment Manufacturer
SCM	Supply Chain Management
SDG	Sustainable Development Goal
cf	compare
eg	for example

III List of illustrations

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1 Introduction

In chapter 1.1 describes the initial situation and the motivation for this paper. Subsequently, chapter 1.2 explains the objectives of the thesis and the research question. Chapter 1.3 describes the structure of the thesis and the process for answering the research question.

1.1 Initial situation

In terms of global gross domestic product, the world economy has quadrupled since the beginning of 1990.[1] Global production networks of multinational companies have contributed significantly to this growth in the course of globalisation. However, *growth* is no longer viewed in an unreservedly positive light. Among other things, critics accuse the profiteers of globalisation of having achieved this growth at the expense of the global climate.[2] Other harmful effects include dwindling raw materials, increasing pollution of the world's oceans and a rising number of disasters caused by climate change.[3] In view of this position, which is increasingly shared by science and the public, sustainability is becoming increasingly important for international companies.[4] In addition to these ecological challenges, social grievances are also part of the sustainability debate. According to the latest data from the WORLD BANK, 690 million people worldwide live in extreme poverty, meaning they have less than USD 2.15 a day at their disposal.[5] According to estimates, 27.6 million people worldwide were affected by forced labour in 2022, including more than 3.3 million children.[6]

Around two-thirds of forced labour takes place in the private sector.[7] This is where action is needed by companies that operate internationally and strive for holistic sustainability. In Germany, the Supply Chain Act, which became effective in 2023, is intended to create a legal framework to improve the protection of the environment as well as human and children's rights along global supply chains.[8] From January 2024, companies with more than 1,000 employees in Germany will have to check their suppliers for compliance with these standards. In this regard they are subject to due diligence and reporting obligations. Violations can be penalised with substantial fines. For example, VW, BMW and Mercedes Benz have been reported to the Federal Office of Economics and Export Control for knowingly profiting from the forced labour of the Uyghur ethnic minority in China.[9] The ecological footprint of most manufacturing companies is concentrated in the upstream value chain.[10] It is therefore important to take as holistic

[1] Cf. International Monetary Fund (05.10.2023) Global gross domestic.
[2] See Stobierski, T. (12.09.2022) Effects of globalisation.
[3] See World Meteorological Organisation (2023) State of the, p. 38.
[4] See Kropp, A. (2019) Fundamentals of sustainability, p. 2 - 4.
[5] See The World Bank (18.12.2023) 2023 in Nine Charts.
[6] See International Labour Office et al. (2022) Global estimates of, p. 2.
[7] See International Labour Office et al. (2022) Global estimates of, p. 3.
[8] Cf. Federal Ministry of Labour and Social Affairs (23.12.2023) Home game for human rights.
[9] See European Centre for Constitutional and Human Rights (ECCHR) (June 2023) German economic engine.
[10] See Choi, S. et al. (2022) Building sustainability, p. 4.

a perspective as possible when considering sustainability within global production networks. This is all the more important as sustainability is also increasingly becoming a critical decision-making factor for investors.[11]

Most location structures in global production networks have grown historically.[12] Setting up a production network requires considerable investment over the course of multiple years, which means that such decisions have a major impact on the company's development. Current events such as Brexit, the war in Ukraine, the COVID-19 pandemic, the increasingly clear consequences of climate change and growing protectionism in the wake of geopolitical competition between the USA and China require international companies to continuously re-evaluate their global production networks.[13] According to SYDOW and MÖLLERING, this results in "competition [...] between networks"[14]. However, these networks have extraordinarily complex structures that make short-term adaptation difficult.[15] To facilitate this task network configurations can be summarised in the form of phenotypes, which can serve as a template when planning new production networks. To date, however, network planners have primarily orientated themselves on economic factors.

1.2 Aim of the work

Based on the initial situation presented above, the aim of this work is to develop sustainable network phenotypes. To this end, all dimensions of sustainability are to be considered. The newly developed, sustainable phenotypes are to be named, described and placed in relation to each other in a system. To summarise, the following research question needs to be answered:

> *How can a system of network phenotypes be developed taking into account the holistic sustainability dimension?*

The following chapter presents the structure of this thesis. The focus here is on explaining the procedure for answering the research question.

1.3 Structure of the work

The development of a system of network phenotypes, taking into account the holistic sustainability dimension, comprises six chapters. The structure is based on ULRICH's applied research process. Illustration 1.1 shows the link between the structure and the phases of applied research according to ULRICH.

[11] See Alsford, J. (2023) Navigating the Next, p. 4.
[12] See Abele, E. et al. (2008) Global Production, p. 15.
[13] See Heading, S./Zahidi, S. (2023) Global Risks Report 2023, p. 6.
[14] Cf. Sydow, J./Möllering, G. (2004) Produktion in Netzwerken, p. 246.
[15] See Ferdows, K. (2014) Relating the Firm, p. 1.

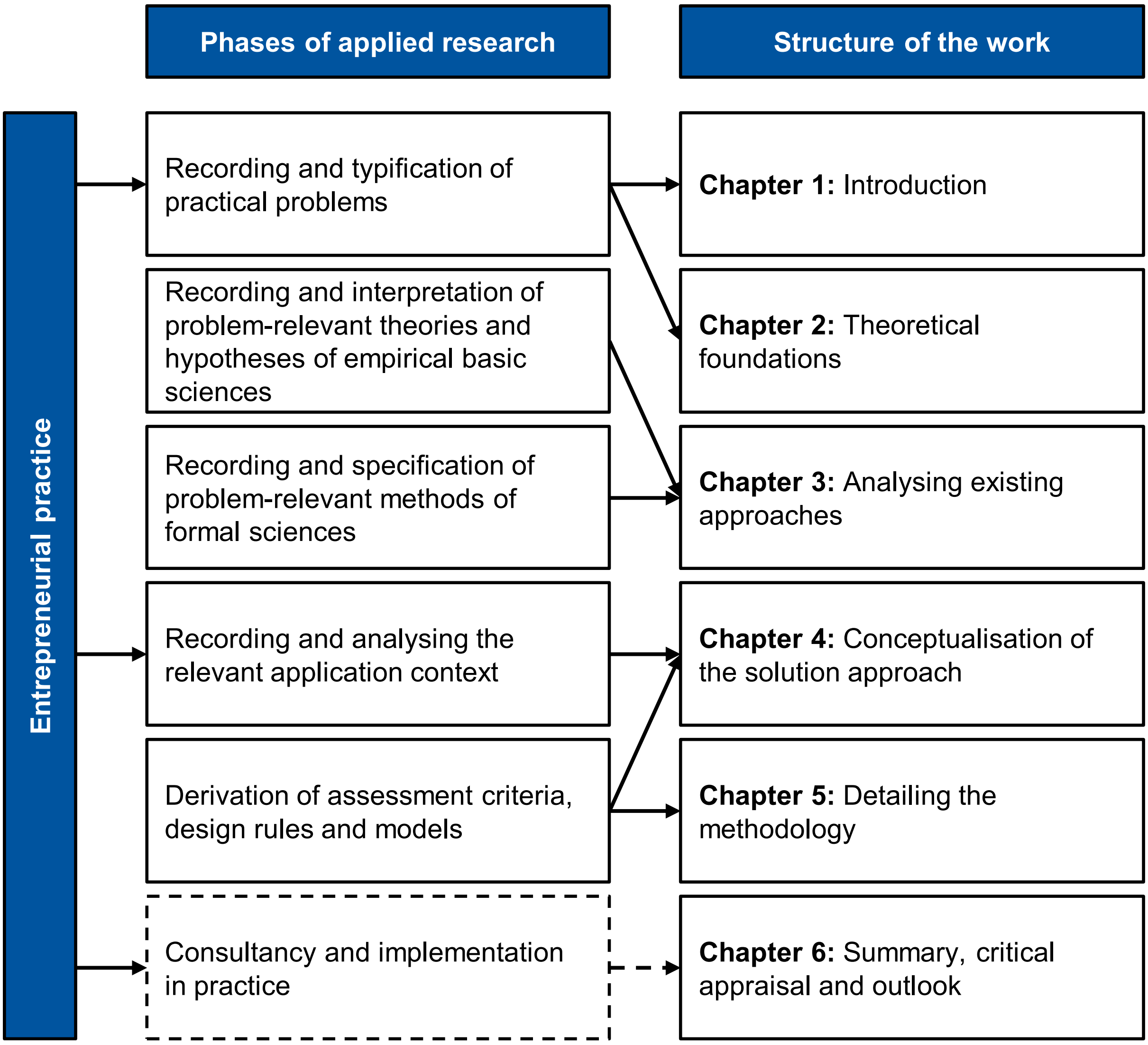

Illustration 1.1: Structure of the work based on the applied research process[16]

Chapter 1 explained the motivation for the thesis and described the initial situation. The objectives of the thesis were then explained, and the research question formulated. This section describes the structure of the thesis.

Chapter 2 develops the theoretical basis for answering the research question and first defines the relevant terms *global production networks*, *sustainability* and *network phenotypes*. It concludes by identifying the deficits in practice and then derives the resulting call for action.

In Chapter 3, the state of the art is determined by analysing existing approaches. The first step in this process is the definition of requirements from the practice deficit. The approaches are then analysed in detail and critically evaluated on the basis of the previously defined requirements. The research deficit results from the comparison of the approaches.

[16] Cf. Ulrich, H. (1984) Management, p. 193.

Based on both the practical and the research deficit, the rough concept of the methodology is developed in Chapter 4. First, the basic idea behind the concept is explained. This is followed by an overview of the framework conditions on which the methodology is based.

Chapter 5 details the methodology presented in Chapter 4 by way of three solution modules. First, the method used and the key-factors influencing global production networks are explained. Assumptions and sub-models are then presented, from which a descriptive model is developed. This overall model is transformed into a system from which network phenotypes are derived.

Chapter 6 summarises and critically reflects on the findings of the work and provides an outlook for future research.

2 Theoretical basics

This chapter lays down the theoretical foundations for this work. For this purpose, section 2.1 first categorises global production networks (GPNs). Network phenotypes are introduced as the final part of the section on GPNs (cf. subsection 2.1.3). These idealised network structures form the link between the GPNs and the concept of sustainability as presented in section 2.2.

2.1 Global Production Networks (GPN)

This section sets out the theoretical foundations of global production networks. Therefore subsection 2.1.1 begins with a categorisation and definition of the term. The subsection 2.1.2 on the management of global production networks is divided into the subsections Strategy Layer (cf. subsection 2.1.2.1) and Configuration Layer (cf. subsection 2.1.2.2). The closing topic is subsection 2.1.3 in which network phenotypes are introduced for the first time.

2.1.1 Classification and definition of terms

In the literature there is no clear definition of the term *global production network* (GPN).[17] Originally coming from economic geography, GPNs are based on both global value chains and global flows of goods.[18] Today, GPNs are part of an interdisciplinary field of research that analyses the relationships between GPNs, global value chains and global commodity flows.[19] Common to all these approaches is the assumption that a network consists of nodes and edges. The nodes are either groups, organisations or nations. The edges describe direct or indirect relationships, interactions and activities between the nodes.[20] There are various theories for categorising GPNs. Presented below are a model with a top-down perspective and a model with a matrix perspective.

According to COE and YEUNG's definition, a GPN is an organisational structure that is managed by a global management company. Companies within the network produce goods at several geographical locations for the global market. In their work on GPNs the authors focus on the nodes.[21]

In RUDBERG and OLHAGER's definition, a factory network has a matrix structure in which each node influences other nodes and therefore the network must be considered as a whole.[22] To this end the logistics management perspective and the operations management perspective come together to describe the GPN (cf. Illustration 2.1).[23]

[17] See Thomas, S. (2013) Production network systems, p. 24.
[18] See Coe, N./Yeung, H. (2015) Global production networks, p. 12.
[19] See Coe, N./Yeung, H. (2015) Global production networks, p. 1 - 2.
[20] Cf. Kutschker, M./Schmid, S. (2011) International Management, p. 534.
[21] See Coe, N./Yeung, H. (2015) Global production networks, p. 1 - 3.
[22] See Rudberg, M./Olhager, J. (2003) Manufacturing networks and SCs, p. 30.
[23] See Rudberg, M./Olhager, J. (2003) Manufacturing networks and SCs, p. 30.

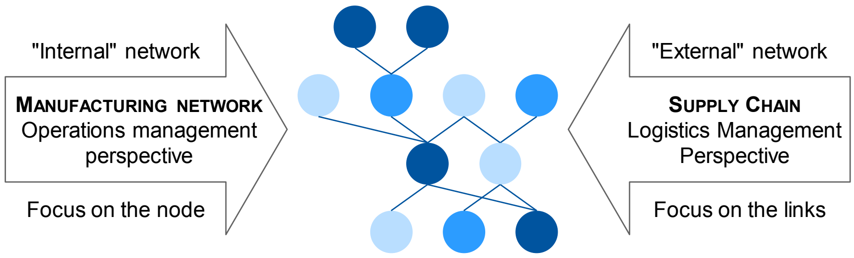

Illustration 2.1: Production networks and supply chain[24]

The logistics management perspective focuses on the edges, referred to as links, in the network, whereas the goal of the operations management perspective is to optimise the respective nodes. In their work, the authors emphasise how important it is to consider the network holistically, as otherwise a sub-optimal solution will result.[25] This requires a case discrimination for the selection of nodes and edges.

RUDBERG and OLHAGER distinguish between four types of production networks, based on the number of locations within the organisation and the number of organisations within the network (cf. Illustration 2.2).[26]

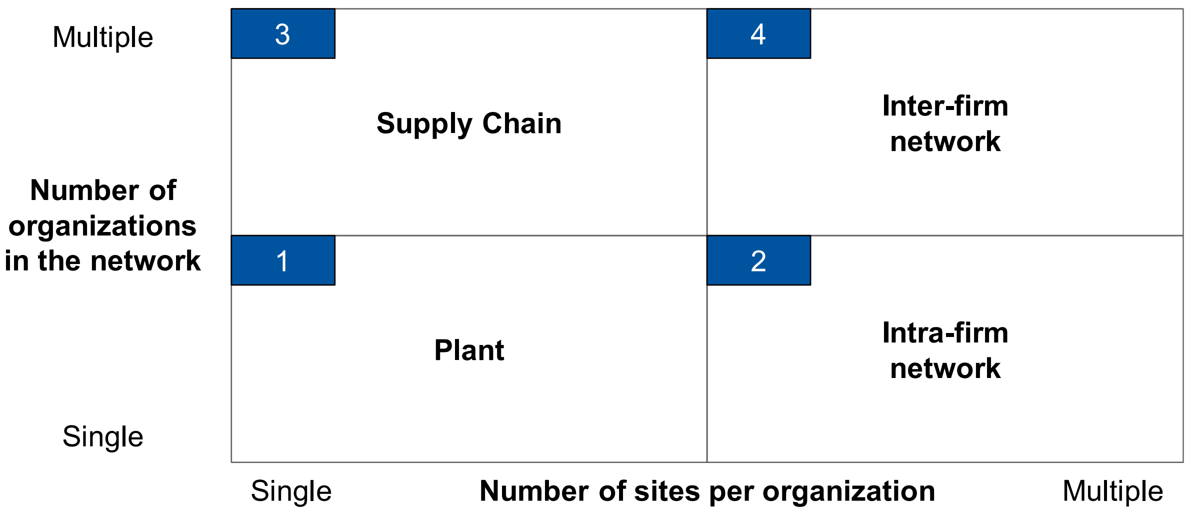

Illustration 2.2: Four types of production networks[27]

The *plant is* the simplest form of a production network, as it consists of just one organisation with just one location. The *supply chain* consists of several organisations, each of which has only one location or very few locations. Distinct from the supply chain, the authors further introduce an intra-organisational network and an inter-organisational network. *Intra-organisational* networks describe structures within a company, whereas *inter-organisational* networks refer to the structures between different companies.[28] According to KUTSCHER and SCHMID, this division goes back to the end of the 20th century, when companies increasingly developed

[24] See Rudberg, M./Olhager, J. (2003) Manufacturing networks and SCs, p. 30.
[25] See Rudberg, M./Olhager, J. (2003) Manufacturing networks and SCs, p. 30.
[26] See Rudberg, M./Olhager, J. (2003) Manufacturing networks and SCs, p. 30.
[27] See Rudberg, M./Olhager, J. (2003) Manufacturing networks and SCs, p. 35.
[28] Cf. Rudberg, M./Olhager, J. (2003) Manufacturing networks and SCs, p. 35 - 36.

into inter-organisational networks in the course of globalisation.[29] In the context of this paper, network phenotypes are considered which can be classified as intra-organisational networks.

An alternative perspective for categorising GPNs is presented below. From the spatial approach of WIENDAHL[30] and the resource-orientated approach of WESTKÄMPER[31], AYS developed the hierarchical structure which is shown in Illustration 2.3.

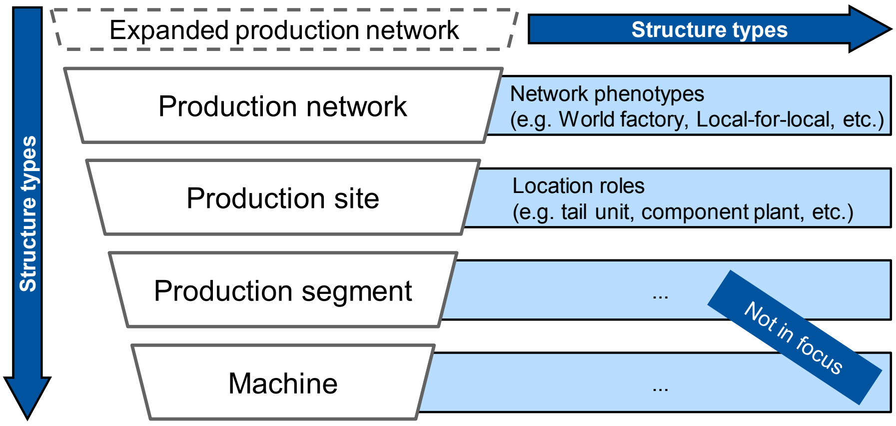

Illustration 2.3: Structural levels of production networks[32]

The vertical structural levels begin with the extended production network and extend to the machine. The extended production network is not discussed further in this paper for reasons of clarity since it also includes cross-company production sites. The top half of the here shown hierarchy levels is relevant for this paper and are therefore discussed in more detail below.[33] There are different structure types within the structural levels. Both the location roles according to FERDOWS and the network types are described in detail in the course of this chapter.[34]

A comprehensive definition of GPN also requires decision criteria for the choice of location and the site's role within the network. Based on the trade-offs formulated by SKINNER decisions are made in global competition.[35] According to this definition, trade-offs refer to situations in which the decision is made in favour of one outcome at the expense of the other option. PORTER is the first to describe the dimensions of geographical dispersion and mutual coordination between companies as central elements in the organisation of production networks.[36] This trade-off is taken up and further differentiated by numerous authors (cf. chapter 3).

[29] Cf. Kutschker, M./Schmid, S. (2011) International Management, p. 535.
[30] See Wiendahl, H.-P. et al. (2007) Changeable Manufacturing - Classification, p. 785.
[31] Cf. Westkämper, E. (2006) Organisation of production, p. 55 - 58.
[32] See Ays, J. (2021) Designing agile production networks, p. 20.
[33] See Ays, J. (2021) Designing agile production networks, p. 16.
[34] See Ays, J. (2021) Designing agile production networks, p. 19 - 21.
[35] Cf. Skinner (1969) Manufacturing - missing link, p. 140.
[36] See Porter, M. (1997) Competitive Strategy, p. 13.

This paper follows THOMAS, who integrates the aforementioned approaches and defines GPN as follows:

> *A global production network consists of geographically distributed locations of a company that primarily carry out manufacturing, assembly or development activities.*[37]

2.1.2 Management of global production networks

With their management framework for global production networks, FRIEDLI ET AL. present a holistic approach for GPNs. The framework is divided into three layers: strategy, configuration, and coordination. Each layer has design dimensions and corresponding decision categories. The three layers are linked through a network FIT, which aims to harmonise the levels (cf. Illustration 2.4).[38]

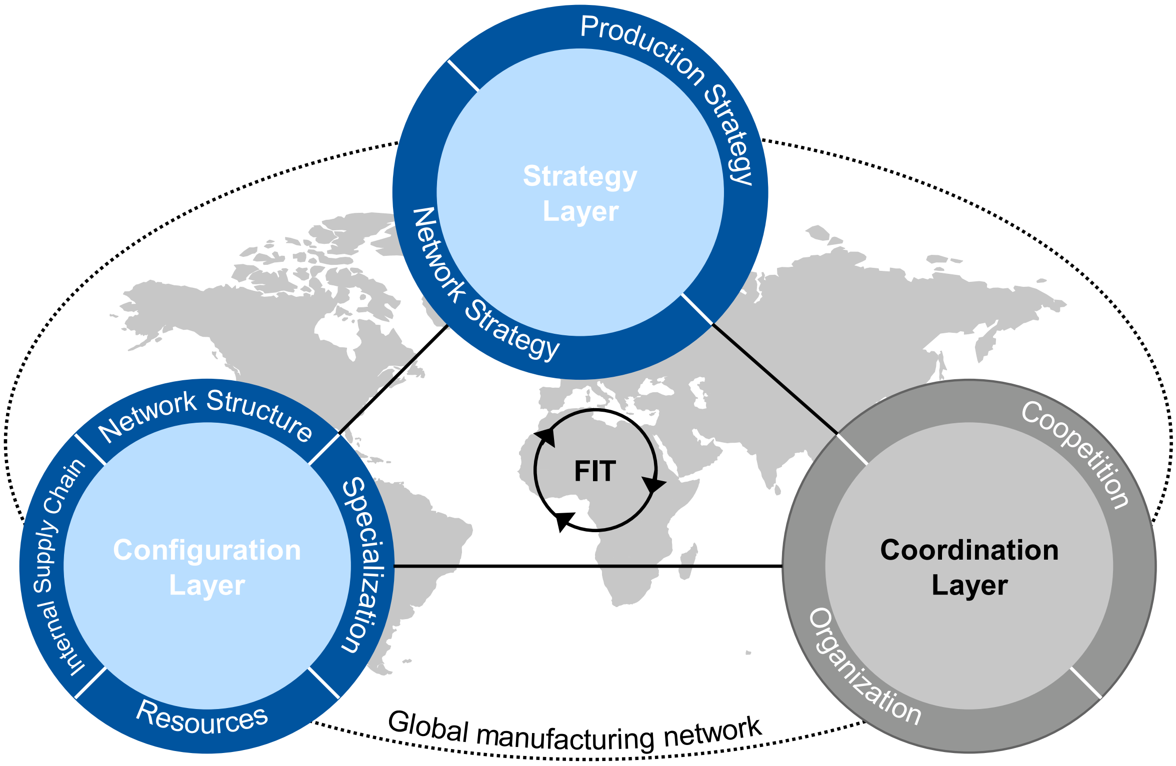

Illustration 2.4: Management framework for global production networks[39]

The focus of this paper is on the development of network phenotypes. Both the strategy layer and the configuration layer contain network decision dimensions. Therefore, these two layers are presented in detail below.

For the sake of completeness, the *coordination layer* is also introduced briefly without going into more detail later. The differentiation between the configuration layer and the coordination

37 See Thomas, S. (2013) Production network systems, p. 27.
38 See Friedli, T. et al. (2014) Strategic management of GPNs, p. 45 - 47.
39 See Friedli, T. et al. (2014) Strategic management of GPNs, p. 46.

layer dates back to PORTER, who assigns the entire physical design to the configuration layer.[40] The central remaining dimensions of the coordination layer are the organisation of the geographically dispersed actors within the network and their relationships within the network. For this purpose, decision rules regarding the exchange of information, resources and knowledge are defined. The final decision made on this layer, is the degree of cooperation or competition within the company network.[41]

2.1.2.1 Strategy layer of global production networks

The strategy layer consists of the two design dimensions of *production strategy* and *network strategy*. Both dimensions prevail over the configuration and coordination layers respectively and must therefore be considered first.[42] Only once objectives have been defined can specific requirements be placed on the production network. As part of this process, a market analysis must be carried out, taking into account the existing capacities, which often already necessitates initial restrictions. From the analysis of the market and competition according to NALEBUFF and BRANDENBURGER, differentiation factors can be derived at group level, which are called *strategic success positions*.[43] For each sub-strategy, strategic success positions are used to clearly define which aspects must be fulfilled in order to successfully implement the strategy. Crucial to this approach is considering the market gaps in connection with all required competences and capacities.[44]

Production strategy

SKINNER first recognised the importance of production strategy in 1969, laying the foundation for the differentiation factors defined by other authors later on.[45] PÜMPIN and AMANN prove that companies achieve a long-term competitive advantage over their competitors by focussing on these differentiation factors.[46] At the same time, differentiation factors form the target system for production.[47] The basis is usually formed by the four factors of price or costs, quality, delivery capability, and flexibility.[48] There exists no standardised definition of differentiation factors in the literature.

This lack of consensus is partly due to the different perspectives that the authors adopt when evaluating the factors. While the market view (external view) looks at differentiation factors from the customer's perspective, the resource view (internal view) focuses on the production

[40] See Porter, M. (1986) Changing Patterns of, p. 18.
[41] See Friedli, T. et al. (2014) Strategic management of GPNs, p. 57 - 63.
[42] See Friedli, T. et al. (2014) Strategic management of GPNs, p. 67.
[43] Cf. Nalebuff, B./Brandenburger, A. (1997) Co-Opetition, p. 28.
[44] See Pümpin, C./Amann, W. (2022) SEP - Strategische Erfolgspositionen, p. 30.
[45] Cf. Skinner (1969) Manufacturing - missing link, p. 140.
[46] See Pümpin, C./Amann, W. (2022) SEP - Strategische Erfolgspositionen, p. 30.
[47] See Friedli, T. et al. (2014) Strategic management of GPNs, p. 47.
[48] See Miller, Jeffrey G. , Roth, Aleda V. (1994) A Taxonomy of, 285.

perspective.[49] In the context of this paper, differentiation factors are considered from the market perspective.

This decision is due to two key elements: On the one hand, from the customer's perspective, it is clear which factor contributes to differentiation. There is no interdependence between the factors. Secondly, market requirements determine the design of the production network.[50] For example, if short delivery times are particularly important to customers, production must either be located close to the customer or it must be located at a site with strong infrastructure links. At group level the strategic success positions may differ greatly; therefore, THOMAS has compiled a series of fundamental differentiation factors for the production strategy, shown here in Table 2.1.

Table 2.1: Differentiation factors of the production strategy[51]

Differentiation factors		Definition
Price		Products and services fulfil or exceed the price expected by the customer.
Quality	Compliance with specifications	Products and services that meet or exceed the customer's specifications.
	Product quality	Products fulfil a consistent quality standard.
Delivery	Delivery speed	Products meet or exceed the delivery time expected by the customer (from order until delivery).
	Delivery reliability	Products are reliably delivered on time and in the right quantity.
Flexibility	Product range and design flexibility	The customer is offered a wide range of products or the option of customised designs.
	Order quantity flexibility	Order quantities or delivery times are flexibly customised.
Innovation		Customers are offered innovative solutions.
Service		In addition, customers are offered product-related services.

Although there are no interdependencies due to the choice of market view, there are still conflicts of objectives between the differentiation factors. A company cannot pursue all differentiation factors at the same time. To prioritise, both the customer requirements and the position of the company in relation to the competition should be used.[52] However, DEFLORIN shows that it is not necessary to apply a pure trade-off; rather, successful companies pursue several differentiation factors in parallel.[53] In the following, the production strategy is understood as the "sum of the targeted differentiation factors"[54].

Network strategy

In addition to the differentiation factors of the production strategy, the literature also discusses network-specific competitive advantages that result from the global positioning of companies.

[49] See Slack, N./Lewis, M. (2011) Operations strategy, 52-53.
[50] See Shorten, D. et al. (2006) Taking the Right, p. 66.
[51] See Thomas, S. (2013) Production network systems, p. 54.
[52] See Slack, N./Lewis, M. (2011) Operations strategy, p. 53.
[53] Cf. Deflorin, P. (2008) Implementation skills, p. 224 - 230.
[54] See Thomas, S. (2013) Production network systems, p. 51.

They are referred to as network strategy, analogous to the differentiation factors of production strategy.[55]

As a starting point, BARTLETT and GOSHAL identify three strategic competitive advantages of global corporations: *local presence, global cost advantages* and *global learning.*[56] They elaborate further by describing local presence as an advantage of multinational corporations, global cost advantages as a characteristic of global companies and global learning as an advantage of international companies.[57]

FERDOWS expands this list by shifting the focus to geographical location.[58] VEREECKE and VAN DIERDONCK build on FERDOWS' five location advantages and name a total of eight factors: *access to suppliers, access to labour, access to know-how, access to markets, socio-political factors, position in relation to the competition, access to energy* and *other factors*.[59] Where previously the focus was on access to markets and resources, SHI and GREGORY shift the focus to inner workings of the network: *efficiency* describes the realisation of economies of scale and scope or the avoidance of redundancies. The prerequisites are the bundling of production volumes at selected locations and a high degree of global standardisation. *Mobility* describes the ability to allocate production volumes flexibly within the network as well as to distribute resources within the network. *Learning* describes the various facets of learning about customer needs, cultures and national circumstances, market developments and competitors, through to internal learning about product and process technologies.[60] This thesis follows the structure of THOMAS, who collected all the network capabilities listed above as part of a systematic literature analysis and summarised them as shown in Table 2.2.

[55] See Friedli, T. et al. (2014) Strategic management of GPNs, p. 48 - 49.
[56] Cf. Bartlett, C./Ghoshal, S. (1990) International Corporate Management, p. 32.
[57] Cf. Bartlett, C./Ghoshal, S. (1990) International Corporate Management, pp. 29 - 33.
[58] See Ferdows, K. (1997) Making the Most, 77.
[59] Cf. Vereecke, A./van Dierdonck, R. (2002) The strategic role, 513f.
[60] Cf. Shi, Y./Gregory, M. (1998) International manufacturing networks, 209f ; Cf. Miltenburg, J. (2009) Setting manufacturing strategy, p. 6186.

Table 2.2: Network capabilities of the network strategy[61]

Network capability		Definition
Access to markets	Access to markets and customers	The network endeavours to be close to customers and markets.
	Access to competitors	The network endeavours to be close to the main competitors.
	Access to socio-political factors	The network is orientated towards socio-political factors.
	Access to image factors	The network is orientated towards particular image factors.
Access to resources	Access to suppliers/ raw materials	The network endeavours to be close to suppliers and raw materials.
	Access to skilled labour	The network focuses on access to skilled labour.
	Access to cheap labour	The network focuses on access to low-cost labour.
	Access to external sources of knowledge	The network is orientated towards access to external knowledge carriers.
Efficiency	Economies of scale	The network aims to achieve high economies of scale.
	Compound effects	The network aims to achieve high economies of scope.
	Avoidance of redundancies	The network endeavours to avoid redundancies.
Mobility	Mobility of products, processes and personnel	The network strives for the mobility of products, processes and personnel.
	Mobility of production volumes	The network strives for the mobility of production volumes and orders.
Learning	External learning	The network strives for global learning of external knowledge.
	Internal learning	The network strives for worldwide learning of internal knowledge.

As with the differentiation factors of the production strategy, there are conflicting objectives with the network strategy. For example, it is impossible to distribute production worldwide and simultaneously achieve economies of scale by bundling production volumes. However, there are synergies between mobility and learning, so that targeted optimisation is possible.[62]

2.1.2.2 Configuration layer of global production networks

The configuration layer is divided into four design dimensions, which are dependent on each other as well as on the elements of the strategy layer.[63] This means that the configuration layer must not only be consistent in itself, but also harmonise with the strategy.[64] Decision categories can in turn be derived from the configuration dimensions. The design dimensions and decision categories are discussed in more detail below.

Design dimensions of the network configuration

The four design dimensions according to FRIEDLI ET AL. are network structure, specialisation, resources and internal supply chains. They are listed in

[61] See Thomas, S. (2013) Production network systems, p. 60.
[62] Cf. Shi, Y./Gregory, M. (1998) International manufacturing networks, 209-210.
[63] See Friedli, T. et al. (2014) Strategic management of GPNs, p. 51.
[64] See Thomas, S. (2013) Production network systems, p. 61.

Table 2.3.

Table 2.3: Design dimensions of the network configuration[65]

Design dimension	Decision categories
Network structure	Geographical location of the site
	Distribution of production capacities
Specialisation	Location specialisation
	Network specialisation
Resources	Technology
	Investment
Internal supply chains	Procurement / Purchasing
	Internal supply services between the locations
	Distribution

The four design dimensions are discussed in more detail below. The underlined aspects in

[65] See Friedli, T. et al. (2014) Strategic management of GPNs, p. 46.

Table 2.3 are of particular relevance to this work.

Network structure

The network structure decision category covers both the *geographical distribution of locations* and the *distribution of production capacities* across these locations. The key question here is whether business activities should be bundled centrally at one point or whether it is more appropriate to establish a globally distributed production network. The question of how many locations of what size a network should contain and where exactly they should be located is even more specific. This is where decision-makers need to take a close look at their network strategy.[66] Based on these questions, PORTER[67], DUBOIS[68], and SHI ET AL[69] have created idealised typologies. These are referred to as network phenotypes by MEYER and JACOB.[70] Network phenotypes form a central element of this work; in the context of global production networks, they are discussed in chapter 2.1.3 and described in further detail in chapter 3 by means of an analysis of existing approaches to network phenotypes.

Specialisation

Specialisation describes how many locations with which capacities are required in which regions of the world. In particular, it is important to determine which locations manufacture which products, which markets are to be served and which competences are required for this. These decisions should explicitly be made taking a viewpoint of the entire network and not merely for individual sites.[71] *Location specialisation* takes place at location level and network specialisation at network level. The locations are assigned strategic importance based on specific criteria. Location roles, for example according to the FERDOWS model, thus have a meaningful effect for the locations.[72] *Network specialisation* is closely based on the four strategies identified by SCHMENNER, which he calls multi-plant strategies. Illustration 2.5 shows these strategies.

[66] See Friedli, T. et al. (2014) Strategic management of GPNs, p. 51.
[67] Cf. Porter, M. (1986) Changing Patterns of, 17ff.
[68] Cf. DuBois, F. et al. (1993) International Manufacturing Strategies, 309ff.
[69] Cf. Shi, Y./Gregory, M. (1998) International manufacturing networks, 210ff.
[70] See Abele, E. et al. (2008) Global Production, 164-167.
[71] See Friedli, T. et al. (2014) Strategic management of GPNs, p. 52.
[72] Cf. Thomas, S. (2013) Production network systems, 64ff.

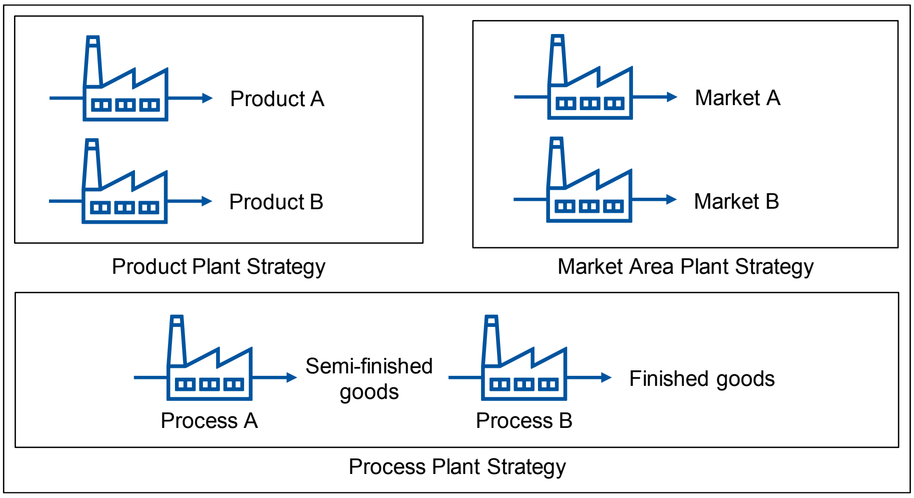

Illustration 2.5: Location strategies by action strategy[73]

In the *product plant* strategy, each site produces one product. This strategy is chosen if the products differ significantly in terms of their complexity. In the *market area plant strategy,* each site produces the majority of the company's products for a specific geographical area. This strategy is particularly relevant for products with low added value, where transport costs make up a sizeable proportion of total costs. In the *process plant* strategy, the production sites are organised according to manufacturing processes or technologies. The main applications of this strategy are found in industries in which the production sites are tied to natural resources and in manufacturing processes in which scale-intensive processes are used. As part of the *general purpose plant* strategy, the production sites can flexibly focus on products, processes or markets for a limited period of time. Such a flexibility-orientated strategy is particularly worthwhile for products with uncertain demand or short product life cycles.[74] When selecting the location strategy, it is always important to check the extent to which it fits the global production strategy and how it influences the reduction of redundancies and the realisation of economies of scale.[75]

[73] Cf. Hayes, R./Schmenner, R. (1978) How Should You, p. 111.
[74] Cf. Schmenner, R. (1982) Multiplant manufacturing strategies, 77f.
[75] Cf. Thomas, S. (2013) Production network systems, 64ff.

Resources

The resources dimension includes both the technological equipment of the locations and the investment strategy. *Technological equipment* is assessed on the basis of three criteria: scaling, automation and process interlinking.[76] Many authors understand these criteria as a single factor, which they call the degree of automation. The degree of automation at a given site depends largely on the heterogeneity of the products to be manufactured on the one hand and on the wage level at the respective location on the other. For example, in high-wage countries the production of large quantities requires a high degree of automation, whereas in low-wage countries, manual production remains attractive even for large quantities.[77]

The *investment strategy* describes how investments are made in technologies within the network. Here, a distinction is made between the copy-paste approach and the local customisation strategy. The aim of the copy-paste approach is to establish quality and efficiency in production processes throughout the network by using familiar technologies in all locations worldwide.[78] In the local adaptation strategy, the production technology is adapted to local conditions. The reciprocal relationship between product design and production technology should also be considered here.[79]

Internal Supply Chain

The internal supply chain design dimension contains three aspects: Fragmentation, procurement, and distribution. *Fragmentation* distinguishes between horizontal structures, in which one site manufactures a product in its entirety, and vertical structures, in which the production process is distributed across several locations.[80] While the supply chain structure is mainly influenced by network specialisation, mixed forms also occur in some cases. The aspect of fragmentation is fundamental for network phenotypes, which chapter 2.1.3 describes in further detail.

The aspect of *procurement* is a key success factor and becomes even more important the lower the degree of vertical integration. However, as THOMAS points out network managers are not usually responsible for procurement.[81] Three types of procurement can be strategically differentiated at network level: In global procurement, components and materials are procured from the world's best or cheapest suppliers; in centralised procurement, global requirements are bundled with one or very few suppliers; and in local procurement, each production site is supplied by suppliers from the geographical area. While centralised procurement is suitable for technically complex components or materials with quantity bundling,[82] local procurement is

[76] See Slack, N./Lewis, M. (2011) Operations strategy, 185ff.
[77] Cf. Tobias Liebeck et al. (2008) Production Technology: Adapting, 197ff.
[78] Cf. Tobias Liebeck et al. (2008) Production Technology: Adapting, 229ff.
[79] Cf. Thomas, S. (2013) Production network systems, 72ff.
[80] Cf. Karlsson, C./Sköld, M. (2007) The manufacturing extraprise, p. 914; Cf. Thomas, S. (2013) Production network systems, 75ff.
[81] See Thomas, S. (2013) Production network systems, p. 80.
[82] Cf. van Weele, A./Eßig, M. (2017) Organisation and structure, 397f.

primarily used for components that are difficult to transport and products with a low value density.[83] In principle, it is always necessary to check which type of procurement is worthwhile for each material group.

The *distribution* aspect deals with issues relating to direct supply, storage and handover of the product to the customer. It usually arises from the structure of the production network and is of secondary interest here.[84]

Decision dimensions of the network configuration

To date, there is no standardised definition of the decision dimensions of network configuration in the literature. Instead, authors such as FRIEDLI ET AL.[85], LANZA ET AL.[86], MENGEL[87] or SAGER[88] define configuration tasks in their own organisational frameworks. This work follows WELSING's system, which is based on the structural levels of the production system (cf. chapter 2.1.1). In it, he relates the most frequent decisions to the associated planning tasks.[89] The levels and elements of a production network are directly dependent on the decisions relating to the network configuration introduced in chapter 2.1.1.[90] Illustration 2.6 presents the decision dimensions.

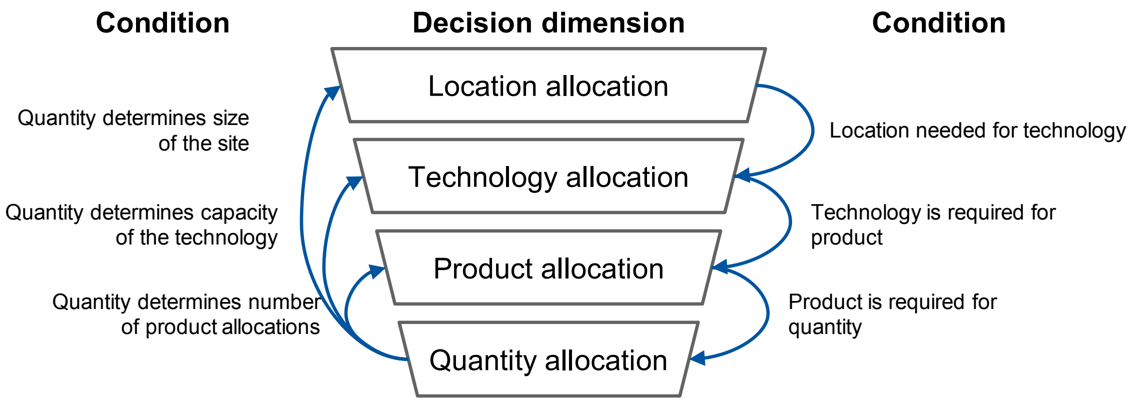

Illustration 2.6: Decision dimensions in the network configuration[91]

The decision on *site allocation* includes the number of locations required for the production network and their geographical distribution. As a result of these decision-making processes, a site can either be opened, closed, or retained.[92] *The technology allocation* is based on the site allocation. Technology allocation deals with production technologies and the necessary

[83] Cf. van Weele, A./Eßig, M. (2017) Organisation and structure, 405f.
[84] Cf. Friedli, T. et al. (2014) Strategic management of GPNs, 56f.
[85] See Friedli, T. et al. (2014) Strategic management of GPNs, p. 72.
[86] See Lanza, G. et al. (2019) Global production networks, p. 825.
[87] See Mengel, S. (2017) The Alignment of, p. 39.
[88] See Sager, B. (2018) Configuration of global production networks, p. 13.
[89] See Welsing, M. (2023) Bewertung der ökologischen, 23f.
[90] Cf. Rodemann, N. et al. (2021) Systematisation of Adaptation, 653ff.
[91] See Welsing, M. (2023) Evaluation of the ecological, p. 24.
[92] See Chen, L. et al. (2014) Manufacturing facility location, p. 154; Cf. Meijboom, B./Voordijk, H. (2003) International operations and, p. 465.

investments in production resources such as machinery and equipment. As part of *product allocation,* products or components are allocated to the sites at which they are to be produced.[93] Closely related to this is *quantity allocation*, in which the quantity to be produced at each site is determined. The results of the quantity allocation are used to determine whether further product allocations are required, whether the production technologies require additional capacity and how large a site, including its logistical connections, must be in order to produce the desired quantities.[94] More than anything else this sequential description underlines the strong interdependence of these seemingly independent decisions. Alternatively, simultaneous decision-making or a combined approach based on scenarios may also be expedient.[95]

2.1.3 Phenotypes

Network phenotypes can be used to illustrate the basic principles of the configuration of global production networks according to FRIEDLI ET AL. Therefore, this entire section is dedicated to introducing them, whereas chapter 3 discusses models from the literature.

Idealised network structures are a tool in the discussion and decision-making process, for example at interfaces between different departments.[96] However, MEYER and JACOB also emphasise the importance of conducting additional quantitative analyses when selecting a manufacturing site.[97]

MEYER and JACOB's work is so influential in the literature that various authors refer to it and expand the typology through their models.[98] The framework is based on two axes through which on one hand, they vary the degree of centralisation and decentralisation, which results in economies of scale and scope. On the other hand, they vary the degree of localisation to minimise transaction costs.[99] Due to its academic significance, this paper also follows MEYER and JACOB's approach, shown here in Illustration 2.7.

[93] Cf. Friedli, T. et al. (2014) Strategic management of GPNs, 19ff; Cf. Schuh, G. et al. (2018) Reduction of Decision, 250f.
[94] Cf. Olhager, J. et al. (2001) Long-term capacity management, 215ff.
[95] See Eppen, G. et al. (1989) OR Practice-A, p. 519.
[96] See Abele, E. et al. (2008) Global Production, p. 167.
[97] See Abele, E. et al. (2008) Global Production, p. 175.
[98] See Váncza, J. et al. (2011) Cooperative and responsive, p. 804; Cf. Schönsleben, P. et al. (2015) Toward the integrated, p. 6.
[99] See Lanza, G. et al. (2019) Global production networks, p. 826.

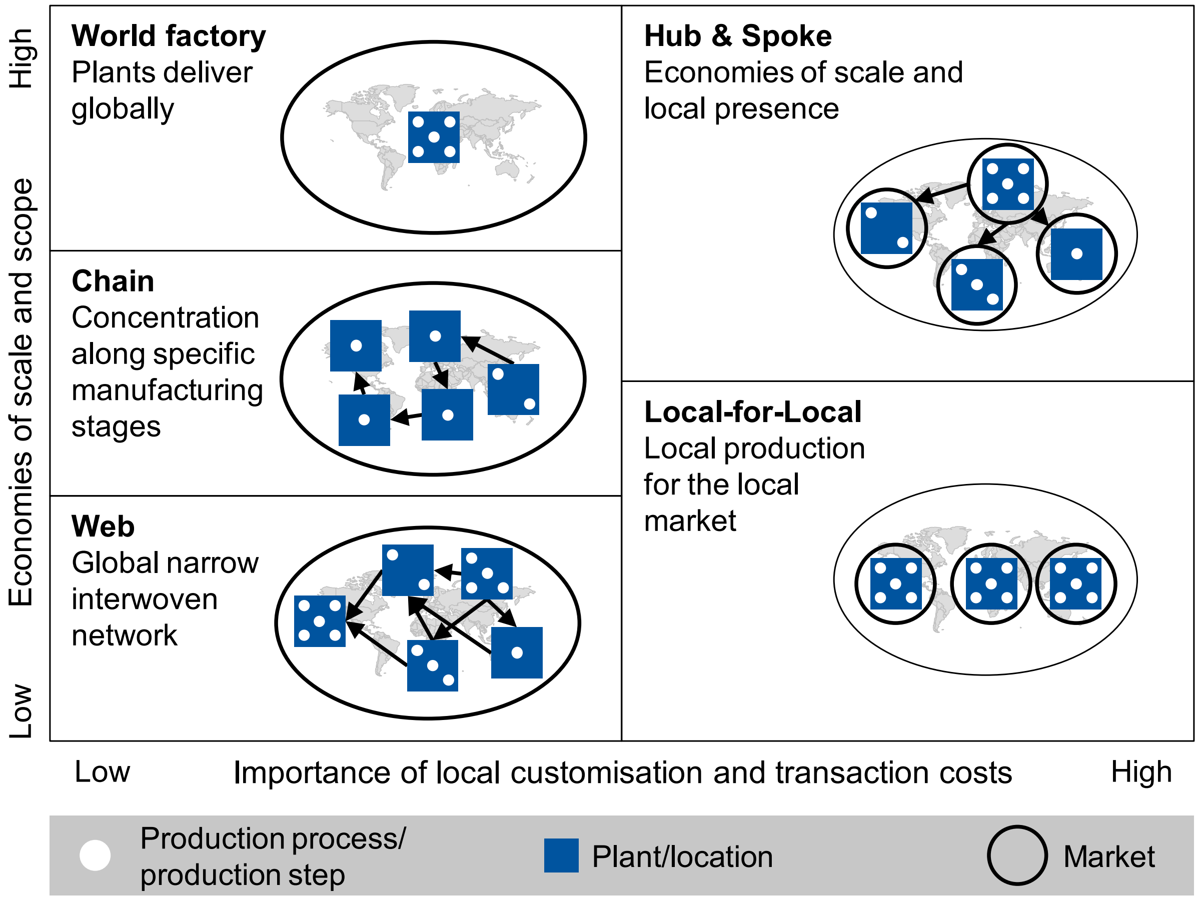

Illustration 2.7: Network phenotypes over economies of scale and transaction costs[100]

The *world factory* describes a phenotype in which global production takes place at a single location. Successful implementation can achieve significant economies of scale and economies of scope. The products must have both a high value density and be able to be produced with sufficiently long delivery times. The combination of both these requirements is why this type, which has evolved over time, has become increasingly less important in traditional industry, but is still fundamental to high-tech industry.[101]

The *local-for-local* phenotype is the counterpart to the global factory. Both types require only a low level of exchange of goods and information. The local-for-local model has established itself for products with a low value density, a high number of market-specific features, short delivery times or a large number of product variants. In an increasingly globalised world in which transaction costs are decreasing, local-for-local is the best possible strategy only for a shrinking number of products.[102]

The *Hub&Spoke* phenotype combines the advantages of the two previous models. On the one hand, products with many variants and short delivery times are provided via the spokes and,

[100] See Abele, E. et al. (2008) Global Production, p. 164.
[101] See Abele, E. et al. (2008) Global Production, p. 165.
[102] See Abele, E. et al. (2008) Global Production, p. 166.

on the other hand, economies of scale can be achieved in the production of parts and components in the hubs. This approach also minimises logistics and customs costs, as customs duties on finished products are significantly higher than on intermediate products.[103]

In the *chain,* the products pass through a series of different production sites in which the advantages of each individual site are fully utilised. This maximises economies of scope and scale at every stage of production, but this model leads to even higher transaction costs than the global factory. The model is therefore only used for products with a high value density, such as in the electronics or semiconductor industry.[104]

The *web* is characterised by the possibility of being able to manufacture all products within the network at all locations. On the one hand, this makes it virtually impossible to achieve economies of scale or economies of scope. On the other hand, the web offers maximum agility and flexibility. This means that the locations can be utilised almost constantly even if demand fluctuates in individual markets.[105] This is why LANZA ET AL also call the web the "phenotype of the future"[106].

This framework of network phenotypes according to MEYER and JACOB is exclusively economically motivated. In the further course of this thesis, phenotypes are also analysed taking ecological and social factors into consideration. To this effect, the concept of sustainability is discussed in the following section.

2.2 Sustainability

This section explains the theoretical foundations of sustainability. Firstly, in subsection 2.2.1 a categorisation of the relevance and a definition of the term. The second subsection 2.2.2 introduces the three dimensions of sustainability. Subsection 2.2.3 deals with sustainability strategies. Subsection 2.2.4 looks at sustainability from a corporate perspective. In the final subsection 2.2.5 sustainability trends in production are discussed.

2.2.1 Relevance and definition of terms

Sustainability and climate neutrality have become an integral part of the political debate. The 2015 *Paris Climate Agreement* was ratified by 195 countries and aims to limit the global temperature rise to well below two degrees Celsius by 2100 compared to the pre-industrial era. The states commit to using financial resources for the climate targets, for example to reduce emissions.[107] Also adopted in 2015, the United Nations *Sustainable Development* Goals (SDGs) are a call to end poverty and protect the planet. By 2030, 17 closely interlinked goals

[103] See Abele, E. et al. (2008) Global Production, p. 166.
[104] See Lanza, G. et al. (2019) Global production networks, p. 827.
[105] See Abele, E. et al. (2008) Global Production, p. 167.
[106] See Lanza, G. et al. (2019) Global production networks, p. 827.
[107] Cf. Federal Ministry for Economic Cooperation and Development (22/08/2023) Paris Climate Agreement.

are intended to help the least developed regions develop economically, socially and ecologically.[108] As part of the *European Green Deal,* the European Union has set itself the goal of becoming the first climate-neutral continent by 2050, i.e. not to emit more greenhouse gases than can be compensated for. To achieve this, investments and subsidies totalling one trillion euros are planned over a period of ten years.[109] In Germany, the federal government is aiming to achieve climate neutrality by 2045.[110] To this end, climate policy responsibilities have been transferred from the Ministry of the Environment to the Ministry of Economic Affairs.[111] This action expresses organisationally that climate policy has now become part of economic policy.

The concept of sustainability first appeared in literature in 1713, when VON CARLOWITZ used the example of the timber industry to formulate the demand to "[...] prevent the loss of wood [...] through new insemination".[112] The term entered the scientific debate in 1972 with the publication of the title *The Limits to Growth* by MEADOWS ET AL.[113] This group is more commonly referred to as the Club of Rome. The report highlights the problems posed by the exponential growth of a resource- and emission-intensive industrialised society.[114]

Of the many different definitions of sustainability, the one used in the *Brundtland Report* has proven to be the lowest common denominator.[115] This states that the needs of the present must be met sustainably without restricting the possibilities of future generations. Sustainable development is limited by the state of technology and social organisation and the ability of the biosphere to absorb the impact of human activity.[116] In the literature this concept is also known as *intergenerational* equity. It is contrasted with *intragenerational* justice, which is about political and economic equality for all levels of society.[117]

For sustainability in companies ELKINGTON specifies that our actions today must not have an impact on the economic, ecological or social consequences for future generations. In 1999, he also postulated the growing relevance of sustainability for industry and emphasised that all three dimensions must be in balance with each other.[118] In this paper, ELKINGTON's definition of sustainability is used because it has the greatest relevance for manufacturing companies.

108 See Independent Group of Scientists appointed by the Secretary-General (2023) Global Sustainable Development.
109 Cf. Deutschlandfunk.de (22/08/2023) "Green Deal" - Europe's.
110 Cf. Deutschlandfunk.de (22/08/2023) On the way.
111 See Kreutzfeldt, M. (2021) New Ministry of Economics.
112 Cf. Carlowitz, H. v. (1713) Sylvicultura oeconomica, p. 105 - 106.
113 See Meadows, D. et al. (1972) Limits to Growth.
114 See Pufé, I. (2012) Sustainability management, p. 13.
115 See Kropp, A. (2019) Grundlagen der Nachhaltigen, p. 6; Cf. Johnston, P. et al. (2007) Reclaiming the definition, p. 60; See Martins, V. et al. (2019) Knowledge management in, p. 490.
116 See Brundtland, G. (1987) Our Common Future, p. 15.
117 See Pufé, I. (2012) Sustainability management, 28-29.
118 Vgl. Elkington, J. (1999) Cannibals with forks, S. 20.

2.2.2 Dimensions of sustainability and conflicting goals

According to ELKINGTON, sustainability is divided into three dimensions: social, ecological and economic. Before covering the various models in the literature that describe the relationships between the dimensions, an introduction concerning each of the individual dimension of sustainability will follow.

Ecological sustainability means that natural resources should only be utilised to the extent that they can be regenerated.[119] Resource conservation is reflected in the reduction of raw material extraction and consumption as well as in the redirection of material and energy flows.[120] Ecological sustainability on the producer side is often at odds with consumer sovereignty, which favours a choice of different products. At this point, politicians are called upon to build a bridge through regulation.[121]

Economic sustainability means achieving or maintaining a sufficient quality of life by strengthening economic power.[122] In the literature, economic sustainability represents a further development of neoclassical growth theory, in which growth is based on human capital, education and technological progress.[123] An economic system is considered sustainable if it can be operated in the long term, i.e. in particular if it does not exploit resources, accumulate debt or cause irreparable damage.[124]

Social sustainability is characterised by the pursuit of justice and peace. One indicator of social sustainability is the World Happiness Index, which focuses on the intangible foundations of life.[125]

Three models have emerged to illustrate the interdependencies between the three dimensions: The three-pillar model of sustainability, the intersection model and the sustainability triangle. Illustration 2.8 shows graphical representations of these three.

[119] See Pufé, I. (2012) Sustainability management, p. 29.
[120] See Hauff, M. v. (2021) Sustainable development, p. 36.
[121] See Hauff, M. v./Jörg, A. (2017) Sustainable growth, p. 40 - 42.
[122] See Hauff, M. v. (2021) Sustainable development, p. 37.
[123] See Hauff, M. v. (2021) Sustainable development, p. 38.
[124] See Kropp, A. (2019) Fundamentals of sustainability, p. 12.
[125] See Kropp, A. (2019) Fundamentals of sustainability, p. 11.

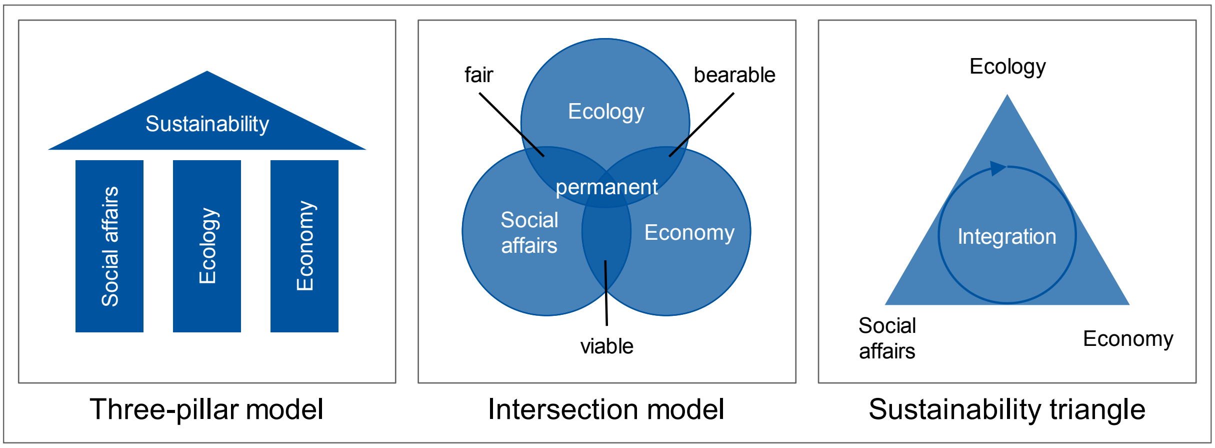

Illustration 2.8: Three-pillar model, intersection model and sustainability triangle[126]

In the *three-pillar model,* the three dimensions of sustainability are equally important. When implementing goals, all pillars should be considered equally and simultaneously.[127] Critics of the model criticise the fact that, metaphorically speaking, it would also be possible to omit one or even two pillars for static reasons, and that there are "no clear exchange relationships or dependencies [...] between the pillars"[128].

At the heart of BARBIER's *intersection model* are three overlapping discs, which map the influences of the dimensions on each other.[129] This means that the dimensions are no longer viewed as isolated units. It shows that there can be multiple assignments between the dimensions and that they influence each other. Each overlapping area is assigned its own description.[130] For example, the intersection between the economic and social dimensions is called viable, alluding to the core themes of the area. The intersection of all three dimensions is long-term sustainability.[131] The model is criticised for the fact that the strong focus on the intersections means that the non-overlapping areas lose too much importance.[132]

The aim of the *sustainability triangle* is to integrate, combine and consider the dimensions simultaneously.[133] To achieve this, we initially draw on a concept from the engineering sciences: Gibb's triangle. Each side X, Y, Z is assigned a value in order to graphically represent the varying degrees of the three sides. The sum of X + Y + Z = 100%.[134] A skewed triangle indicates an imbalance between the dimensions. When combined with the intersection model, the integrative sustainability triangle according to KLEINE results as a special form.[135] This is an equilateral triangle with an integrative factor in the centre, where the distribution is clear at first glance. There are different zones within the integrative sustainability triangle, depending

126 See Pufé, I. (2012) Sustainability management, p. 34.
127 See Pufé, I. (2012) Sustainability management, p. 33.
128 See Hauff, M. v. (2021) Sustainable development, p. 171.
129 Vgl. Edward B. Barbier (1987) Concept of Sustainable Economic, p. 104.
130 See Pufé, I. (2012) Sustainability management, p. 35 - 36.
131 See Kropp, A. (2019) Fundamentals of sustainability, p. 12.
132 See Hauff, M. v. (2021) Sustainable development, p. 172.
133 See Pufé, I. (2012) Sustainability management, p. 36.
134 Cf. Kleine, A. (2009) Operationalisation of a sustainability strategy, p. 83.
135 Cf. Kleine, A. (2009) Operationalisation of a sustainability strategy, p. 81 - 87.

on the degree of allocation to the respective dimension.[136] Of the models presented, the sustainability triangle has prevailed.[137]

There are not only interdependencies between the dimensions of sustainability, but also conflicts of objectives. If sustainability goals are presented as incompatible with each other, this often leads to blockades. In this case, DUSSELDORP suggests creating sustainability standards in which the prioritisation of goals is clearly defined.[138]

2.2.3 Sustainability strategies in the design of GPNs

There are three sustainability strategies for implementing sustainable development: efficiency, consistency and sufficiency strategies. According to HUBER, each of these complementary strategies is a necessary but not a sufficient element of sustainable economic activity.[139] In terms of prioritisation, the consistency strategy should be implemented before the efficiency strategy, and both in turn before the sufficiency strategy.[140] The three strategies are explained in more detail using the SCHMIDT cost-income diagram shown in Illustration 2.9.

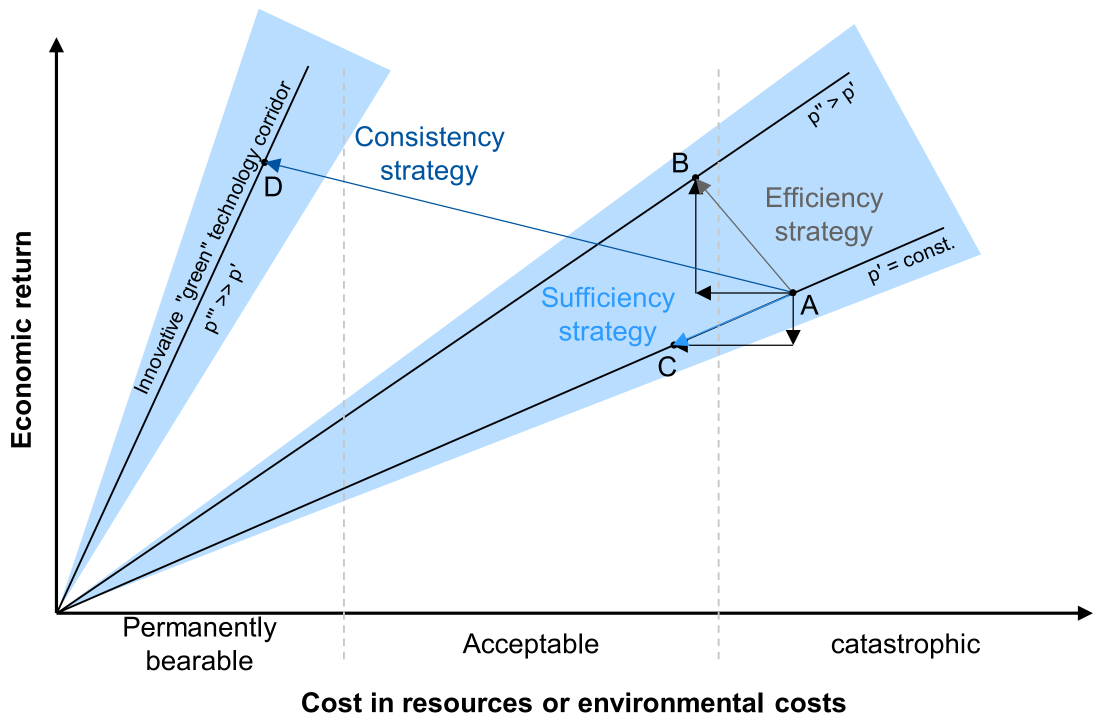

Illustration 2.9: The three sustainability strategies in the cost-income diagram[141]

[136] Cf. Kleine, A. (2009) Operationalisation of a sustainability strategy, p. 85.
[137] See Kropp, A. (2019) Fundamentals of sustainability, p. 12.
[138] See Dusseldorp, M. (2017) Zielkonflikte der Nachhaltigkeit, p. 1.
[139] Cf. Huber, J. (2001) General Environmental Sociology, p. 250.
[140] Cf. Huber, J. (2000) Industrial Ecology: Consistency, p. 124.
[141] See Schmidt, M. (2008) Efficiency for sustainability, p. 40.

In the cost-income diagram, expenditure is shown on the abscissa and income on the ordinate. The black straight lines indicate points of equal productivity, which result from the quotient of expenditure and income. A steeper straight line indicates higher productivity.[142]

The aim of the *efficiency strategy* is to influence the relative proportion of resource expenditure in relation to revenue. In doing so, it closely reflects traditional economic thinking, for example by maximising the yield with constant expenditure according to the maximisation principle.[143] In a business context, this increase in efficiency is also known as productivity and is achieved through technical innovation. The above Illustration 2.9 shows that a company utilises a technology corridor in order to move from the productivity line p' to p''. The technology corridor is limited to the top left by the best available technology. According to SCHMIDT, there are two ways of widening this corridor: by improving productivity in the form of internal measures based on the available state of the art or by driving forward technical innovation through research and development.[144] The efficiency strategy is very important in the economy and is the most operationalised sustainability strategy. The efficiency strategy leads to cost reduction and increased resource security while maintaining the same output quantity.[145] From a sustainability perspective, however, the rebound effect must also be considered at this point. As early as 1865, JEVONS postulated that increases in efficiency sometimes make new applications attractive, which in turn increase the consumption of resources.[146] If the consumption of the new, more efficient solution is higher than that of the status quo, this occurrence is known as the backfire effect.[147]

The *consistency strategy* is closely related to the previous strategy. Whereas the efficiency strategy is primarily concerned with analysing quantities, the consistency strategy takes a sustainable approach to the consumption of materials, products, and technologies. In its pure form, this means the use of "renewable raw materials - to an extent that preserves natural capital and has no negative side effects"[148], in the form of a closed-loop economy with renewable energy.[149] However, KROPP points out that a true circular economy is difficult to achieve.[150] In the Illustration 2.9 point D is located in a new, innovative, "green" technology corridor. This means that production in this area is sustainable in the long term. Successful implementation takes place at both the macroeconomic and the microeconomic level. This distinguishes it from both the efficiency strategy, where companies are largely responsible, and the sufficiency strategy, where the renunciation originates the individual.[151]

[142] See Schmidt, M. (2008) Efficiency for sustainability, p. 38 - 39.
[143] See Schmidt, M. (2008) Efficiency for sustainability, p. 35 - 36.
[144] See Schmidt, M. (2008) Efficiency for sustainability, p. 39 - 40.
[145] See Hauff, M. v. (2021) Sustainable development, p. 67.
[146] Cf. Jevons, W. (1865) The Coal Question.
[147] See Hauff, M. v. (2021) Sustainable development, p. 68.
[148] See Schmidt, M. (2008) Efficiency for sustainability, p. 36.
[149] See Schmidt, M. (2008) Efficiency for sustainability, p. 37.
[150] See Kropp, A. (2019) Fundamentals of sustainability, p. 24.
[151] See Hauff, M. v. (2021) Sustainable development, p. 68.

The *sufficiency strategy* centres on per capita consumption and the question: "How much is enough?". Sufficiency is always based on the end consumer, as it would contradict the principles of the market economy to demand that producers limit their sales.[152] HAUFF structures the sufficiency strategy into three components: self-restriction based on voluntary decisions; a change in lifestyle towards a qualitative change in consumption; and the structural change of the basket of goods towards services and immaterial goods.[153] According to HUBER, however, the sufficiency strategy is unrealistic, as it conflicts with maximising material benefits for the greatest possible number of people.[154] With productivity remaining the same, this would imply a proportionally lower yield, as shown in Illustration 2.9 over the distance from point A to point C.

In terms of overall sustainability, the sufficiency strategy is often preferable to the efficiency strategy. The reason for this is the limited extent to which it is possible to move from a catastrophic to an acceptable range within the technology corridor. However, the step towards sustainable production can only be achieved by utilising the consistency strategy.[155] As manufacturing companies are the focus of this paper, the following section will go into further detail on sustainability from a corporate perspective.

2.2.4 Sustainability from a corporate perspective

Companies are economic entities with the aim of maximising profits for their owners. According to ELKINGTON's triple bottom line theory, the success of a company depends on an extended spectrum of values and criteria. The social, environmental, and economic triple bottom lines correspond to the three dimensions of sustainability.[156]

ORTIZ-DE-MANDOJANA and BANSAL also emphasise the importance of sustainability for the long-term success of companies.[157] As explained in the previous chapter, the path to sustainability leads through a combination of the three sustainability strategies. While the efficiency strategy has a direct influence on sales, the consistency strategy in particular is characterised more by indirect effects. Based on the definitions of BRUNDTLAND and DYLLICK ET AL., *corporate sustainability* refers to the ability of a company to fulfil the requirements of direct and indirect stakeholders without compromising its ability to meet the needs of future stakeholders.[158]

FREEMAN defines stakeholders as any individual or group that influences or is influenced by the fulfilment of an organisation's objectives.[159] Against this background, it is necessary to

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[152] See Schmidt, M. (2008) Efficiency for sustainability, p. 35.
[153] See Hauff, M. v. (2021) Sustainable development, p. 70.
[154] Cf. Huber, J. (2000) Industrial Ecology: Consistency, p. 119.
[155] See Schmidt, M. (2008) Efficiency for sustainability, p. 41 - 42.
[156] Vgl. Elkington, J. (1999) Cannibals with forks, S. 20.
[157] See Ortiz-de-Mandojana, N./Bansal, P. (2016) The long-term benefits, p. 1615.
[158] See Dyllick, T./Hockerts, K. (2002) Beyond the business, p. 131.
[159] See Freeman, R. (2015) The Stakeholder Concept, p. 46.

consider the various stakeholders in an organisation and their respective requirements for sustainability separately.[160] The division into internal and external stakeholders is shown in Illustration 2.10.

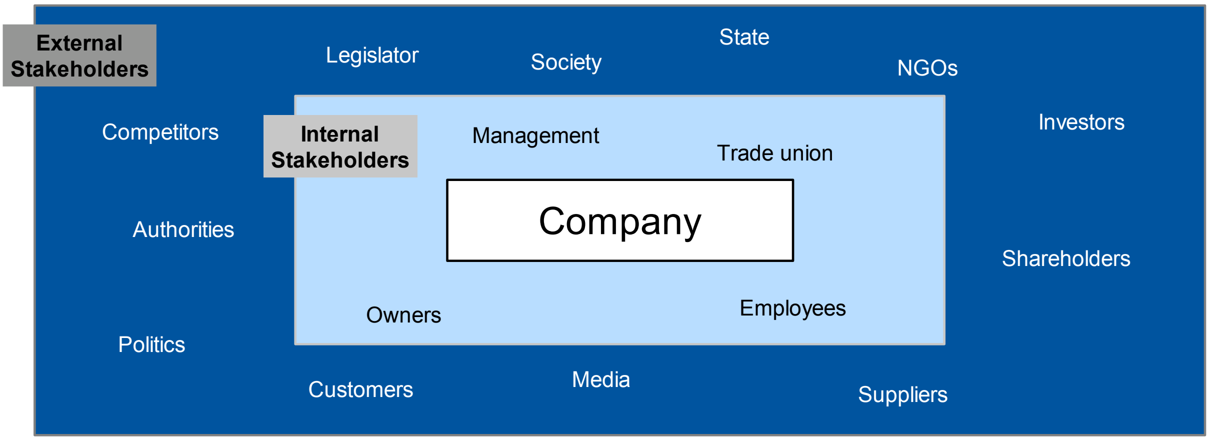

Illustration 2.10: Stakeholders in the context of manufacturing companies[161]

Different stakeholders have different levels of influence on companies. Their respective demands on companies also differ from one another and the group of all stakeholders is very heterogeneous.[162] While internal stakeholders - such as owners or employees - often exert a direct influence on the company, the group of external stakeholders is more heterogeneous. It comprises many more parties, which is why PUFÉ has categorised external stakeholders into three perspectives. The three perspectives are: Politics & legislation, investors & banks, and non-governmental organisations & customers.[163]

SCHMIDT emphasises the importance of the stakeholder approach, particularly for the social dimension of sustainability.[164] CHRISTENSEN ET AL. even go one step further and describe corporate sustainability as a "commitment to all stakeholders, not just shareholders"[165] (i.e. a commitment to all stakeholders, not just shareholders). Investors in the 21st century have a clear focus on sustainable investments.[166] Sustainability reporting is demonstrably an important driver of sustainability endeavours in companies.[167] The most important sustainability reporting standards are listed below.

The Global Reporting Initiative (GRI) report is a de facto standard in sustainability reporting for large companies. The fact that three quarters of the world's 250 largest companies use the GRI report makes the results comparable.[168] The GRI is a voluntary self-assessment by com-

[160] See Schmidt, B. (2013) Soziale Nachhaltigkeit bei, p. 39.
[161] See Pufé, I. (2012) Sustainability management, p. 81.
[162] See Breuer, W. (2018) Definition: Stakeholder approach.
[163] See Pufé, I. (2012) Sustainability management, p. 81.
[164] See Schmidt, B. (2013) Soziale Nachhaltigkeit bei, p. 39.
[165] See Christensen, H. et al. (2021) Mandatory CSR and, p. 1177.
[166] See Esty, D./Cort, T. (2020) Sustainable Investing at, p. 4.
[167] Cf. Siebenhüner, B./Arnold, M. (2007) Organisational learning to, p. 348 - 349.
[168] See McKenzie, M. (2020) The time has, p. 9 - 25.

panies based on key figures that quantify their impact on the economy, environment and society.[169] As the GRI report is only a voluntary commitment and the performance of external audits is merely optional, the GRI offers companies the opportunity to present corporate sustainability in different ways.[170] WANG ET AL. were able to prove that companies are more willing to conceal their performance on social issues than on environmental issues.[171] The importance of voluntary GRI sustainability reporting is increasingly being replaced by regulatory legislation, e.g. from the European Union (EU).[172] EU Regulation 2020/852 on the taxonomy aims to redirect capital flows towards sustainable investments by creating transparency about companies' resource consumption.[173]

The ESG criteria are another widely used standard for sustainable investments. They consist of three sustainability-related areas of responsibility: environment, social and governance.[174] However, ESG reporting is highly fragmented, meaning that companies are often unclear about which ESG standard should be applied.[175] Therefore it will not be further discussed in the course of this thesis.

2.2.5 Sustainability trends in production

Until the turn of the millennium, continuously falling commodity prices favoured the expansion of manufacturing industry in the countries of the global North.[176] This development has led to a wasteful use of resources, as natural resources have always been cheap compared to labour.[177] In the past, companies have made the greatest efficiency gains by employing more resources to reduce labour costs, in particular energy-costs.[178] The ELLEN MACARTHUR FOUNDATION calls this approach take-make-dispose or the *linear model*.[179] The industry extracts raw materials and processes them into a product. Consumers buy the product and use it until it breaks down or they no longer have any use for it. They then dispose of the product and leading to a loss of the resources tied up in it as well as all the resources involved in the manufacturing of said product.[180]

Since the turn of the millennium, commodity prices have risen so sharply that companies have had to deal with the risk of a volatile commodities market.[181] This favours the emergence of a so-called *circular economy*. The term circular economy describes an industrial economy that

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[169] See Henrich, J. (2018) Compliance in the GRI reporting standard, p. 92 - 95.
[170] See Stubbs, W. et al. (2013) Why Do Companies, p. 459.
[171] See Wang, Z. et al. (2018) CSR Performance and, p. 67.
[172] Cf. Cinquini, L./Luca, F. de (2022) Non-financial disclosure and, p. 63 - 66.
[173] See European Commission (2022) EU Taxonomy.
[174] See Haberstock, P. (2019) Definition: ESG criteria.
[175] See Davies, P. et al. (2020) Recent Developments in, p. 161.
[176] See Dobbs, R. et al. (2011) Resource Revolution, p. 4.
[177] See Ellen MacArthur Foundation (2013) Towards the Circular, p. 14.
[178] See Ellen MacArthur Foundation (2013) Towards the Circular, p. 15.
[179] See Ellen MacArthur Foundation (2013) Towards the Circular, p. 15.
[180] See Ellen MacArthur Foundation (2013) Towards the Circular, p. 15.
[181] See Dobbs, R. et al. (2011) Resource Revolution, p. 4 - 8.

is planned to be renewable.[182] The ecological footprint is minimised by using renewable energies and changing the design of products.[183] Based on CRAMER[184], POTTING ET AL. have categorised the ten different forms of the circular economy, known as R-strategies, into three groups (cf. Table 2.4).

Table 2.4: 10R strategies for sustainability[185]

R-Strategies		Description	
Smarter Production and Use of products	R0: Refuse	Make a product redundant by abandoning its function or offering the same function in a radically different product	circular economy
	R1: Rethink	Intensification of product utilisation (e.g. through joint use of products)	
	R2: Reduce	Increasing efficiency in the manufacture or use of products by reducing the consumption of natural resources and materials	
Extending the service life of products and their components	R3: Reuse	Reuse of a discarded product, which is still in good condition and fulfils its original function, by another consumer	
	R4: Repair	Repair and maintenance of defective products so that they can be original function can be reused	
	R5: Refurbish	Restore an old product and update it to the latest version	
	R6: Remanufacture	Use parts of a discarded product in a new product with the same function	
	R7: Repurpose	Use parts of a discarded product in a new product with a different function	
Useful Utilisation of the materials	R8: Recycle	Process materials to obtain materials of the same (high) or lower quality	
	R9: Recover	Combustion of material with energy recovery	linear economy

The English terms have also become established internationally and are also used in this paper. Smarter product use is defined by refuse (R0), rethink (R1) and reduce (R2); the extension of useful life for products or product components is defined by reuse (R3), repair (R4), refurbish (R5), remanufacture (R6) and repurpose (R7); and the useful utilisation of materials is defined by recycle (R8) and recovery (R9).

The average lifespan of ferrous metals is 150 years which favours recycling.[186] However, even under optimal conditions, demand is currently a third higher than the amount of scrap metal available.[187] Recycling alone is therefore not enough, and the use of further R-strategies must be promoted.

[182] See Ellen MacArthur Foundation (2013) Towards the Circular, p. 14.
[183] See Ellen MacArthur Foundation (2013) Towards the Circular, p. 22.
[184] Cf. Cramer, J. (2014) Milieu.
[185] See Potting, J. et al. (2016) Circular economy: Measuring, p. 15.
[186] Cf. Helbig, C./Charpentier Poncelet, A. (2022) ODYM-MaTrace-dissipation.
[187] See Raabe, D. (2023) The Materials Science, p. 2436.

The smarter product use group in Table 2.4 contains a proposal from the Ellen MacArthur Foundation. The foundation categorises products according to their useful life and complexity. As a result, it considers products with a medium useful life and medium complexity, such as mobile phones, smartphones, cars, washing machines and tools, to be the optimal sector for entering the circular economy.[188] For example, manufacturers could achieve cost reductions of up to 50% by remanufacturing mobile phones.[189]

Based on the 10R strategies, Ekins et al deduce that innovation pressure for manufacturing companies in will focus on three key areas: the underlying manufacturing technology must change; the product design must be adapted; and the business models must be adapted to the new environment.[190]

2.3 Interim conclusion and practical deficit

In the previous subsections, the theoretical foundations of global production networks (cf. subsection 2.1), network phenotypes (cf. subsection 2.1.3) and sustainability (cf. subsection 2.2) were outlined. At the end of this second chapter, an interim conclusion is drawn, and the practical deficit is deduced.

Companies must fulfil the constantly growing demands of various stakeholders regarding sustainability. Sustainable behaviour is therefore becoming increasingly important for companies (see chapter 2.2.4). This requires them to rethink previous corporate behaviour in particular the implications for GPNs. The management of global production networks takes place on three organisational layers: the strategy, configuration, and coordination layer (cf. chapter 2.1.2). The company-wide implementation of sustainability criteria inevitably leads to changes at the strategy and configuration layer.

At this point, network phenotypes serve as a tool in the discussion and decision-making process. In order to define sustainable network phenotypes, it is necessary to adapt the constituent elements of network phenotypes - both nodes and edges. These need to be considered under the three dimensions of holistic sustainability - social, environmental, and economic.

The practical challenge this thesis will have to solve is therefore to develop a method that can be used to describe sustainable network phenotypes. To do this, it must first be clarified which network configurations exist in the context of holistic sustainability. Furthermore, a catalogue of influencing factors is needed to characterise the features of network phenotypes. In the following chapter, existing approaches from the literature are analysed.

188 See Ellen MacArthur Foundation (2013) Towards the Circular, p. 36.
189 See Ellen MacArthur Foundation (2013) Towards the Circular, p. 41.
190 See Ekins, P. et al. (2019) The Circular Economy, p. 11.

3 Analysing of existing approaches

To analyse the existing literature approaches, section 3.1 first formulates requirements. Subsequently, selected approaches are analysed in section 3.2. In the last part of this chapter, section 3.3, the approaches are tested for fulfilment of the requirements and finally the research deficit is highlighted.

3.1 Definition of requirements

The requirements for the development of network phenotypes, taking into account the holistic sustainability dimension, are divided into three sections: sustainability, classification and implementation, and object area. They are each described in more detail below.

In the literature, there are different nomenclatures in the field of GPN. In the context of this work, a phenotype refers to a specific configuration. A classification describes a collection of phenotypes that complement each other to form a logical structure. In MEYER and JACOB's model, the world factory represents a phenotype, and the categorisation of all five phenotypes between transaction costs and economies of scale is a classification.

Sustainability

Is the economic dimension of sustainability considered?

Approaches must be economically sustainable, otherwise implementation in the context of commercially active companies will be difficult. This requirement covers how and to what extent the methodology covers this dimension.

Is the ecological dimension of sustainability considered?

This dimension refers to the contents of chapter 2.2. In addition to the sustainability strategies, the focus here is on the 10R strategies according to POTTING ET AL. (Chapter 2.2.5) and the degree to which these are fulfilled.

Is the social dimension of sustainability considered?

In times of progressive upheaval on the labour market, companies can make a name for themselves by taking the social dimension of sustainability into account. They can also benefit financially from this aspect in the form of subsidies. To do this, the social impact must be clearly listed.

Classification and implementation

Procedure for recording the existing network structure

Any examination of the global production network structure begins with an analysis of the existing network. Every methodology should therefore include a procedure for this step, as it makes the individual phases of restructuring more comparable and creates greater transparency.

Guidelines for implementation

A methodology should show how the existing production network can be transformed into the ideal phenotype. The total cost of restructuring, including all sub-steps, should be clearly evident.

Object area

Clear delineation of phenotypes

Within a system, the phenotypes should be clearly differentiated from one another. Together, the individual phenotypes should cover the entire field of tension of the GPN.

Generic applicability

A system should be applicable across all sectors. The fulfilment of this condition is particularly important for approaches from other fields.

3.2 Presentation of existing approaches

The following section presents five existing approaches for analysing the current structure of networks. The first two approaches describe classifications of GPNs. The third approach is assigned to the GPN approaches without formulating network phenotypes itself. It looks at the main components and configuration options for GPNs. In chapter 2.1.1 the different perspectives of GPNs and supply chains on the design of the network structure were presented. Therefore, the last two approaches are presented from the supply chain perspective.

3.2.1 MEYER and JACOB (2008)

The model of phenotypes according to MEYER and JACOB has already been described in chapter 2.1.3 has already been discussed. It is taken up again here and placed in relation to the other approaches.

MEYER and JACOB argue that companies often miss out on the savings potential of new locations because they act incrementally and too slowly.[191] The authors therefore deliberately consider the entire production network, from purchasing department to the sales department. They simplify by reducing the allocation of global production networks to phenotypes to the two factors of transaction costs and economies of scale. Abstracting the system to just two axes leads to a simplification in communication.[192] While this simplification results in industry-independent, generally valid aspects, according to MEYER and JACOB it is nevertheless essential to adapt the network to the specific industry.[193] In this way, they create a blueprint and show the responsible decision-makers which phenotype is most successful for the long-term development of the company under the given circumstances. In addition, the approach contains an inventory

[191] See Meyer, T./Jacob, F. (2008) Network Design: Optimising, p. 142.
[192] See Meyer, T./Jacob, F. (2008) Network Design: Optimising, p. 164.
[193] See Meyer, T./Jacob, F. (2008) Network Design: Optimising, pp. 164 - 167.

as well as concrete suggestions on how a company can make the transition from the existing production network to the optimal GPN.[194] Since the focus of this paper is on the development of a holistic network structure the implementation stage is not further considered here. The appropriate phenotype is selected based on a cost comparison, taking into account location and process factors. In doing so, the authors follow a clear system so that the results achieve a high degree of comparability.[195]

For a detailed description of the implementation guidelines, please refer to ABELE ET AL.[196] A detailed description of the individual phenotypes, including their allocation to the aspects transaction costs, and economies of scale, can be found in chapter 2.1.3.

Critical appraisal

MEYER and JACOB develop an intuitively understandable typology with clearly differentiated phenotypes based on the transaction costs and economies of scale axes. For each phenotype, they make recommendations on the sectors in which the phenotype in question has proved successful. Although the entire network from purchasing to sales is considered, the focus is on the new phenotypes and their economic network capabilities. Categorising the existing production network using the system is time-consuming and complex. Furthermore, the system considers neither ecological nor social aspects of sustainability.

3.2.2 SHI and GREGORY (1998)

SHI and GREGORY's model is based on the principles of trade-offs according to SKINNER and competitive advantages according to PORTER. It is still recognised in research today and is still frequently the starting point for publications in the field of global production networks. The authors model a GPN as a network of factories with matrix connections.[197] Their 2x4 matrix is based on the degree of coordination within the network on the one hand and the degree of dispersion of production on the other. Following this scheme, they derive seven phenotypes. Illustration 3.1 shows how these interact to form a classification.

[194] See Meyer, T./Jacob, F. (2008) Network Design: Optimising, p. 145.
[195] See Meyer, T./Jacob, F. (2008) Network Design: Optimising, p. 155.
[196] See Abele, E. et al. (2008) Global Production.
[197] Cf. Shi, Y./Gregory, M. (1998) International manufacturing networks, p. 199.

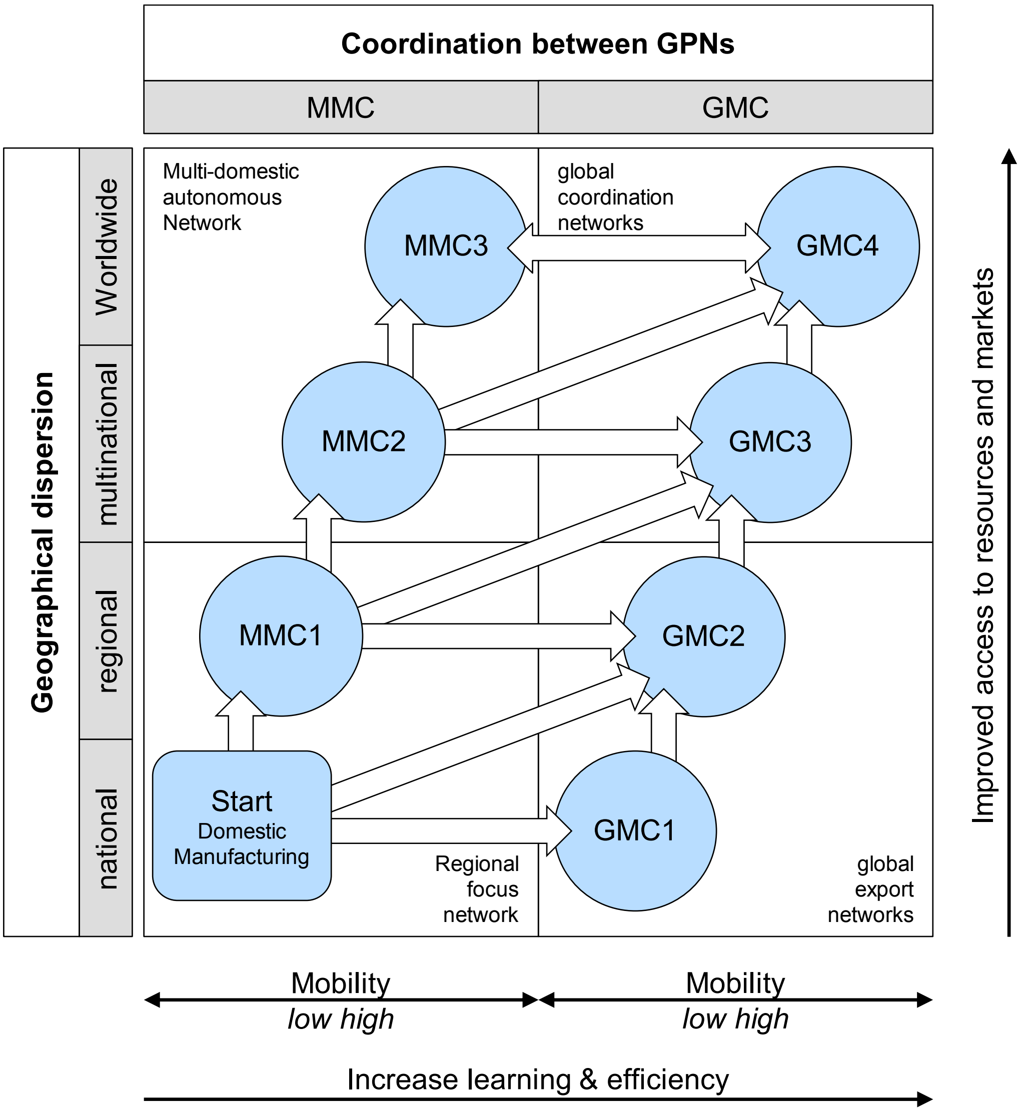

Illustration 3.1: Network phenotypes in the matrix structure[198]

In terms of the degree of coordination of a GPN, the authors differentiate between a network with a multinational orientation and a network with a global orientation. With a multinational orientation, the locations operate almost autonomously, while a high degree of coordination characterises the global orientation. The degree of dispersion of production starts with nationally producing companies and extends to global production.[199] This results in the four blocks, *regionally focussed network*, *globally exporting network*, *multi-domestic autonomous network* and the *globally coordinated network*. The authors observe a trend towards the globally coordinated network with the two phenotypes GMC3 and GMC4. The individual phenotypes are described in more detail below.[200]

[198] See Shi, Y./Gregory, M. (1998) International manufacturing networks, p. 211.
[199] Cf. Shi, Y./Gregory, M. (1998) International manufacturing networks, p. 202.
[200] Cf. Shi, Y./Gregory, M. (1998) International manufacturing networks, pp. 210-212.

MMC1 describes the regionally uncoordinated phenotype. International production is bundled in a single region and there is no coordination between the locations. This is therefore not a GPN.[201]

The *MMC2* phenotype is characterised by production sites in many countries without coordination between them. Production sites have extensive autonomy in terms of products, processes and management. Access to local markets and production factors are decisive for the choice of location within the network. This phenotype is often the result of acquisitions without a subsequent transformation strategy.[202]

In the glocalised *MMC3* phenotype, the MMC2 strategy is continued. The sites continue to operate with a high degree of autonomy, and local management is fully responsible for the local markets and resource procurement. This results in fast response times and synergies with local partners in development projects, favoured by cultural proximity.[203]

The *GMC1* phenotype is characterised by domestically exporting production. Products are manufactured in the home country but are usually sold globally.[204] This often concerns luxury goods where the customer is explicitly informed about domestic production and consciously pays the extra price for the premium labour. It usually involves one-off production or small batches.

The *GMC2* phenotype is a regionally exporting production. Production is concentrated in one geographical region and coordinated with each other. Both product development and sales are global.[205]

Globally integrated manufacturing characterises the *GMC3* phenotype. The global supply chain network is aligned with the corporate strategy in order to achieve the best resources, markets and competitive advantages. In this phenotype, each step of the value chain takes place at a single location to reduce the duplication of production sites and realise economies of scale.[206]

Globally coordinated production describes the *GMC4* phenotype. Production is distributed worldwide, and individual sites are organised homogeneously, but are each strategically responsible for different products. The phenotype is characterised by a high degree of process standardisation and products for the global sales market. At the time of publication (1998), the authors describe a trend in the automotive industry towards GMC4.[207]

[201] Cf. Shi, Y./Gregory, M. (1998) International manufacturing networks, p. 203.
[202] Cf. Shi, Y./Gregory, M. (1998) International manufacturing networks, p. 203.
[203] Cf. Shi, Y./Gregory, M. (1998) International manufacturing networks, p. 203.
[204] Cf. Shi, Y./Gregory, M. (1998) International manufacturing networks, p. 203.
[205] Cf. Shi, Y./Gregory, M. (1998) International manufacturing networks, p. 203.
[206] Cf. Shi, Y./Gregory, M. (1998) International manufacturing networks, p. 203.
[207] Cf. Shi, Y./Gregory, M. (1998) International manufacturing networks, p. 203.

The guideline for implementing the SHI and GREGORY classification is also known as the Cambridge approach. For a detailed description, please refer to CHRISTODOULOU ET AL.[208]

Critical appraisal

SHI and GREGORY's system describes seven phenotypes within a matrix structure and clearly differentiates them from one another. When designing their phenotypes, they do not explicitly address any dimension of sustainability, but merely mention the product life cycle as a relevant factor for the design of production networks. In the context of this paper, this is interpreted as a rudimentary consideration of the ecological and economic dimension. SHI and GREGORY focus on describing and categorising existing network structures. The authors point out the advantages of international production networks and give examples from various branches of industry. The classification is therefore considered to be generically applicable. Furthermore, the publication refers to existing literature on GPNs, making it easier to identify existing network structures. In addition, SHI and GREGORY show links between the phenotypes and thus create a guideline for implementation.

3.2.3 FELDMANN and OLHAGER (2019)

FELDMANN and OLHAGER distinguish between three types of factories based on different work processes for different product groups: Component factories, assembly factories and integrated factories, which combine the two categories. The production of components takes place in *component factories,* in addition to the research and development work carried out in this factory type. They therefore play a key role in terms of intellectual property. *Assembly factories* receive their components from other factories in the network and are usually geared towards utilising the low costs of a local site. *Integrated factories* have both R&D responsibilities and assembly functions.[209]

Looking at the material flow between the internal production networks for a product group, the authors develop four phenotypical network structures: linear, divergent, convergent and mixed (cf. Illustration 3.2).

[208] Cf. Christodoulou, P. et al. (2007) Making the right, p. 3.
[209] See Feldmann, A./Olhager, J. (2019) Taxonomy of IMNs, p. 168.

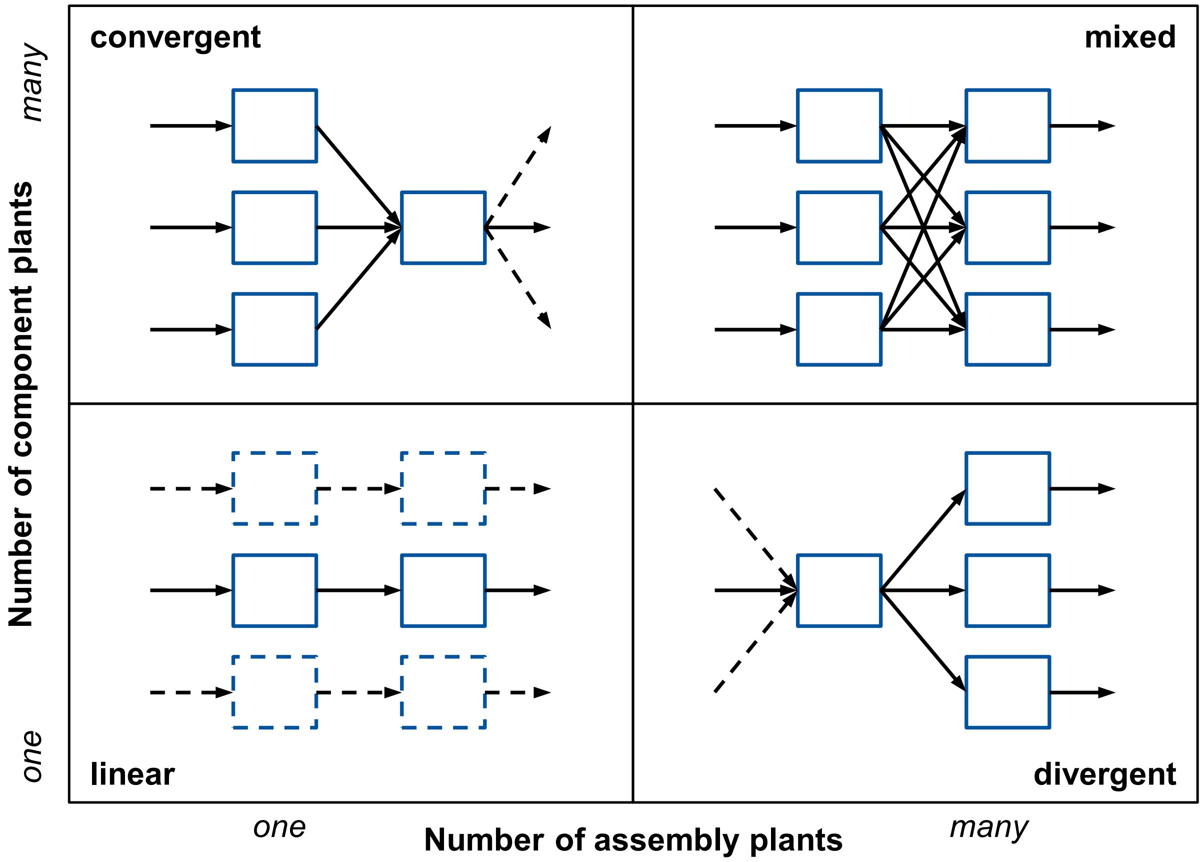

Illustration 3.2: Configurations of network structures[210]

Linear network structures have no material flow between different supply chains in the network. They contain parallel, self-contained supply chains that manufacture the same product group and usually consist of a single integrated factory. The products in these networks are mature and are among the least advanced product types.[211] As such, the products have a low level of intellectual property and are often standardised.[212]

In a *divergent network structure,* a central component plant feeds several assembly factories that are located close to the respective markets. This structure enables economies of scale for critical components and reduces logistics costs. It is particularly suitable for complex products with a high degree of intellectual property.[213]

Convergent networks consist of several component factories, usually strategic suppliers, which manufacture components that have a decisive impact on the performance of the final product. The final product is assembled in a specialised assembly factory or an integrated factory and

[210] See Feldmann, A./Olhager, J. (2019) Taxonomy of IMNs, p. 174.
[211] See Feldmann, A./Olhager, J. (2019) Taxonomy of IMNs, p. 169.
[212] See Feldmann, A./Olhager, J. (2019) Taxonomy of IMNs, p. 173.
[213] See Feldmann, A./Olhager, J. (2019) Taxonomy of IMNs, p. 169 - 170.

distributed worldwide. Centralised quality control ensures the consistent results. These networks manufacture products with highly specialised components that require significant investment in research and development, resulting in products with a high value density.[214]

Mixed networks are the result of mergers, increased capacity requirements or targeted proximity to sales markets. They combine both diverging and converging material flows with and without sub-networks that are orientated towards different market regions. Sub-networks entail additional complexity and a comprehensive division of production tasks between the factories. The manufactured products are primarily modular.[215]

Most companies use different types of networks for different product groups.[216]

Critical appraisal

Feldmann and Olhager develop a clearly delineated network structure that can be applied generically. The defined location roles add a further dimension to the approach. However, the authors consider neither the ecological nor the social dimension of sustainability. Even the economic dimension is merely mentioned indirectly through the level of investment costs and value density.

3.2.4 LAARI ET AL. (2022)

LAARI ET AL. derive four sustainable phenotypes from a structured network analysis, which they call network types. The authors apply a cluster analysis to the automotive sector, which they select for both its important role in the global economy and its global supply chains. They link the results of the cluster analysis with research findings on sustainable supply chain management.[217]

The clusters are generally led by a single company. The sustainability attitude of this company is of decisive importance for the sustainability of the entire partner network. From their analysis, LAARI ET AL. conclude that the most sustainable companies are usually the ones leading a cluster. This finding contradicts existing research that suggests that the most sustainable companies are those closest to the consumer interface.[218] On the one hand the four phenotypes result from a consideration of ecological and social sustainability, and on the other hand from a consideration of the centrality and density of the partner network (cf. Illustration 3.3).

[214] See Feldmann, A./Olhager, J. (2019) Taxonomy of IMNs, p. 170.
[215] See Feldmann, A./Olhager, J. (2019) Taxonomy of IMNs, p. 170 - 171.
[216] See Feldmann, A./Olhager, J. (2019) Taxonomy of IMNs, p. 172.
[217] See Laari, S. et al. (2022) Leveraging supply chain, p. 2.
[218] See Laari, S. et al. (2022) Leveraging supply chain, p. 12.

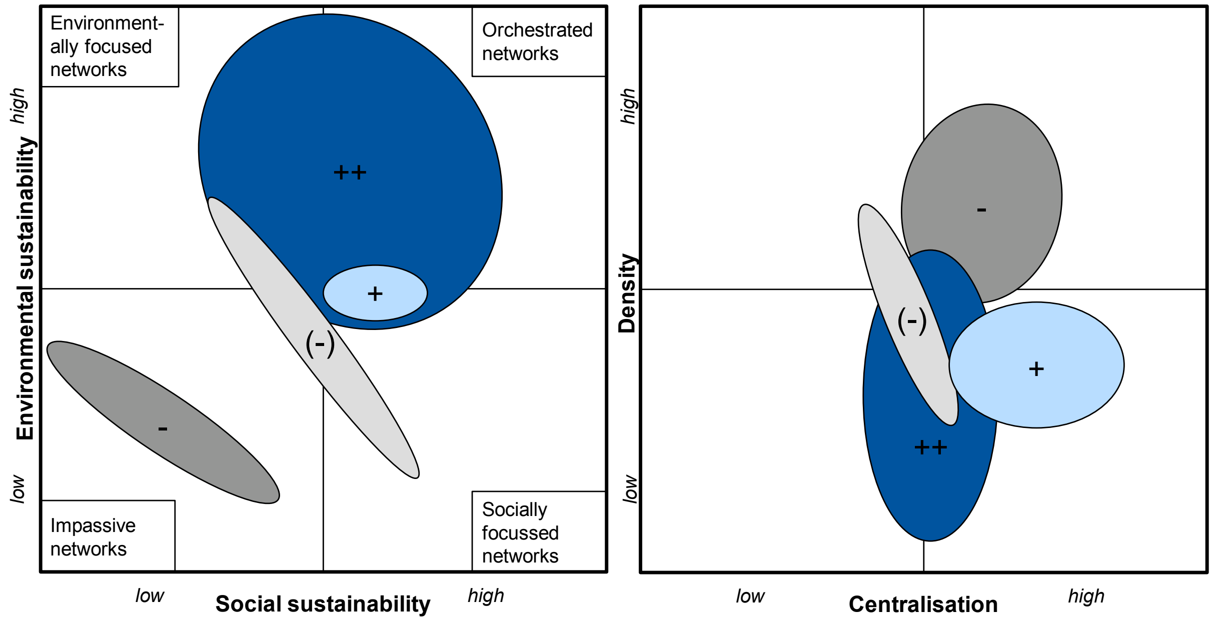

Illustration 3.3: Influence of density and centralisation on sustainability in network clusters[219]

The authors use existing ESG scores to measure social and environmental sustainability. The density of a network assesses the cohesion of the network.[220] Through frequent interactions, a dense network promotes common norms and facilitates the exchange of knowledge.[221] Centrality assesses how strongly the network is concentrated around a few nodes.[222] With increasing centrality, the degree of influence on the partners within the network increases.[223]

The *impassive* phenotype refers to networks with a low degree of ecological and social sustainability. All the clusters analysed have a high degree of centrality and a high density. Despite this, centralised companies have no influence on the sustainability of their suppliers. In addition, the companies within the clusters are hardly connected amongst each other.[224] Typical representatives of this phenotype originate with iron extraction and processing industry.[225]

The *orchestrated* phenotype involves networks with a high degree of environmental and social sustainability. The clusters have a low density, and the leading company achieves a high sustainability score.[226] The authors assume that geographical proximity of the network partners favours the achievement of a very high sustainability score.[227]

The *socially orientated phenotype* describes a network with high values for social sustainability and low ecological sustainability. More precisely, several companies in this phenotype are involved in the extraction of raw materials or process environmentally harmful substances. For

[219] See Laari, S. et al. (2022) Leveraging supply chain, p. 12.
[220] Cf. Wichmann, B./Kaufmann, L. (2016) Social network analysis, p. 742.
[221] See Su, H.-C. et al. (2020) Where in the, p. 531.
[222] See Kim, Y. et al. (2011) Structural investigation of, p. 196.
[223] See Vurro, C. et al. (2009) Shaping Sustainable Value, p. 607.
[224] See Laari, S. et al. (2022) Leveraging supply chain, p. 13.
[225] See Laari, S. et al. (2022) Leveraging supply chain, p. 12.
[226] See Laari, S. et al. (2022) Leveraging supply chain, p. 13.
[227] See Laari, S. et al. (2022) Leveraging supply chain, p. 10.

the most part, the networks have a low density.[228] If the leading company operates very sustainably, this favours the focus on social sustainability among the other network partners. Particularly socially sustainable companies have a conspicuously high number of contacts with third-party companies, which seems to favour the cross-industry exchange of knowledge.[229]

The last phenotype is the *ecologically* orientated one. It achieves high ecological sustainability values, but only a low social rating. This makes it the opposite of the socially orientated phenotype. The low social score is surprising, as it seems easier to achieve for companies in the manufacturing industry than a high ecological score.[230] In general, vertical integration favours high sustainability scores. This phenotype describes most automotive Original Equipment Manufacturers (OEMs), as customers expect a high level of sustainability from brand manufacturers. However, even OEMs fail to influence all partners in a complex network.

Companies with a strong brand name as well as those listed on the stock market and under consumer pressure should opt for the orchestrated phenotype. The authors recommend the socially and ecologically orientated phenotypes only as short to medium-term solutions. The authors do not recommend the impassive phenotype at all but describe it as the result of low visibility and a lack of pressure from market forces and regulatory bodies.[231] Finally, the authors point to differences in data collection. For example, ecological indicators are usually recorded quantitatively, which leads to a high degree of objectivity. Social sustainability indicators, on the other hand, are recorded qualitatively, which gives companies greater freedom in their reporting.[232]

Critical appraisal

LAARI ET AL. introduce four phenotypes that they derive from the cluster analysis of a supplier network. They do not focus on the structure within a GPN, but on the interconnectedness of different companies. Nevertheless, the results on ecological and social sustainability are partly transferable if an analysis of location density and centralisation is carried out, which also serves to record existing network structures. The authors analyse the economic dimension less extensively but do address the return on investment of the entire network at various points. The orchestrated phenotype is seen as the ideal for each type of network. The authors develop a catalogue of measures with recommendations for action for all phenotypes. There is no clear demarcation between the phenotypes, as they partially overlap.

3.2.5 RAUCH ET AL (2017)

RAUCH ET AL. analyse the supplier network from the perspective of sustainability with regard to various manifestations of the local for local phenotype. The basic assumption of their analysis is the observation of increasing decentralisation in global production networks. Therefore, they

[228] See Laari, S. et al. (2022) Leveraging supply chain, p. 13.
[229] See Laari, S. et al. (2022) Leveraging supply chain, p. 10.
[230] See Laari, S. et al. (2022) Leveraging supply chain, p. 10 - 12.
[231] See Laari, S. et al. (2022) Leveraging supply chain, p. 12.
[232] See Wan Ahmad, W. et al. (2016) Sustainable supply chain, pp. 1438 - 1439.

analyse distributed manufacturing (DM). Furthermore, the authors present the evolutionary stages of DM and develop five models for different forms of DM networks.[233] The models are characterised by an increasing degree of cooperation and an opposing degree of invested assets. All models are characterised by a high degree of adaptation to the local market and short transport routes.

The *micro-production network* is a DM system of small, geographically dispersed mini-factories for local or regional market production, customised to the specific needs of customers.[234] These flexible units have the advantage that small production units can be created for a sustainable supply of the chosen market without requiring large investments.[235]

The *service-oriented network model* describes production for third parties in highly flexible, highly adaptable, and geographically dispersed mini-factories. The general characteristics of decentralisation are lower capital- and labour requirements and sustainable resource efficiency.[236] However, instead of investing in their own decentralised production units, companies commission external, specialised contract manufacturers. The production processes must not be dependent on technological advantages or technological expertise. The success of these models depends on the ability to reconfigure and adapt production facilities.[237]

The concept of *mobile factories* involves dividing the production process into flexible, standardised factory modules. These modules are transported to the location where they are needed for a limited period of time and are therefore particularly suitable for situations with otherwise long transport distances. As a result, this model offers economic efficiency, flexibility, and just-in-time delivery.[238]

Production franchising ties in with the franchise system, an organisational form that is suitable for rapidly expanding small businesses. RAUCH ET AL. emphasise the growing importance of the franchise system. As all franchisees are supplied by a central supplier, there are economies of scale at this point. Existing systems of agile and flexible production must be adapted for franchise networks.[239]

Cloud production is a visionary value creation concept that replaces physical product sales with data transfer and enables the manufacture and assembly of products in distributed networks. A virtual network via cloud platforms could revolutionise industrial production in the medium and long term through the wider use of additive manufacturing technologies. Production begins with the transfer of data to the production units, which are then dispatched to the customer.[240] The customer actively helps to design the product. This personalised product is then manufactured at any location in the production network. By producing and assembling

[233] See Rauch, E. et al. (2017) Distributed manufacturing network, p. 187 - 190.
[234] See Zanetti, C. et al. (2015) A production system, p. 452.
[235] See Rauch, E. et al. (2017) Distributed manufacturing network, p. 196.
[236] See Srai, J. et al. (2016) Distributed manufacturing: scope, p. 6917.
[237] See Rauch, E. et al. (2017) Distributed manufacturing network, p. 196 - 197.
[238] See Rauch, E. et al. (2017) Distributed manufacturing network, p. 197.
[239] See Rauch, E. et al. (2017) Distributed manufacturing network, p. 197 - 198.
[240] See Rauch, E. et al. (2016) Sustainable production in, p. 131.

the product close to the customer, fixed location structures are largely dissolved, and delivery routes are de-facto eliminated.[241]

Critical appraisal

Some of the models for DM systems presented by RAUCH ET AL. are still in the conceptual phase. Micro-production networks are similar to the phenotypes of other authors (cf. local-for-local by MEYER and JACOB) and, like these, require a high level of coordination. The service-orientated network model already exists, but has the limitation that only parts requiring a low degree of technological knowledge can be manufactured. The concept of mobile factories is only possible for transportable production facilities that can be assembled in a modular fashion. Neither the production franchise nor cloud production are sufficiently widespread to venture an evaluation of the model at the present time.

3.3 Interim conclusion and research gap

In this section, the five methodologies described in section 3.2 will be compared according to the requirements set out in section 3.1. This leads to the following research gap. For this purpose, a graphical evaluation is carried out using Harvey balls (see Illustration 3.4).

[241] See Rauch, E. et al. (2017) Distributed manufacturing network, p. 198.

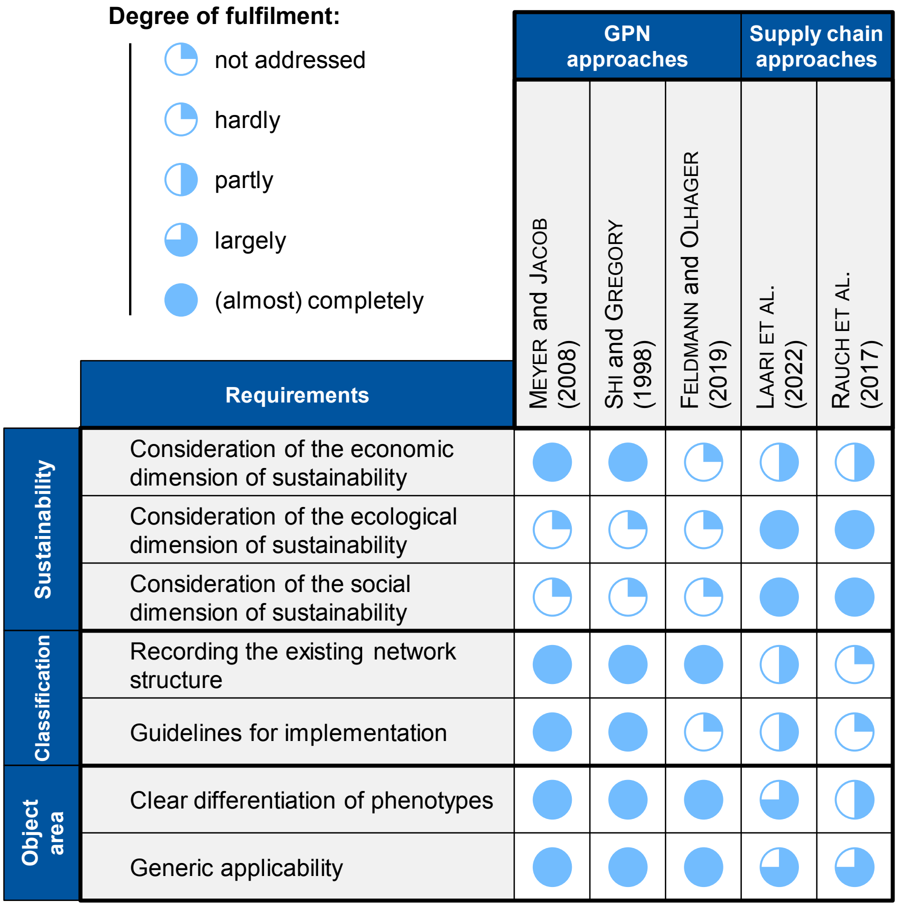

Illustration 3.4: Comparison of the approaches considered

The existing approaches presented are listed on the abscissa. The first three approaches address network configurations from the perspective of the GPN, while the other two approaches were derived from an analysis of the supply chains. The ordinate divides the requirements into three parts: sustainability, classification & implementation, and object area. MEYER and JAKOB's approach and SHI and GREGORY's approach are largely in agreement when it comes to fulfilling the requirements. Both approaches have a comprehensive system and are the only ones with complete implementation guidelines. In terms of implementation, SHI and GREGORY pursue a strongly qualitative approach, while MEYER and JAKOB's approach is primarily data driven. Both GPN approaches focus heavily on the economic dimension of sustainability. For this reason, the supply chain approaches were selected as part of the holistic sustainability perspective, since they fully cover both the environmental and social dimensions. Of these two, only the approach by LAARI ET AL. includes a method for recording existing structures and a guideline for implementation. The network phenotypes by RAUCH ET AL. pick up on current technological developments for distributed networks. These trends could have a major influence on the structure of production networks in the long term. However, the authors neither address the recording of existing structures nor a guideline for their implementation. FELDMANN and OLHAGER present basic plant and network structures that should serve as a basis for the description of network phenotypes. They deal with product characteristics that are clearly differentiated from one another. All five approaches are characterised by a high degree of generic applicability.

To summarise, it can be said that no approach completely fulfils all requirements. Instead, the approaches show strengths in complementary areas. In the context of network phenotypes, the circular economy approach which was described in chapter 2.2 as being crucial for sustainability, has not yet been integrated into network phenotypes. Consequently, the research gap lies in developing a holistic methodology that fulfils all requirements set in this thesis. The methodology of GPNs is to be used to record existing structures. The system is to be expanded via the supply chain approaches in order to ultimately achieve a holistic view of sustainability by including the circular economy.

4 Conception of the solution framework

Based on the information presented in section 2.3 and the practical deficit identified in section 3.3 this chapter contains the concept for the development of network phenotypes as presented below, taking into account the holistic sustainability dimension.

This chapter begins by presenting the concept on which the methodology is based. For this purpose, section 4.1 explains the basic idea of the concept based on the research question. The rough concept of the methodology is described in section 4.2. Following this is a detailed description of the methodology in chapter 5.

4.1 Basic idea of the concept

Section 2.3 calls for a novel way of defining sustainable network phenotypes. This requires an adaptation of the constituent elements of network phenotypes - nodes and edges. These must be considered under the three dimensions of holistic sustainability - social, ecological and economic. From the discussion in section 2.2 it seems that the circular economy is a promising approach for this. The research gap described in section 3.3 shows that existing approaches are all based on the linear economy. Network phenotypes must therefore be supplemented by the circular economy business model. This is the only way to realise holistic sustainability.

Based on the above results, the approach proposed in this thesis offers a solution to the following research question:

> *How can a classification of network phenotypes be developed taking into account the holistic sustainability dimension?*

The proposed methodology closes the gap between existing, economically orientated classifications of network phenotypes and a holistic approach to sustainability. In the GPN environment, decisions are usually made in the field using qualitative methods.[242] In line with this, the rough concept for the methodology to answer the research question is presented below.

4.2 Outline of the methodology

The rough concept of the solution approach is based on three steps. Each of these steps builds on the previous one. Starting point is the practical and research deficit identified in section 4.1. The outline of this concept is shown in Illustration 4.1.

[242] See Khan, Z. et al. (2022) Decision-making in the, p. 525.

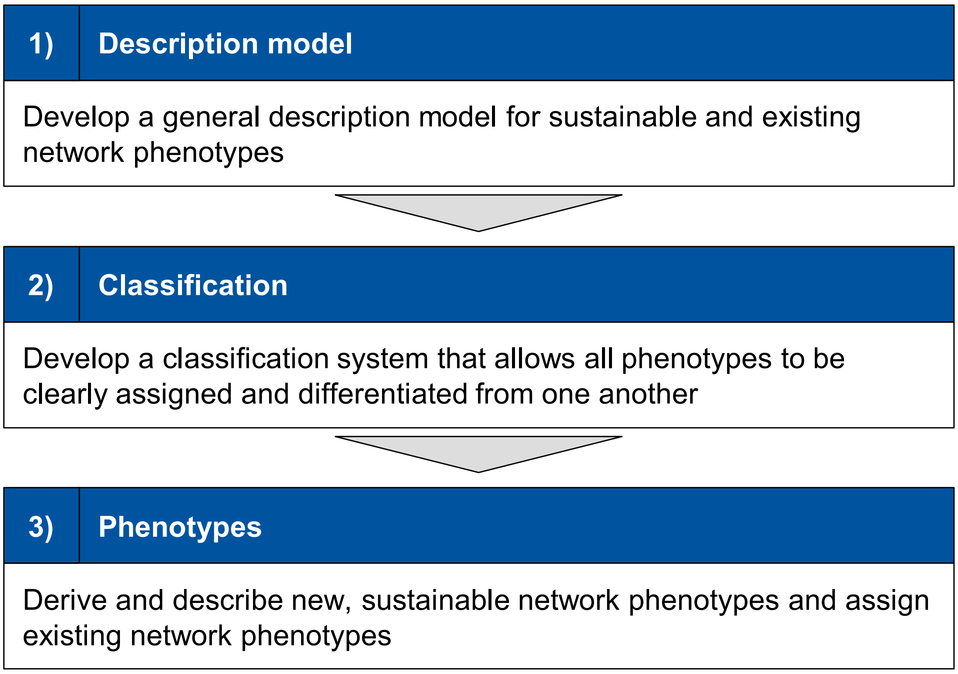

Illustration 4.1: Solution steps of the methodology

To develop a *description model* for network phenotypes, a suitable form must first be selected. In the context of this thesis, the network phenotypes are described using a morphological box. The justification for the choice of this method follows in section 5.1. To create a structure within the morphological box five sub-models are created in keeping with the product life cycle. The influencing factors on each of these sub-models must be fully described by the choice of suitable characteristics and their attributes.

The aim is to develop a *classification system* based on the description model. The entire solution space of existing phenotypes and the new, to be developed, sustainable phenotypes should be mapped in this system. Phenotypes must be clearly differentiated from one another.

Phenotypes must be derived from the classifications. By describing all phenotypes, the existing approaches can be clearly assigned within the classifications.

5 Details of the methodology

The structure of chapter 5 is based on the concept outline of the methodology (see section 4.2). In section 5.1 the morphological box is introduced. The second section presents influencing factors (see section 5.2). Section 5.3 defines terms used in the methodology and describes assumptions for the analyses described in section 5.4 for the sub-models presented in section 5.4. The overall model is presented in section 5.5 as well as the system for deriving phenotypes. In the final section of this chapter 14 network phenotypes are described (see section 5.6).

5.1 The morphological box as an instrument

The aim of the morphological box is to bring order to the creative process using a systematic approach.[243] Instead of the searching for a solution for the overall problem to be solved, it is broken down into sub-problems and alternative solutions are sought for each sub-problem.[244] This results in the largest possible number of alternative solutions. What all morphological models have in common is that they cover the entire solution space. To this end, it is important to represent all intermediate relationships between objects in a value-free manner.[245]

FRITZ ZWICKY developed the morphological box as part of the morphological world view. “Almost all deterministic and stochastic scientific explanatory models are based” [246] on the world view. These include progressive abstraction, functional analysis, the cross-impact matrix, sequential morphology and the morphological box.[247] For an overview of morphological approaches that describe and model production systems, please refer to HARRE.[248]

The application procedure of the morphological box consists of five steps, which are presented below:[249]

The *first step* is to formulate the problem precisely.

In the *second step,* all characteristics that could be part of the solution to this problem must be identified and defined. Existing solutions should also be mapped by the model.[250]

In the *third step,* the morphological box or multidimensional matrix must be constructed. It contains all solutions for the given problem. Due to the combinatorics of all characteristic attributes, the solution space grows exponentially. Even with a restriction to eight to ten characteristics, the solution space can thus span up to several million theoretically possible options.[251]

[243] See Kaufmann, T. (2021) Strategy tools from the, p. 164.
[244] See Göpfert, I. (2019) Logistics of the future, p. 28.
[245] Cf. Zwicky, F./Wilson, A. (1967) New Methods of, p. 277.
[246] See Göpfert, I. (2019) Logistics of the future, p. 28.
[247] See Göpfert, I. (2019) Logistics of the future, p. 28.
[248] Cf. Harre, J. (2006) Strategische Standortstrukturplanung für, pp. 151 - 163.
[249] Cf. Zwicky, F./Wilson, A. (1967) New Methods of, p. 285.
[250] See Kaufmann, T. (2021) Strategy tools from the, p. 164.
[251] See Waal, A. de/Ritchey, T. (2007) Combining morphological analysis, p. 108.

Some authors therefore recommend using only four to eight characteristics for a single model.[252]

In the *fourth step,* all solutions contained in the morphological box are analysed and evaluated in relation to the objective to be achieved. The options must be analysed in terms of their applicability.[253] ZWICKY describes this as the most important of the five steps, but also the most difficult to realise.[254] For example, a pairwise comparison can be carried out using specialised software.[255] Contradictions and logical conclusions usually reduce the options by 90-99%.[256] Alternatively, the solutions are derived from the morphological box based on assumptions.[257]

In the *fifth step,* the best solutions are selected and implemented, provided the necessary resources are available. Another morphological model can be used to implement the developed solution.

5.2 Factors influencing GPNs

Various influencing factors are taken into account when designing GPNs. In the scientific literature, the *network capabilities* (see subsection 2.1.2.1) are particularly prominent. According to THOMAS, these are the capabilities: Access to markets; Access to resources; Efficiency; Mobility; and Learning. However, according to SCHALM ET AL., in practice network capabilities are only used to a limited extent.[258] In contrast, they present *location specialisation* and *production priorities* (costs, quality, flexibility, delivery reliability) as relevant influencing factors for the design of a GPN. Considering the call to action by ZUEHLKE ET AL., this thesis considers both a company's *business model* and its product characteristics.[259]

In principle, a manufacturing company can either sell its products or retain ownership of them. Regardless of the strategy chosen, the company can also offer services for this product. These serve either to maintain or extend the functionality of the product. The *product characteristics* play *a* key role in determining which business models can be selected. If a company employing linear economy practices primarily generates its profit by selling as many of its products as possible, the intrinsic interest in a repair-friendly product design must be critically scrutinised.

However, if a company decides, for example, to retain ownership of the product as part of a circular economy, the maintenance-free longevity will have a positive impact on the balance sheet. Should work on the product nevertheless become necessary, the modular design of the

[252] See Cross, N. (2021) Engineering design methods, p. 130.
[253] See Kaufmann, T. (2021) Strategy tools from the, p. 164.
[254] Cf. Zwicky, F. (1957) Morphological Astronomy, p. 20.
[255] Cf. Cross, N. (2021) Engineering design methods, p. 130. ; Cf. Delibašić, B. et al. (2016) Decision Support Systems, p. 26
[256] See Waal, A. de/Ritchey, T. (2007) Combining morphological analysis, p. 109.
[257] See Lüdeke-Freund, F. et al. (2019) A Review and, p. 45.
[258] See Schalm, K. et al. (2022) Global production strategies in, p. 809.
[259] See Zuehlke, H. et al. (2023) What goes around, p. 13.

products favours their sustainability. Specific modules can be repaired or replaced by more advanced modules.

5.3 Definitions and assumptions of the typology

As stated before, the typology of network phenotypes should follow the product life cycle. Therefore, the procurement market is the first element. Each element has at least one characteristic, and each characteristic has several attributes. The sub-elements should be selected in such a way that they are clearly distinguishable from each other and as a whole, reflect the complete information content of the network structure. As this theoretically results in 186,624 potential combinations for the following model, the solution space is restricted by several fundamental assumptions.

The system boundaries should include all decisions made directly by the company, starting with the procurement market and ending at the sales market. *Decisions* explicitly refers only to the strategic decisions in the context listed above. This means that operational and tactical questions such as how exactly a product is transported from the consumer back to the company or how the parts and materials are reintegrated into the forward-oriented cycle are not part of the model.

In the long term any solution worth considering must be economically viable. The economic perspective in the planning of global production networks has already been extensively analysed in the literature, which is why this paper will focus on the social and ecological dimensions. Nevertheless, all three dimensions are part of sustainability and together form a solution space.

The product considered in this thesis consists of a *core* and an unspecified number of *modules*. The products are, at least to some extent, modular. They have a sufficiently high value to make the processes described here worthwhile for companies. The core forms a platform onto which the modules are installed.

The products are manufactured in a *two-staged production process*. In the forward-oriented production network, the core and the modules are first manufactured in one or more *component plants.* The core and the specific modules are assembled at the process level of the *assembly plant.* In the reverse production network, the first process step takes place in the *disassembly plant*, where the modules are uninstalled and serviced. Assuming that the cores are more complex than the modules installed onto them, they are always repaired as part of the second process step in the *core processing plants*.

5.4 Definition and dimensioning of sub-models

Global production networks exist as part of multinational companies. The environment of multinational manufacturing companies is not a homogeneous sphere. Therefore, when designing GPNs, different spheres must be taken into account, each of which spans sub-models. Independent optimisation of these sub-models leads to contradictions, meaning that a holistic approach is required in order to achieve the global optimum of the model. Nonetheless, in the interests of academic completeness, the sub-models are introduced individually below, defining characteristics and their attributes and analysed in terms of their individual best possible solutions. Illustration 5.1 shows the overall model and the interactions between sub-models.

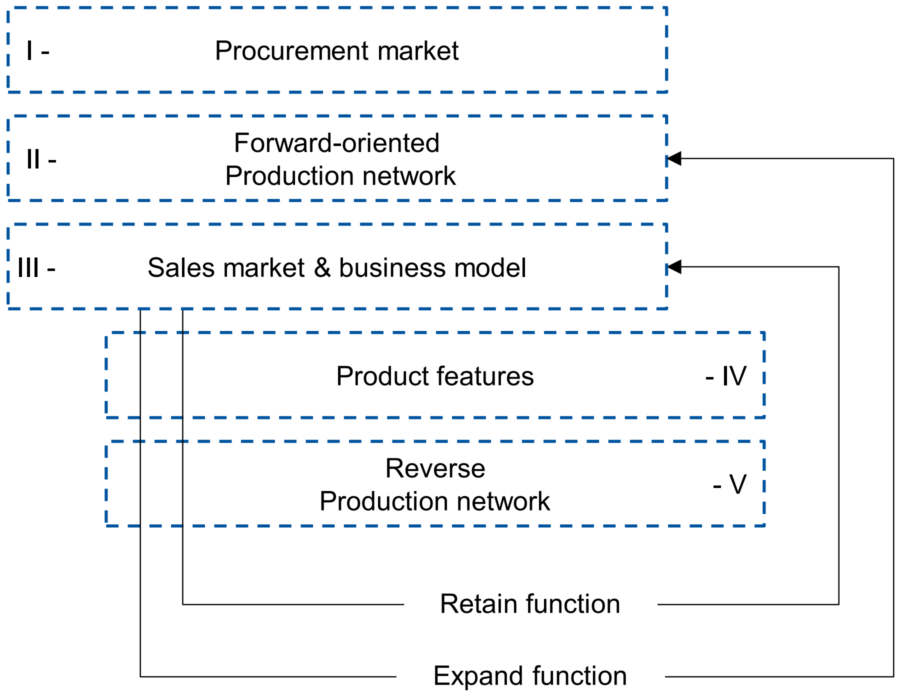

Illustration 5.1: Structure of the overall model

The core of the model and the first sphere to be considered is the location structure in the forward-oriented production network (II). Classic location research distinguishes between motives for internationalisation based on whether their orientation is procurement- (I) or sales market (III) oriented.[260] These two motives are analysed in the second and third spheres. Procurement market motives are characterised by the desire to reduce production factor costs. This is achieved, for example, through lower local labour costs or proximity to suppliers of raw materials and parts.

The motives driven by the sales market describe the other side of the coin. The aim here is to expand revenue by gaining access to new markets. In some cases, this decision is driven by a protectionist trade policy, in other cases local adaptation of the products necessitates it.

When planning a circular economy network, further spheres need to be added. In particular, the location structure as part of the reverse production network (V) must be considered. Although product characteristics (IV) are of great importance for both forward-oriented and reverse network planning they will only be considered as part of the reverse production network.

[260] Cf. Harre, J. (2006) Strategische Standortstrukturplanung für, p. 181 - 183.

The reason being that there are some factors that only have a significant influence on the planning of the reverse location structure.

5.4.1 Procurement market (I)

In relation to the procurement market, the perspective strongly determines which characteristics are decisive for the respective model. This paper focuses on the three holistic sustainability dimensions, which ELKINGTON refers to as the triple bottom line.[261] As set out in the assumptions of the model, consideration of the economic dimension is implicitly assumed (see chapter 5.3). Nevertheless, all three dimensions must be optimised simultaneously in order to achieve the best quality, the highest flexibility and the lowest costs while taking social and environmental sustainability into account.[262]

According to COSTA ET AL., *infrastructure* and the *availability of raw materials* are the two most important factors for a sustainable value chain.[263] The core mandate of the procurement market is to provide the production network with the required raw materials and components. Therefore, the procurement market plays a particularly important role in terms of sustainability.

Many procurement markets may be dominated by social, cultural, economic, and ecological standards because of historical and political reasons. These can be very different from what a customer might expect from their supplier. The list of social grievances ranges from inadequate pay and a lack of occupational health and safety to modern slavery in labour camps. However, these grievances are often difficult to identify in the upstream value chain due to intermediaries.[264] In selected cases, a company decided to create transparency by carrying out audits at its suppliers, although due to cost reasons this step was only an option for the most important suppliers.

With the enactment of the German Supply Chain Act, companies that employ more than 1,000 employees within Germany will have to assume due diligence obligations for their entire supply chain beginning in 2024.[265] As it is sometimes uneconomical for a manufacturing company to analyse its suppliers' suppliers, purchasing departments are addressing this lack of knowledge with contractually binding voluntary commitments from their suppliers.[266] Maintaining long-term partnerships is therefore of central importance for achieving social sustainability in production. Long-term partnerships indicate integrity and reliability, which in turn are good indicators that commitments are honoured. MURCIA ET AL. observe that internationally active companies favour collaborations rather than relying on controls.[267] However, these aspects are strongly

[261] Vgl. Elkington, J. (1999) Cannibals with forks, S. 20.
[262] See Handfield, R. et al. (2002) Applying environmental criteria, p. 74.
[263] See Costa, Y. et al. (2017) A decisional simulation-optimisation, p. 188.
[264] See Wilhelm, M. et al. (2016) Sustainability in multi-tier SCs, p. 210.
[265] Cf. Federal Ministry of Labour and Social Affairs (23.12.2023) Home game for human rights.
[266] Cf. Belotserkovskiy, R./Britta Lietke (2018) Contracting for performance; See Wilhelm, M. et al. (2016) Sustainability in multi-tier SCs, p. 210.
[267] See Murcia, M. et al. (2021) Socially Responsible Firms, p. 1532.

qualitative in nature and therefore only of limited applicability for the planning of a global production network.

Due to the high level of complexity brought about by interdependencies, e.g. in the different perspectives of the perception of stakeholder interests, there are significantly fewer models focussing on social sustainability than on the other two dimensions.[268] To summarise, it can be said that *cultural and geographical distance* reduces the degree of transparency in the supplier selection process and thereby potentially also reduces the degree of social sustainability.

The ecological factors in supplier selection can be categorised into two stages. Supplier selection is of particular importance, as the environmental impact in most manufacturing companies is concentrated in the upstream supply chain.[269] In the extraction of raw materials, the focus is on the extent to which nature is affected and the long-term consequences ensuing for future generations.[270] In the subsequent processing of the raw material into intermediate products, resource consumption, ecological product design, and the control of environmental impacts dominate the model.[271] Which specific factors are selected here is highly dependent on the industry and the product to be manufactured. However, common to all industries and products is the existence of transportation from the last step of the procurement market to the first step of the production network. The geographical distance between these stations is either short, (i.e. local), or long, (i.e. global).

Considering all social and environmental factors, a binomial attribute scaling should be selected for the characteristics on the procurement market. However, in the context of this paper, a mere division into socially or ecologically sustainable and non-sustainable would be a trivial solution. Instead, it is assumed that a supplier selection fulfils minimum social and ecological standards. In line with COSTA ET AL., the focus is on infrastructure, particularly transport. For the social dimension, geographical distance can be used to describe the degree of transparency. Local suppliers can be audited more easily, while audits carried out far away are associated with considerable additional effort. As the degree of environmental sustainability can also be abstracted via the geographical distance between the procurement market and the GPN, both dimensions are summarised in the characteristic *Distance of raw materials & parts*. The following morphology results as a description model for the procurement market sphere (see Illustration 5.2).

	Characteristic	Attribute	
I	*Procurement market*		
	Raw materials & parts	local	global

Illustration 5.2: Sub-model of the procurement market

The characteristics span a typology of either local or global procurement markets.

[268] See Zimmer, K. et al. (2016) Sustainable supplier management, pp. 1429 - 1431.
[269] See Choi, S. et al. (2022) Building sustainability, p. 4.
[270] See Brundtland, G. (1987) Our Common Future.
[271] See Zimmer, K. et al. (2016) Sustainable supplier management, p. 1430.

5.4.2 Forward-oriented production network (II)

The description of the forward-oriented production network is divided into two blocks. On the one hand, it is necessary to determine the geographical location structure of the network. On the other hand, the relationship between the locations must be analysed based on the production technology selected.

Location structure

As described in subsection 3.2.3 there are four different ways to describe a two-part production process according to FELDMANN and OLHAGER. It consists of at least one location at the first stage, at least one location at the second stage and the transportation links between the two stages (see Illustration 5.3).

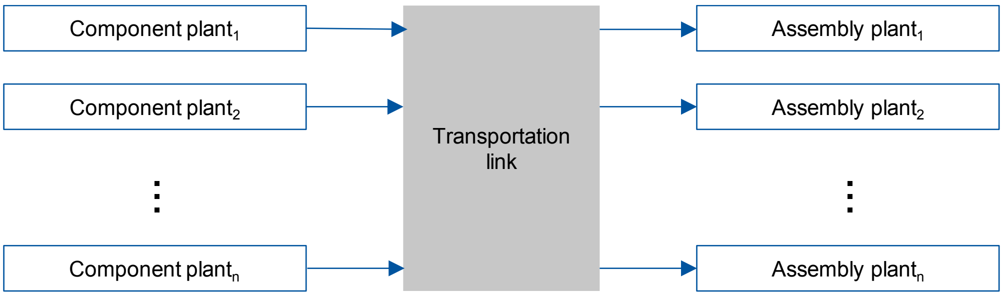

Illustration 5.3: Components of the site structure

In keeping with FELDMANN and OLHAGER'S nomenclature this paper refers to the locations of the first production stage as component plants and the locations of the second production stage as assembly plants (cf. subsection 3.2.3).[272] In this subsection, it is therefore necessary to define the configuration of the component plants, the assembly plants, the relationship between the plants and the transports on the basis of clear characteristics.

Against the background of location planning, a consideration of transfer restrictions from the procurement market to the GPN is relevant. According to HARRE, production factors can be divided into transferable factors and those that are either non-transferable or difficult to transfer.[273] If the company relies on non-transferable production factors, the component plants must be located in close geographical proximity to the procurement market. The location of subsequent production stages may still be organised flexibly. If the production factor is substitutable or consists entirely of transferable factors, the location structure can be actively organised. According to FLEISCHMANN ET AL., the degree of density and thus the number of locations in each region is a fundamental strategic decision for both forward-oriented and reverse-oriented location planning. The choice of their exact locations, in turn, is primarily determined historically and depends on the availability of both production factors and infrastructure.[274] At this point, explicit foresight is required, as the sourcing of materials shifts in the reverse-oriented location structure. In a linear economy, many raw materials are extracted at a relatively small number

[272] See Feldmann, A./Olhager, J. (2019) Taxonomy of IMNs, p. 165.
[273] Cf. Harre, J. (2006) Strategische Standortstrukturplanung für, p. 193 - 194.
[274] See Fleischmann, M. et al. (2005) Reverse Logistics - Capturing, p. 180.

of selected locations, are then processed, and afterwards supplied to a relatively large number of end consumers. Once they no longer have a use for them, consumers buy a new product when they have a need and dispose of the old one. In a circular economy the customer thus becomes a supplier to the company and the formerly discarded product can be reprocessed, transforming the sales market areas into new procurement markets. This excursus is intended to illustrate the strong interdependence between the choice of suppliers and the structure of the production network.

As in the previous section, the density level characteristic should also be described with binomial-scaled attributes. In the definition of their network phenotypes, LAARI ET AL. describe the degree of density with the attributes low and high (see chapter 3.2.4). A low degree of density leads to a dispersed site structure, whereas a high degree of density describes a concentrated site structure. In the case of maximum concentration, there is only one single plant. This work therefore uses the extreme attributes of *one* and *scattered* for the characteristic density level. A concentrated network generally has fewer sites, but ceteris paribus the individual sites are larger than in a scattered network for the same total production volume. From a larger size of the sites result gains in efficiency and economies of scale, both of which lead to cost advantages. These effects are often achieved with an increased level of automation technology. Should the machines initially require a larger amount of energy, it is important to balance this out from an ecological perspective by optimising the use of resources.

The prevailing assumption in the literature is that human labour will be replaced by automated processes in the future. A 2021 study on behalf of the European Commission concludes that 5% to 44% of jobs in Europe will be lost, yet fails to include a projection of the timeline. According to the authors of the study, the impact this will have on social sustainability depends on the steps taken by policymakers between now and then.[275]

The counterpart of the concentrated network is the dispersed network. The distributed manufacturing networks described in chapter 3.2.5 are characterised by production close to the consumer, a high degree of personalisation of the products, short delivery times, higher costs for the individual production sites and a reduction in transport routes.[276] This radical form of dispersed network focuses on minimising transport by favouring both local procurement and local sales markets.[277] According to RAUCH ET AL., such a network not only has a positive effect on the reduction of transport and thus on environmental sustainability, but also on the social development of regions and their populations.[278] However, HARRE points out that the coordination effort increases with the number of locations.[279] Accordingly, a dispersed production network is particularly advantageous if it operates largely autonomously.

[275] See European Commission (2021) Understanding the social.
[276] See Rauch, E. et al. (2017) Distributed manufacturing network, p. 189.
[277] See Rauch, E. et al. (2016) Sustainable production in, p. 132.
[278] See Rauch, E. et al. (2016) Sustainable production in, p. 132.
[279] Cf. Harre, J. (2006) Strategische Standortstrukturplanung für, p. 187 - 189.

This results in three characteristics for transport from the component plant to the assembly plant: if the process steps are carried out at different locations, they are either *locally* accessible or at a *global* distance from each other. If both process stages are co-located, there is *no transport.*

Manufacturing technologies

When selecting manufacturing technologies to describe GPNs, two strategic aspects are considered below. Firstly, the manufacturing processes are considered and then the vertical integration.

Two opposing strategies are possible for focusing manufacturing: specialisation or flexibility. In the previous section, economies of scale at large locations were already discussed in the context of the degree of density. While economies of scale are associated with large volumes, it is also possible to achieve the associated efficiency gains at small sites through appropriate process specialisation. In a study on the distribution of phenotypes according to MEYER and JACOB, the most common phenotype is the *web*, which is characterised primarily by the flexibility of its processes.[280] As phenotypes also exist in practice outside of the pure form, it makes sense to include a *mixed manufacturing process form* in addition to the two characteristics of *specialisation* and *flexibility* already mentioned.

GPNs are part of the value chain but describe company-owned locations (see section 2.1). Accordingly, it may initially seem counterintuitive to also consider vertical integration at this point. According to FERDOWS, a long-term, intensive partnership with an external manufacturing company can be regarded as an integral part of a company's own network and is therefore also part of the GPN.[281] Nevertheless, outsourcing is so widespread that some authors refer to it as a competitive strategy in its own right.[282] The main reasons for companies to choose this path are higher cost transparency with a reduction in fixed costs and increased flexibility by utilising the expertise of suppliers. On the downside, this is accompanied by a loss of expertise within the company, increased coordination costs, the disclosure of trade secrets and dependence on the supplier.[283] Under the title *Socially Responsible Firms Outsource Less,* MURCIA ET AL. analyse the impact of trust on companies' CSR ratings.[284] CSR is an acronym for corporate social responsibility and is a widely used tool for measuring the social sustainability of companies.[285] On the one hand, the authors note that there is a fundamental dissonance between outsourcing and a high CSR rating. Furthermore, partnerships are successful when there is strong trust between companies and therefore there is no need to vertically integrate the partner company.[286] In the event of sustainability violations, the company itself is

[280] See Schreiber, B./Brundin, N. (2015) Managing Global Production, p. 7.
[281] See Ferdows, K. (2009) Shaping Global Operations, p. 144.
[282] Cf. Contractor, F. et al. (2010) Reconceptualising the Firm, pp. 1428 - 1429.
[283] Cf. Stremme, U. (2000) International Strategic Production Management, p. 188.
[284] See Murcia, M. et al. (2021) Socially Responsible Firms.
[285] See Kropp, A. (2019) Fundamentals of sustainability, p. 38.
[286] See Murcia, M. et al. (2021) Socially Responsible Firms, p. 1507.

ultimately held responsible.[287] The trust factor particularly benefits companies with strong brand names and those which are in direct contact with the end consumer[288] and should therefore maintain a *high proportion of in-house production* in their network organisation. The counterpart is the *low proportion of in-house production*.

This results in the following description model for the forward-oriented production network (see Illustration 5.4):

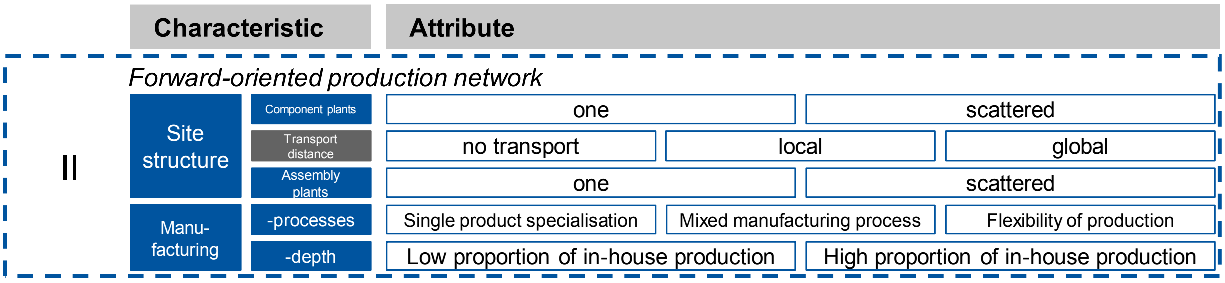

Illustration 5.4: Sub-model of the forward-oriented production network

5.4.3 Sales market and business model (III)

In the product life cycle, the next step after production is the sales market. While all decisions previously discussed and introduced are part of both a circular and a linear economy, there are now major differences. Depending on the chosen business model, different target groups are addressed in potentially different sales markets. For this reason, we will first analyse the business model and then look at the sales markets.

According to the strategic management model by FRIEDLI ET AL., there is a strong interdependence between the three layers of strategy, configuration, and coordination (see chapter 2.1.2). As the configuration layer, and with it the location structure, is influenced primarily by the strategy layer, the chosen business model is decisive at this point. At the most fundamental level, the first decision to be made is whether the manufactured product *remains in the company* or whether it *leaves the network* for good. In the linear economy, the latter option is the rule, as disposal and utilisation are usually carried out by external companies. The sales market is therefore the company's last point of contact with the product. In the context of a sustainable company, ZUEHLKE ET AL. call for the product design to be optimised for dismantling on the one hand and the concept of ownership to be rethought on the other.[289] BOCKEN ET AL. develop eight typologies of sustainable business models, which they group according to their orientation as being either technological, social or organisational.[290] According to this system, adapting product design and switching to a circular economy is part of the technological business models, while rethinking ownership belongs to the social business models. However, the influence that the choice of a business model has on production network planning has not yet been

[287] See Schrempf-Stirling, J./Palazzo, G. (2016) Upstream Corporate Social, p. 491.
[288] See Saavedra, Y. et al. (2013) Remanufacturing in Brazil, p. 274.
[289] See Zuehlke, H. et al. (2023) What goes around, p. 13.
[290] See Bocken, N. et al. (2014) Sustainable business model archetypes, pp. 47 - 54.

researched.[291] A key element of the circular economy is feeding used cores from the consumer back into the production network. While it is common to use multiple sourcing methods for cores, buy-back programmes are the most common method used by European companies.[292] However, the buy-back programme takes place at a time chosen by the consumer, so the company must expect fluctuations. In addition, there is an information asymmetry in favour of the consumer regarding the product condition at the time of repurchase. For this reason, this thesis aims to combine both typologies to create a basis for the development of sustainable network phenotypes.

From a sustainability perspective there are several positive effects if the product remains the property of the company and its use is monetised. Firstly, the company endeavours to maximise the utilisation of the product. The rethinking (R1) within the 10R structure according to POTTING ET AL. leads to smarter product utilisation (see subsection 2.2.5).[293] A manufacturing company in the linear economy generates revenue primarily through the sale of its products. Therefore, it has no intrinsic interest in providing its customers with unlimited product life. Maximising product life is the key to success in the circular economy; the extent of product design changes required to achieve this depends on the strategy chosen. If the products remain the property of the company, there are two options: to maintain the functionality or to expand the functionality. According to the nomenclature of POTTING ET AL., *maintaining the functionality* corresponds to the processes repair (R4) and refurbish (R5). This is more sustainable than a functional extension, which POTTING ET AL. call remanufacture (R6), as it requires fewer new resources. The focus of function maintenance is on a robust design in which heavily used components can be replaced easily and cost-effectively. This aspect is also important when *expanding functionality,* but it requires the cores to be designed in such a way that interfaces to the modules are futureproof regarding all new functions in later development cycles. With both options, customers benefit from lower prices, high quality and a longer service life compared to new products.[294]

Reference is made to the existing literature on the choice of sales market for a linearly distributed product in relation to the planning of the site structure and its effects on network phenotypes.[295] Instead, the focus is on the circular economy and the development of new phenotypes. For example, ALSHAMSI and DIABAT recommend locating the market for products from the reverse-oriented part of the production network in a region where high profits are already being realised.[296] The distance to the sales market has a direct influence on transport costs and therefore on delivery times. In addition, products can exist in different local variants, which reduces batch sizes and thus cancels out economies of scale in large production facilities. In symmetry with the procurement market, the characteristic transport is also chosen here with

[291] See Klenk, F. et al. (2020) Approach for developing, p. 129.
[292] See Sundin, E. et al. (2016) Map of Remanufacturing, p. 18.
[293] See Potting, J. et al. (2016) Circular economy: Measuring, p. 15.
[294] See Sundin, E. et al. (2016) Map of Remanufacturing, p. 21.
[295] Cf. Trautmann, T. (2022) Development of sustainable network phenotypes.
[296] Cf. Alshamsi, A./Diabat, A. (2015) A reverse logistics, p. 589.

the attributes *local* and *global* in order to map the sales market. For the sales market and the business model this discussion results in Illustration 5.5 which is displayed below.

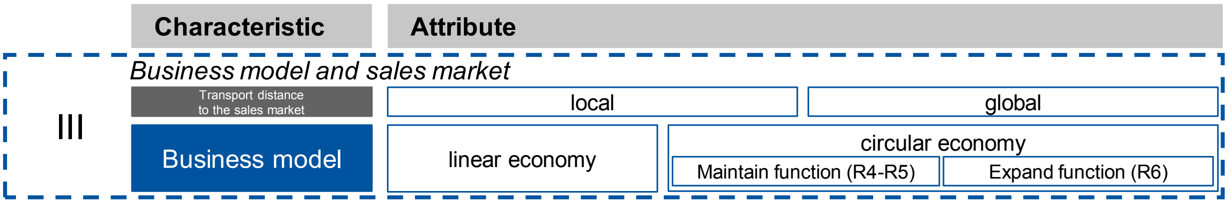

Illustration 5.5: Sub-model of the sales market

The sales market is either located at a local distance from the forward-oriented production network or is at a global distance. When choosing the business model, a company can either decide to pursue the linear economy where its products leave the network or pursue a circular economy where its products remain in the network. If the products remain in the network, it is still necessary to decide whether the functionality of the products should be retained or whether it should be expanded.

5.4.4 Product features (IV)

This section looks at the transport distance from the consumer to the reverse production network, as well as the most important product characteristics for the design of a reverse network.

For the characteristic *transport distance,* the *local* and *global* attributes known from sections (I) and (III) are selected. For this reason, the characteristics are not discussed separately here.

In addition to modularity, heterogeneity and complexity are the most important product characteristics. As a minimum level of modularity is a prerequisite and has already been briefly touched on in the previous section, the focus is now on the other two characteristics. According to STREMME, the *diversity of variants* describes the tension between standardisation and differentiation.[297] Products with a high degree of standardisation are well suited to automated processes. For example, breaking down products into their components by machine leads to a high level of efficiency and enables a greater degree of freedom in operational planning. A high number of variants also results in a high level of coordination effort for products within a circular economy, as it may not be possible to process every product at every disassembly plant. The attributes *homogeneous* and *heterogeneous* should serve as indicators of the heterogeneity of the products.

Product characteristic *complexity* is also related to knowing which product can be processed in which plant. A highly complex product can have various implications from a production perspective. On the one hand, the production of a complex object can require expensive specialised machinery, the acquisition costs of which make it uneconomical to purchase for several different locations. Complex products should contain improvements that are often the result of research and development work. To maintain a competitive advantage, the company protects this investment by maintaining strict confidentiality and filing patents. ALCÁCER ET AL. describe

[297] Cf. Stremme, U. (2000) International Strategic Production Management, 176-181.

a dissonance between the increasing importance of worldwide protection of intellectual property in a globalised world and the opportunities that companies have to do so.[298] This is partly due to a system that has remained largely unchanged for 50 years. A further reason is the significant differences between individual regions in terms of both enforcement and the cost of registering patents. For example, in a global comparison these costs are lower in the countries of the European Union than they are in the USA, China or Japan.[299] Companies with a high proportion of technology, such as the pharmaceutical industry, mechanical and plant engineering or the chemical industry, are particularly sensitive to infringements of intellectual property. In regions with high levels of intellectual rights infringement, companies from the sectors listed above as well as from other sectors prefer to set up distribution centres instead of production facilities.[300] The global protection of intellectual property is expensive, complex, and unenforceable in some countries. For this reason, location structures with a high degree of dispersion are more suitable for products or process steps with low complexity.[301] In this paper, product complexity is therefore modelled with the two attributes of *low complexity* and *high complexity.*

This results in the product properties shown in Illustration 5.6 for the sub-model:

	Characteristic		Attribute	
IV	*Product features*			
	Transport distance from the customer		local	global
	Reverse products	Variants	homogeneous	heterogeneous
		Complexity	low	high

Illustration 5.6: Sub-model of the product properties with focus on reverse products

All three characteristics are described in this sub-model with a binomial value.

5.4.5 Reverse production network (V)

The features and characteristics of the reverse-oriented production network overlap to a large extent with those of the forward-oriented production network in (II). Accordingly, the paramters of transport and density are not reintroduced here and the reader is referred to the previous section (II). Instead, this section discusses specific characteristics of the reverse-oriented site structure with regard to the attributes shown in Illustration 5.7.

	Characteristic		Attribute		
V	*Reverse production network*				
	Site structure	Dismantling plants	co-located with assembly plants	one	scattered
		Transport distance	no transport	local	global
		Core processing plants	co-located with component plants	one	scattered

Illustration 5.7: Sub-model of the reverse-oriented production network

[298] See Alcácer, J. et al. (2017) Capturing Value from, p. 181 - 183.
[299] See Alcácer, J. et al. (2017) Capturing Value from, p. 192.
[300] See Smarzynska Javorcik, B. (2004) The composition of, p. 40.
[301] See Feldmann, A./Olhager, J. (2019) Taxonomy of IMNs, p. 169.

The reverse-oriented production process is a two-stage process, just like the forward-oriented process. However, now the products first pass through the *disassembly plant,* where the specific modules are removed, and then the core is processed at the *core processing plant*. According to CARRASCO-GALLEGO ET AL., this leads to the emergence of two fundamentally different network configurations for the reverse production network[302]: the multi-depot network and the star-shaped network. The multi-depot network is characterised by a large number of largely autonomous locations where the complete preparation of the product takes place. The star-shaped network is a converging structure at two spatially separated locations. The disassembly plants represent the tips of the star and the core processing plant the heart of the star. While the former network is particularly suitable for simple products that can be repaired using standard machines, the star-shaped network is the better choice for complex products. Complex products often require specialised machines that are only installed at strategic points in the network due to their high acquisition costs or specific operating characteristics.

The results of a survey of European business practitioners, the most important prerequisites for setting up a network for functional expansion are the availability of cores, technically trained staff and the necessary facilities.[303] This result confirms and expands on the observations of COSTA ET AL. who focussed on infrastructure and raw materials.[304] In the reverse-oriented production network, the cores replace the raw materials as production input, resulting in a geographical shift of the procurement market, as discussed above. FLEISCHMANN ET AL. also consider locations in the forward-oriented production network to be suitable for the reverse-oriented production network.[305] The idea is to increase the efficiency of existing resources and thus create an economically and ecologically sustainable solution. This option is also advantageous from a social sustainability viewpoint, as the existing workforce can be kept in the company even if the degree of automation is increased. The option *at forward locations* therefore complements the existing options. If this option is selected, the disassembly plants are located at the assembly plant sites and the core processing plants at the component plant sites. However, since the sites should correspond to a similar area of influence, the authors conclude a fundamental suitability of any of the previously introduced local-for-local phenotypes.[306]

Additionally, the circular economy entails an increased significance for transaction costs within corporate networks, while the significance for economies of scale decreases.[307]

[302] See Carrasco-Gallego, R. et al. (2012) Closed-loop supply chains, pp. 5588 - 5589.
[303] See Sundin, E. et al. (2016) Map of Remanufacturing, p. 26.
[304] See Costa, Y. et al. (2017) A decisional simulation-optimisation, p. 188.
[305] See Fleischmann, M. (2001) Reverse Logistics Network, p. 19.
[306] See Fleischmann, M. (2001) Reverse Logistics Network, p. 18.
[307] See Schuh, G. et al. (2022) Sustainability-driven transformation of, p. 533 - 534.

5.5 Overall model and classifications for deriving phenotypes

Having introduced the sub-models in the previous section 5.4, we will now focus on the interdependencies within the overall model. To do this, the detailed overall model is first shown in Illustration 5.8.

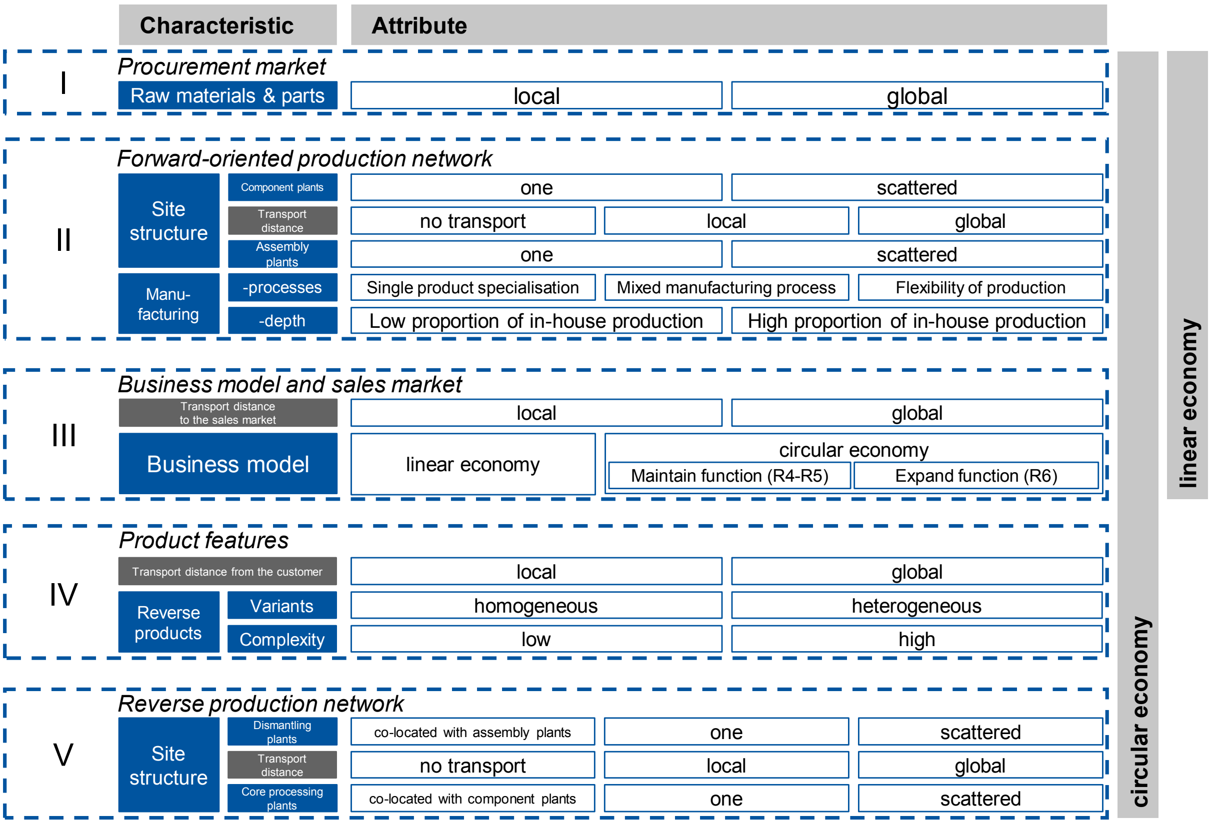

Illustration 5.8: The overall model for developing sustainable network phenotypes

In section 5.4 the sub-models (I - V) were presented together with their characteristics and all of their attributes. Derived from the origin of the morphological box, for the circular economy 186,824 theoretically possible results follow for the combinatorics of all possible characteristic attributes (cf. section 5.1). The basis for this is initially formed by 864 possible results for the linear economy. These are supplemented through multiplication with the 216 theoretically possible results for the extension.

$$N_{Circular\ Economy} = 186.624 = N_{Linear\ Economy} * N_{Expansion}$$
$$N_{Linear\ Economy} = 864 = N_I * N_{II} * N_{III}$$
$$N_{Expansion} = 216 = N_{IV} * N_V$$

Even after sorting out all logical contradictions, the number of types to be described would exceed the scope of this work and it would therefore lose all practical value. To derive a manageable number of network phenotypes from the overall model despite this, further restrictions are therefore required.

To do this, we will first look at two types of characteristics in more detail: *Transport distance* is highlighted in grey as it is a central pillar of environmental sustainability in this model, as well as contained within four of the five sub-models. It is also relevant for decisions on the procurement market but is named differently in this sub-model as it plays a subordinate role there. The second feature to be discussed is the business models. The circular economy is the only model with a sub-level, meaning that the network is either designed to maintain the function of the product or to expand it.

To analyse the interdependencies, two differentiations are made here, which are used to structure the results. The first differentiation is based on the business models. Companies whose products leave the network belong to the linear economy. Their network consists of three elements: Procurement market, the forward-oriented production network, and the sales market (elements I - III in Illustration 5.8). GPNs in circular economy companies, on the other hand, comprise all the elements in the above diagram. The points of interactions for each of the three business models are shown schematically in Illustration 5.9.

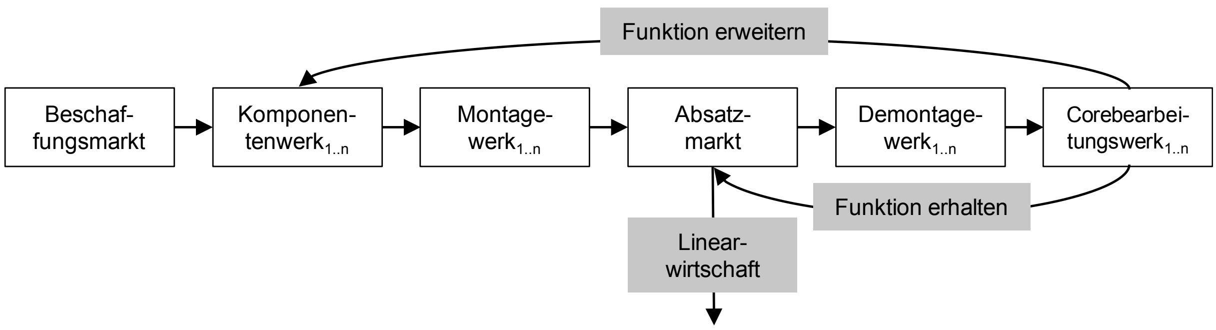

Illustration 5.9: Business models and production plants

When designing the location structure, it is important to differentiate exactly how the sales market is supplied in the above diagram. In the linear economy, the sales market is supplied directly from the assembly plants. The circular economy requires, a case-by-case analysis: In the case of *function expansion,* the product leaves the sales market and then returns to the GPN, passes through the reverse process stages, followed by the forward-oriented production steps, before it reaches the sales market again via the assembly plants; In contrast to the two business models described previously, in the case of *function retention* the sales market is supplied directly from the core processing plants.

The results will be further structured through an analysis of the sustainability dimensions. In this case it makes sense to choose one of the forms of presentation that were introduced in subsection 2.2.2. As it is necessary to consider both the individual dimensions of sustainability as well as their hybrid forms in the following, the decision was made in favour of the sustainability triangle by KLEINE.[308] This form of presentation makes it possible to summarise both the different business models and the sustainability dimensions with their hybrid forms (see Illustration 5.10).

[308] Cf. Kleine, A. (2009) Operationalisation of a sustainability strategy, p. 81 - 87.

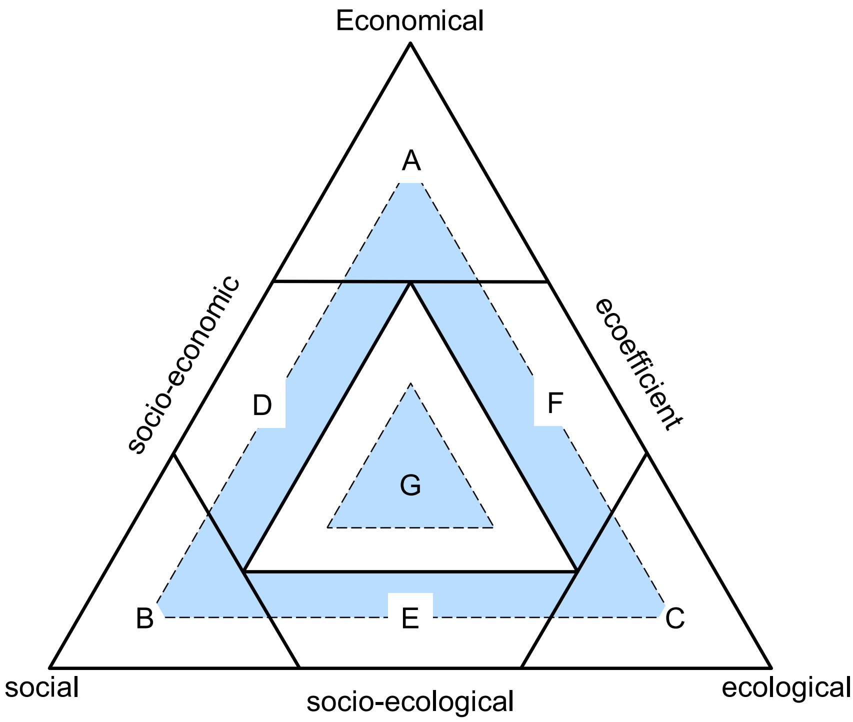

Illustration 5.10: Typology of holistic sustainability phenotypes

The tips (see A - C) of the outer triangle show the pure forms of the sustainability dimensions. The sides (see D - F) each show a hybrid form between two dimensions, and case G describes a completely sustainable perspective that includes all three dimensions. The typology shown above therefore contains seven perspectives on sustainability. The decision on the business model therefore leads to two strategic options for each of these perspectives: Either produce products for the linear economy (white areas); or to produce products for the circular economy (blue areas).

In total, the typology therefore contains 14 different phenotypes, divided into seven perspectives of sustainability (A - G), each of which has two different options (linear or circular).

5.6 Phenotypes

The phenotypes are presented sorted according to the seven perspectives of sustainability (A - G). In line with the product life cycle, the first phenotype to be introduced for each perspective will always be viewed from the linear economy perspective. Only then will the circular economy phenotypes be introduced. While the second, circular phenotype is partly based on the respective section on the linear economy and therefore shares several characteristics regarding the sub-models (I - III), the content of the discussion on circular economy phenotypes will focus on the differences that set it apart from the linear economy phenotypes. The most significant change is a shift within the sales market to a newly created procurement market for circular products. This greatly reduces the significance of the sub-model (I) within the circular economy.

Phenotypes describe idealised patterns (cf. chapter 2.1.3), which is why the attributes of selected characteristics are particularly important for certain phenotypes. These characterising trait expressions are marked in *blue* below. Characteristic attributes marked in *grey* represent a likely solution that can be used to describe the phenotype. The result of mainly focussing on the characterising traits, is a large number of optional solutions, particularly in the perspectives of the pure forms (A - C). Combinations of multiple pure forms results in clear solutions for mixed forms (D - G).

In order to create a reference point for the reader, the phenotypes developed in this research are assigned phenotypes from chapter 3 whenever possible.

5.6.1 Phenotypes from an economic perspective (A)

In the following, we will first analyse the linear economy. Building on this, the model will be expanded to include the circular economy.

Linear economy

When considering the economic perspective, reference is made to the existing approaches from chapter 3. A consolidation takes place at this point, the result of which is shown in Illustration 5.11.

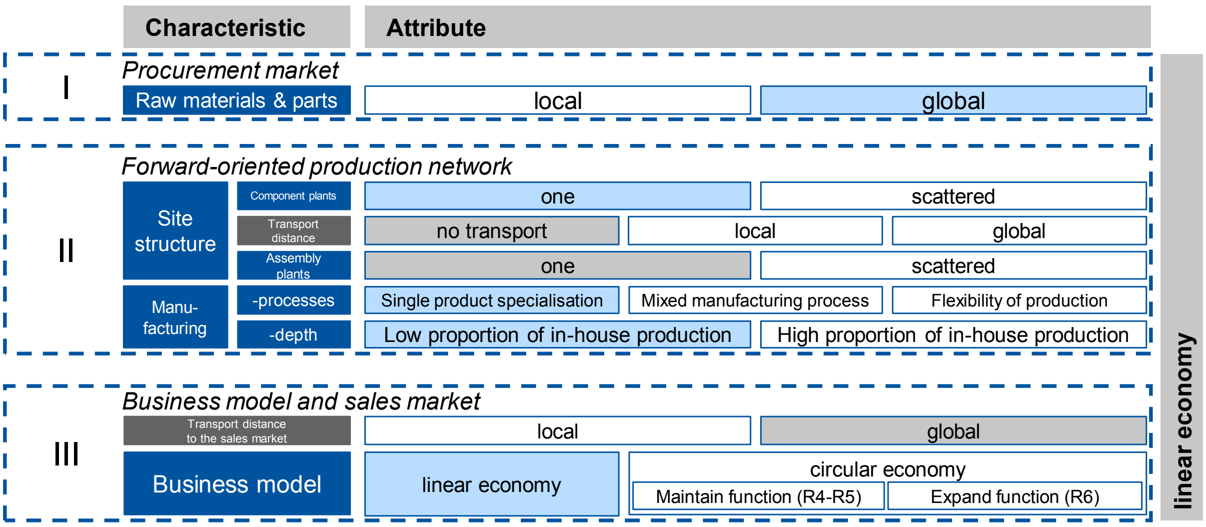

Illustration 5.11: The economic phenotype in the linear economy

Sub-model (I) describes the procurement market: Due to falling transport costs, globalisation has created a worldwide procurement market.[309] More suppliers are active on a global market than on a smaller, local market.[310] In a perfect market, the price regulates the relationship between supply and demand. Ceteris paribus, a larger supply leads to falling prices if demand

[309] See Abele, E. et al. (2008) Global Production, p. 11.
[310] See Abele, E. et al. (2008) Global Production, p. 9.

remains constant.[311] This is why on a global procurement market it is possible to find better prices for movable raw materials and components than on a local market.

Sub-model (II) describes the forward-oriented production network: There are different approaches to the structure of the *forward-oriented production network* in the literature: In the case of single product specialisation, economies of scale favour a large production volume, as it leads to higher productivity and efficiency; if a flexible production process is chosen, a high variety of product variants can be produced, e.g. for local adaptation. Giving up economies of scale goes hand in hand with higher production costs. Assuming that the products are offered worldwide in both standardised and local variants at the same price, the margin is higher for the first option. Therefore, if the economic perspective is chosen, a *single product specialisation* takes place. This efficiency strategy is of great importance in the economy (see sub-section 2.2.3). Selecting a single component plant leads to the maximisation of production volumes. When inspecting the economic phenotype, the degree of density of the assembly plants is considered solely in terms of the resulting costs. Either cost advantages are also achieved at this process stage by producing large quantities at one location or the products are assembled locally at scattered assembly plants. The higher coordination effort with lower volume advantages associated with the choice of a dispersed assembly network must be justified from an economic perspective. This requires widening the scope of the analysis at this point to compare not only the costs but also the margin. If there are access restrictions to markets that require a local production step to offer products on the local market, there is no alternative to a dispersed assembly network. If the target markets do not include access restrictions, individual product specialisation promotes a high degree of automation technology in assembly. Due to the associated investments, this option results in a single assembly plant. This characteristic is considered a solution in the presented model.

The transport of goods creates basic logistics costs on both the sender and recipient side, regardless of the transportation distance between the two process steps. The basic costs describe the fixed costs of operating infrastructure such as warehouses and means of transport. From an economic perspective, it is therefore optimal to eliminate all transport and the associated costs. If this is not possible, the distance between the process steps should be as short as possible, as transport costs increase with increasing distance travelled.[312]

A low proportion of in-house production is economically desirable if the company limits itself to the targeted optimisation of individual areas of production. Outsourcing further production steps to a subcontracted company specialised in the production of these components leads to a reduction in costs and increases economic transparency through clear allocation to cost centres.

Sub-model (III) describes the sales market: The products should be offered in all lucrative markets, regardless of the transport distance. If a single plant is selected, this leads to global

[311] See Göke, M. (2020) Supply and demand, p. 138.
[312] See Abele, E. et al. (2008) Global Production, p. 11.

transport distances to the sales market and if a dispersed assembly network is selected, to local distances.

The world factory according to MEYER and JACOB serves as an example of the economic phenotype in the linear economy (cf. sub-section 2.1.3). It combines both process stages at one location in order to optimally utilize the power of economies of scale in the case of single product specialisation. It can be assumed that a company chooses this phenotype in order to specifically optimise certain aspects of the process, resulting in a low degree of in-house production. The world factory is active on global procurement and global sales markets.

Circular economy

Changing to a circular economy business model, requires a distinction between the options of pure functional maintenance and functional expansion. The latter can be monetised by the company in the form of a surcharge. Therefore, the economic phenotype in the circular economy follows the second option. The resulting configuration of the overall model is shown in Illustration 5.12.

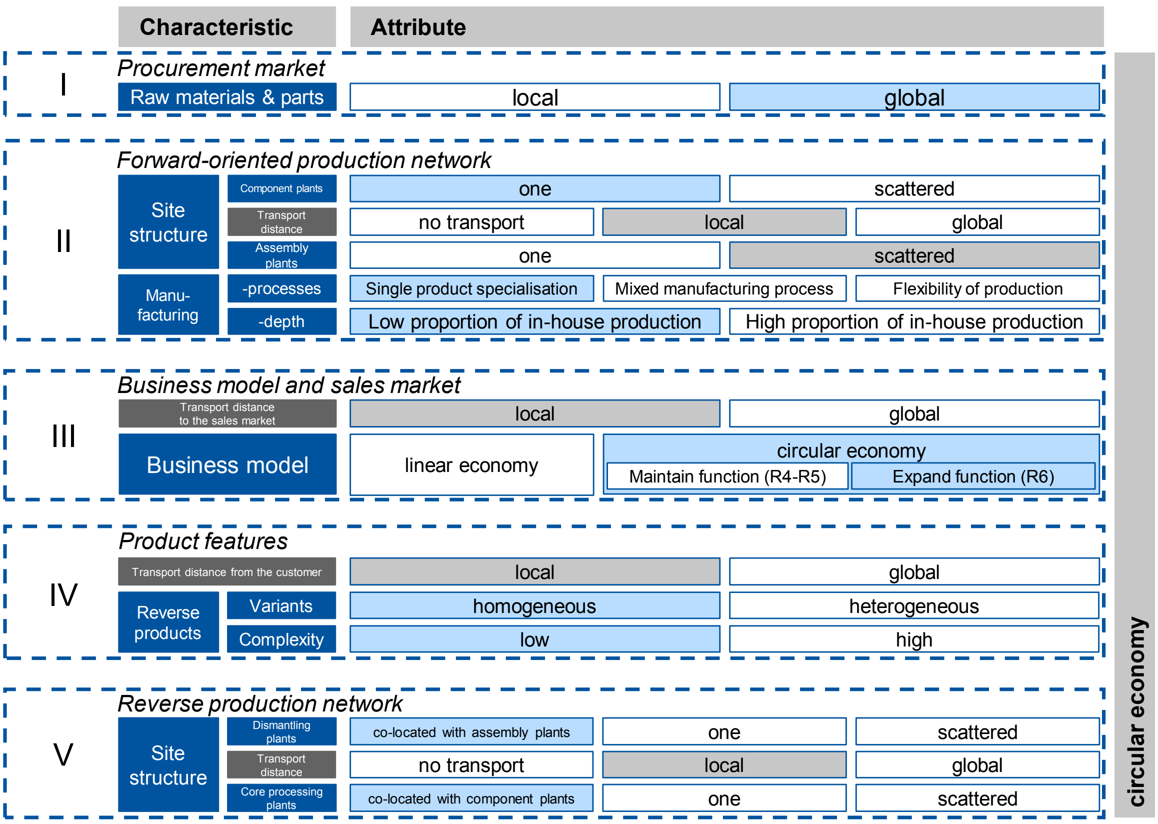

Illustration 5.12: The economic phenotype in the circular economy

The sub-model (I) remains unchanged compared to the characteristics of the linear economy. The characterising features of the sub-model (II) shown in blue also remain unchanged. Sub-model (III) ends the linear economy with the sales market. In sub-model (III), the transport distance changes due to the dispersion of the assembly and disassembly plants discussed below. Sub-model (IV) marks the beginning of the circular economy through transport from the sales market back into the production network. The integration of the circular economy affects location structures in both the forward-oriented and reverse production network. For companies with many end-consumer customers, each cycle of the circular economy means a high level of coordination and costs since end-consumers tend to be highly scattered and usually only purchase a small quantity of the product. Both types of effort increase with increasing distance. In a dispersed network, the distances between the GPN and the sales market decrease, meaning that the process step immediately adjacent to the sales market should have a high degree of dispersion. Accordingly, both the assembly and disassembly plants have a high degree of dispersion here. For the assembly plants, the structure of the reverse-oriented production network in sub-model (V) results in a change towards a dispersed location structure. The reason for this is the changed flow of goods in the product life cycle (cf. Illustration 5.9). This also changes the transport distance between the plants. In the interests of a cost-effective solution, short distances between the individual production steps should be favoured. As the core processing and component plants are co-located at the same site, there is no need for transport between the two process steps.

Uniform products with low complexity also boost economies of scale in the disassembly process. They are therefore preferable to those with high complexity and many variants. If an adaptation for the local market requires a heterogeneous product range, the variants should appear in the modules and the core should remain the same worldwide.

If a reverse-oriented production network is set up to complement an existing forward-oriented production network, it is advantageous from an economic perspective to use existing site structures. This for example creates synergies at the level of the component and core processing plants. As a result, duplicate investments can be avoided.

5.6.2 Phenotypes from a social perspective (B)

The social phenotype in the linear economy is described below, followed by the social phenotype in the circular economy.

Linear economy

Using the characteristics and attributes described in section 5.4, the social phenotype in the linear economy is outlined here. The specific selection of the individual characteristics and their categorisation in the overall model are shown below (cf. Illustration 5.13).

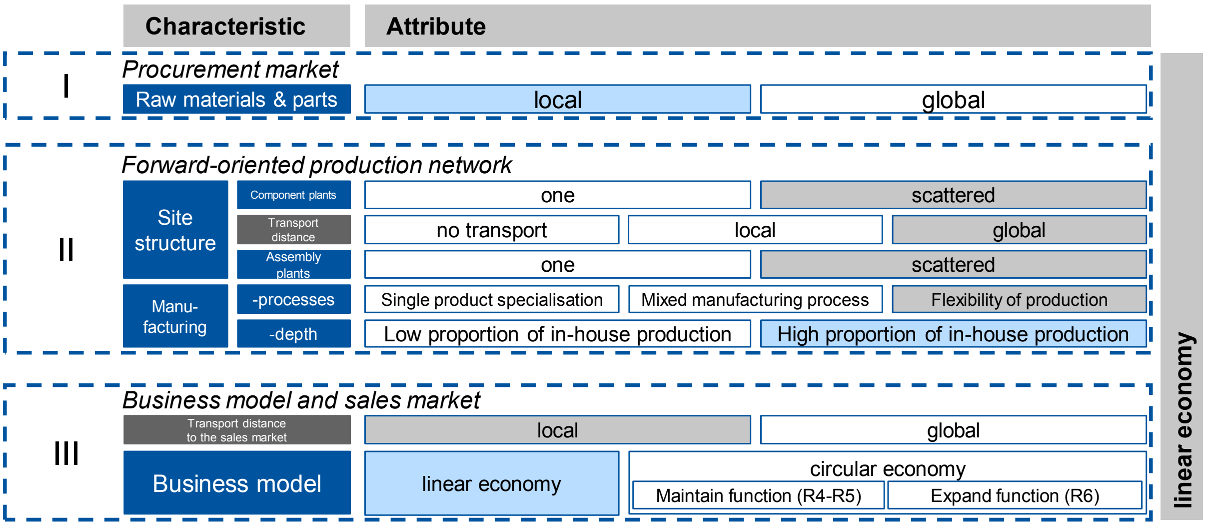

Illustration 5.13: The social phenotype in the linear economy

Sub-model (I) describes the procurement market: Gaining complete control over the actions of players on the procurement market lies outside the active sphere of influence of companies. However, by making a targeted choice of its direct suppliers, a company can exert its influence directly on them and indirectly on their suppliers' suppliers.[313] To act according to the criteria of social sustainability, high-quality information is required. This work is based on the premise that the accuracy of information decreases with increasing geographical and cultural distance. Therefore, at this point the localised form is chosen for the social phenotype in the linear economy.

Sub-model (II) describes the forward-oriented production network: Regarding the configuration of the forward-oriented production network, the social focus in this thesis is on vertical integration (cf. sub-section 5.4.2). Derived from a comparison of CSR values of different companies, MURCIA ET AL. come to the conclusion that a high degree of social sustainability goes hand in hand with a high degree of in-house production.[314] The social impact of the location structure is analysed using two scenarios as examples: First, a production network with strong single product specialisation and a central component and assembly plant at one location; second, a production network with flexible manufacturing in dispersed plants. In the first scenario, in line with the assumptions of the model (cf. section 5.1), this leads to a single production site with a higher number of employees than scattered sites. This large number of employees raises the influence they have in negotiations with the company management. Social sustainability throughout the company can be further improved for example by electing a works council. In the second scenario, the individual sites are smaller, and each has fewer employees. These employees are extensively trained for flexible production processes and this in turn makes them assets not easily replaceable. The company endeavours to retain employees and invests in social sustainability of its own initiative.

[313] See Wilhelm, M. et al. (2016) Sustainability in multi-tier SCs, p. 210.
[314] See Murcia, M. et al. (2021) Socially Responsible Firms, p. 1507.

Sub-model (III) describes the sales market: The transport distance to the sales market has no direct impact on social sustainability, meaning that both local and global distances are possible.

An example of the social phenotype in the linear economy according to MEYER and JACOB is the web (cf. sub-section 2.1.3). It has scattered locations on both process steps. The aim of the web is to fully utilise the company's own production facilities by making production as flexible as possible. It can be assumed that a company will only undertake this coordination effort if it has a high degree of in-house production. The network is active on global sales markets.

Circular *economy*

Compared to the characteristics of the linear economy, there is no need for changes in the sub-models (I - III). When pursuing the circular economy, from the social perspective of sustainability it is irrelevant whether the product undergoes a functional expansion as part of the strategy selection or whether the functionality is maintained. In both cases, the work processes taking place inside the company are similar. The resulting characteristics are shown in Illustration 5.14.

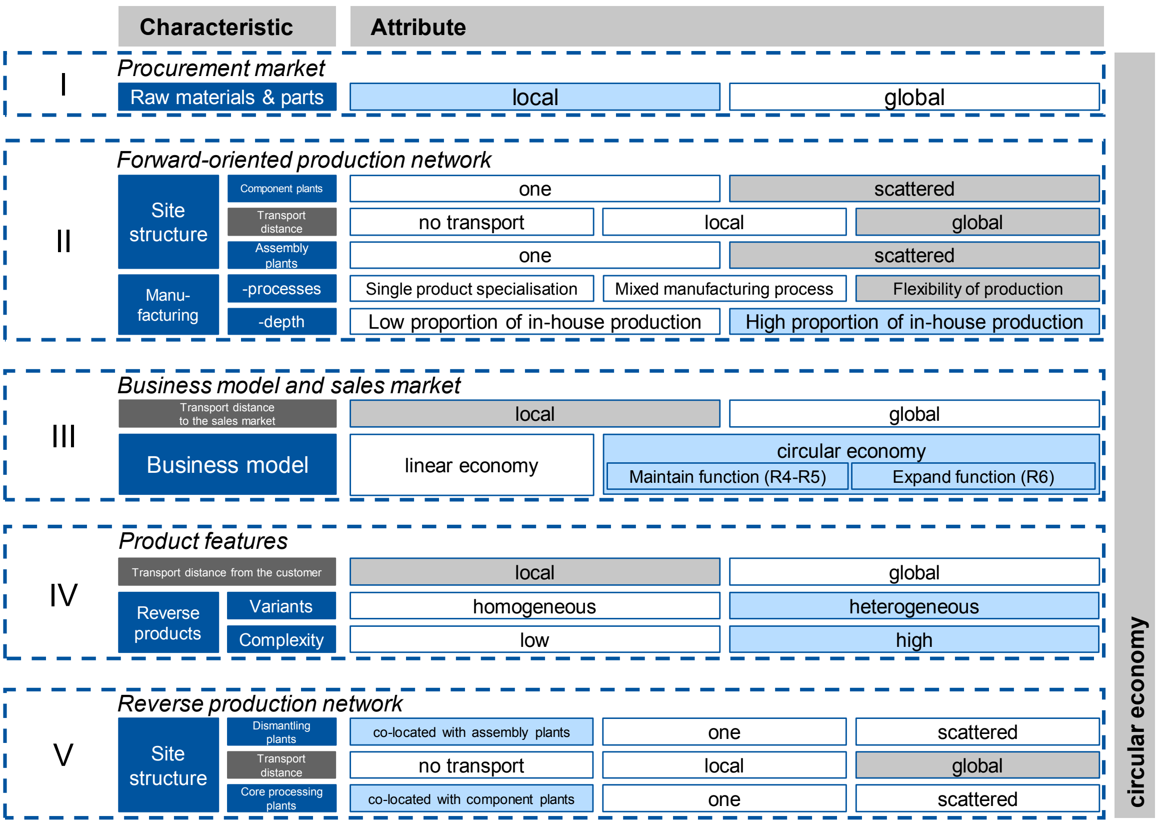

Illustration 5.14: The social phenotype in the circular economy

The product characteristics are described in sub-model (IV): In terms of product characteristics, products with higher complexity are preferable to those with lower complexity. With increasing complexity, it can be assumed that employees perform a wider range of differing activities. It can also be assumed that automation of the process is less lucrative, which increases the value of employees' expertise for the company. Similar to the second scenario in the linear economy, this results in a situation in which employees can achieve an improvement of their social situation. This in turn results in an improvement of social sustainability for the company as a whole. The transportation distance from the customer to the dismantling plant has no significant effect on the social perspective, so the localised version was chosen here.

The reverse production network is described in sub-model (V): Similar to the location structure in the linear economy, the exact location of the disassembly and core processing plants as well as the transport distance between the plants are of secondary importance for the characteristics of the reverse-oriented production process. However, from a social perspective it is desirable to manufacture at existing locations within the forward-oriented production network. When entering the circular economy, some of the tasks shift from the forward-oriented production network into the reverse production network. If this shift takes place at different locations, employees in the forward-oriented production network are laid off and new employees are hired at the locations of the reverse production network. If a shift takes place within a location, existing employees can be retrained. The latter option has the added side benefit of avoiding negative press for the company related with major lay-offs.

5.6.3 Phenotypes from an ecological perspective (C)

The ecological phenotype in the linear economy is described below, followed by the ecological phenotype in the circular economy.

Linear economy

Using the characteristics and attributes described in section 5.4, the ecological phenotype in the linear economy is defined next. Various strategic perspectives are conceivable to consider ecological sustainability. The specific selection of the individual characteristics and their categorisation as chosen in this thesis for the overall model is discussed below (cf. Illustration 5.15).

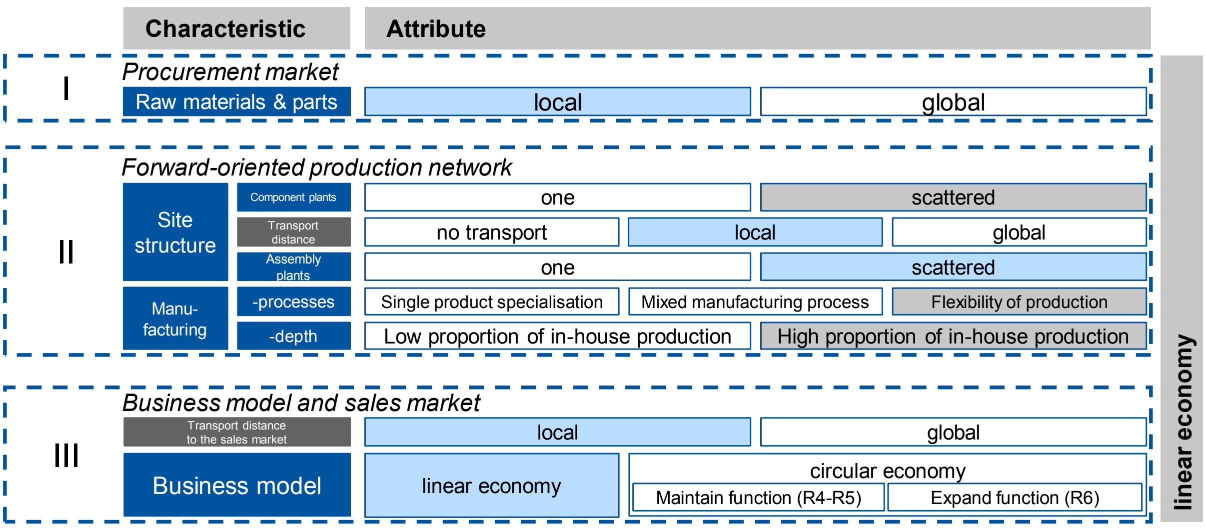

Illustration 5.15: The ecological phenotype in the linear economy

Three scenarios are discussed below for the selection of characteristics: The bundling of processes with high energy requirements at one location; A targeted settlement at advantageous locations; A reduction in transport. In this model, production within the two-stage manufacturing process takes place entirely at the level of the component plants (cf. section 5.1). For processes with fixed, high-energy requirements, such as melting processes that require a certain temperature regardless of the quantity processed, it makes sense to bundle these in a central component plant. In the second scenario, local conditions such as a large supply of sustainably generated electricity at a specific location are utilised in order to reduce the GPN's ecological footprint. In order for the production network to benefit from these sustainable input factors the company must purchase them via the procurement market; Therefore, the conditions of the second scenario are fulfilled by selecting a local procurement market. As part of the discussion of the third scenario, reference is made to COSTA ET AL. regarding the crucial importance of infrastructure assessment (cf. sub-section 5.4.1). Consequently, the reduction of transport distances is a key element of the ecological perspective in all three sub-models.

Sub-model (I) describes the procurement market: As the environmental footprint of most manufacturing companies is concentrated in the upstream value chain, the procurement market plays a pivotal role in the assessment of a company's environmental sustainability (cf. sub-section 5.4.1). For this reason, the choice of localisation on the procurement market side is a characteristic feature. This allows for short transport distances and local sourcing.

Sub-model (II), the forward-oriented production network, is covered by the scenarios discussed above. They result in a scattering of assembly plants.

Sub-model (III) describes the sales market: In order to be able to supply the local sales markets over short transport distances, the company must have a dispersed structure of assembly plants. Under the premise of transport minimisation, component and assembly plants are ideally located in the same place or close to each other. A dispersed structure of component plants was therefore chosen for this solution. Analogous to the social phenotype, a high proportion of in-house production enables a company to directly influence the realisation of its ecological goals. If the company opts for flexible production, the same product range can be manufactured on a smaller number of machines due to the multiple use of machines. This reduces the ecological footprint of the production machine fleet.

By establishing a distributed network of assembly plants, the sales market can be supplied over short distances. Consequently the localised form is selected for this characteristic.

The local-for-local type according to MEYER and JACOB serves as an example of the ecological phenotype in the linear economy (cf. sub-section 2.1.3). Its local focus on the procurement and sales market is supported by a network spread across both process steps. The proportion of in-house production is not further defined. Characterised by the strong local focus, this results in an allocation to the ecological phenotype in the linear economy.

Circular economy

SCHMIDT's consistency strategy is the most important of the three sustainability strategies, as it is the only one that represents a permanently tolerable cost to both the environment and resource use (cf. sub-section 2.2.3). It describes a circular economy in which renewable raw materials and renewable energies are used for production. When opting for a circular economy, the preservation of product functions is more sustainable from an ecological perspective than their expansion (cf. sub-section 5.4.3). In the functional preservation business model, the sales market is supplied by the core processing plants from the first pass of the reverse production network. No changes are required for the sub-models (I - III) compared to the characteristics of the linear economy. The resulting characteristics and attributes are shown in Illustration 5.16.

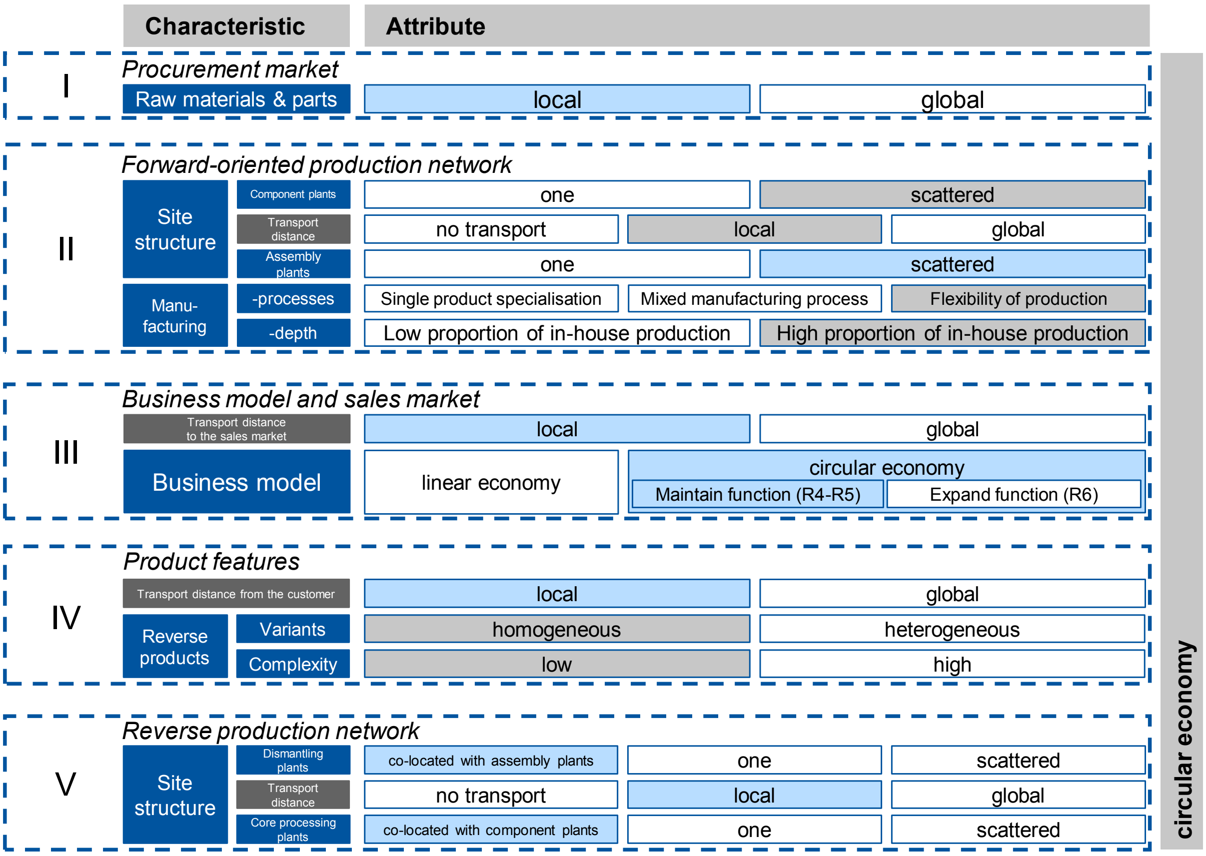

Illustration 5.16: The ecological phenotype in the circular economy

In the circular economy, transport routes have an even greater impact on the ecological perspective than in the linear economy. Assuming that manufacturing emissions are the same at all locations worldwide, the level of transport emissions is an important variable. Each time the product passes through the cycle, the relevance of transport increases. Therefore, the choice of local distance from the sales market to the reverse production network is a characterising feature.

When analysing product characteristics, it is assumed that products with few variants and low complexity can be dismantled at any location. This would result in short transport routes from the customer to the dismantling plant avoiding time-consuming sorting or the need to transport goods over long distances.

The site structure of the reverse production network should also be co-located with the sites of the forward-oriented production process. In line with the reuse (R3) strategy by POTTING ET AL., co-locating the reverse manufacturing at the existing sites would mean continuing to use the existing infrastructure (cf. sub-section 2.2.5). If the entire production network is planned from scratch, it makes sense to invest in scattered core processing plants.

5.6.4 Phenotypes from a socio-economic perspective (D)

The socio-economic phenotype in the linear economy is described below, followed by the socio-economic phenotype for the circular economy. Both phenotypes are hybrid forms that are derived from the phenotypes of the economic perspective (cf. sub-section 5.6.1) and the social perspective (cf. sub-section 5.6.2).

Linear economy

Compared to the models of the pure forms, there are two clashes among the characterising features. The first is the global nature of the procurement market in the economic perspective. The second difference lies in the vertical range of manufacture, where the social perspective with a high in-house production depth was chosen. There are no contrasts in the remaining characterising features, so these are adopted analogously to the pure forms. The entire resulting model is shown in Illustration 5.17.

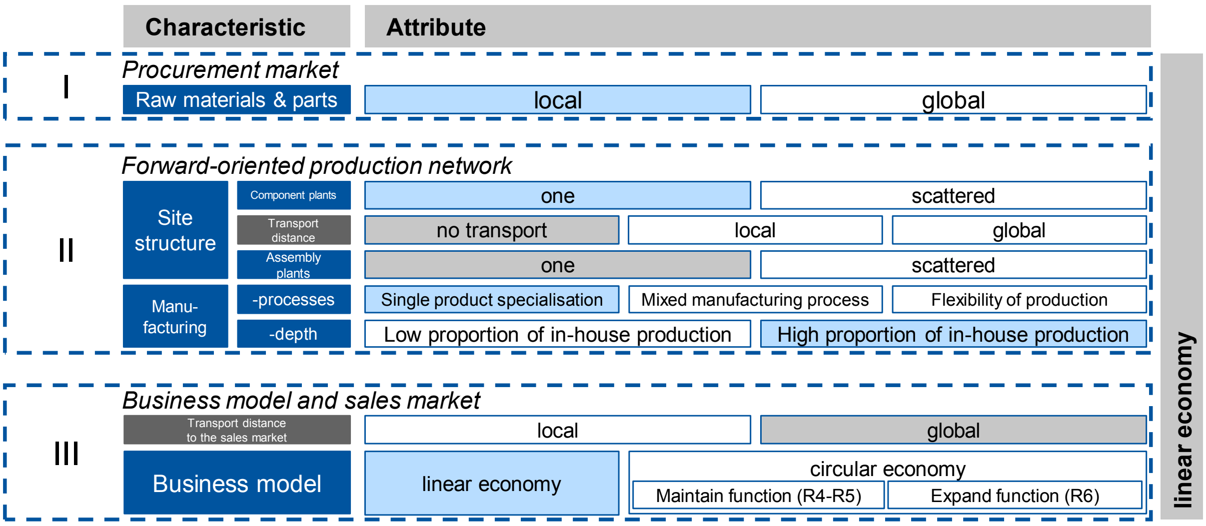

Illustration 5.17: The socio-economic phenotype in the linear economy

From a socio-economic perspective, particular attention must be paid to the choice of suppliers on the procurement market. Monitoring transparency is more difficult than monitoring prices, as it is more complex and cannot be easily quantified. The local focus enables the company to concentrate not only on the economic benefits, but to also take social aspects into account. This enables the establishment of a socio-economic procurement model that prioritizes long-term stability and reputation over short-term economic gains.

The location structure is chosen analogous to the phenotype of the economic perspective as a single plant with a high degree of specialisation in the production processes. This results in efficiency effects due to the aforementioned economies of scale. In this case, there is no need for transport between the plants as they are located at the same site.

From the social perspective of sustainability, it follows that the proportion of in-house production must be high. Regarding external production, this should only be carried out by known partner companies with which there are long-standing, established relationships and whose own production also complies with social standards.

Distribution of the products can be organized from the single plant to a global sales market.

The chain according to MEYER and JACOB serves as an example of the socio-economic phenotype in the linear economy (cf. sub-section 2.1.3). The global search for the optimal production factors is at the centre of the description. Thus it results in only one location at each process step. It can be assumed that a company only chooses this phenotype if it has a high proportion of in-house production. The chain also exhibits a high degree of specialisation.

Circular economy

Based on the economic phenotype, the functional expansion is chosen as the business model. As with the linear economy model previously described, there are two notable differences when comparing it with the models of pure forms. These differences relate to the distinctive characteristics of the circular economy. The first difference stems from the economic perspective, which favours low product complexity. The second difference also concerns the product characteristics. As in the social perspective, there are a large number of product variants. Illustration 5.18 shows the resulting final model.

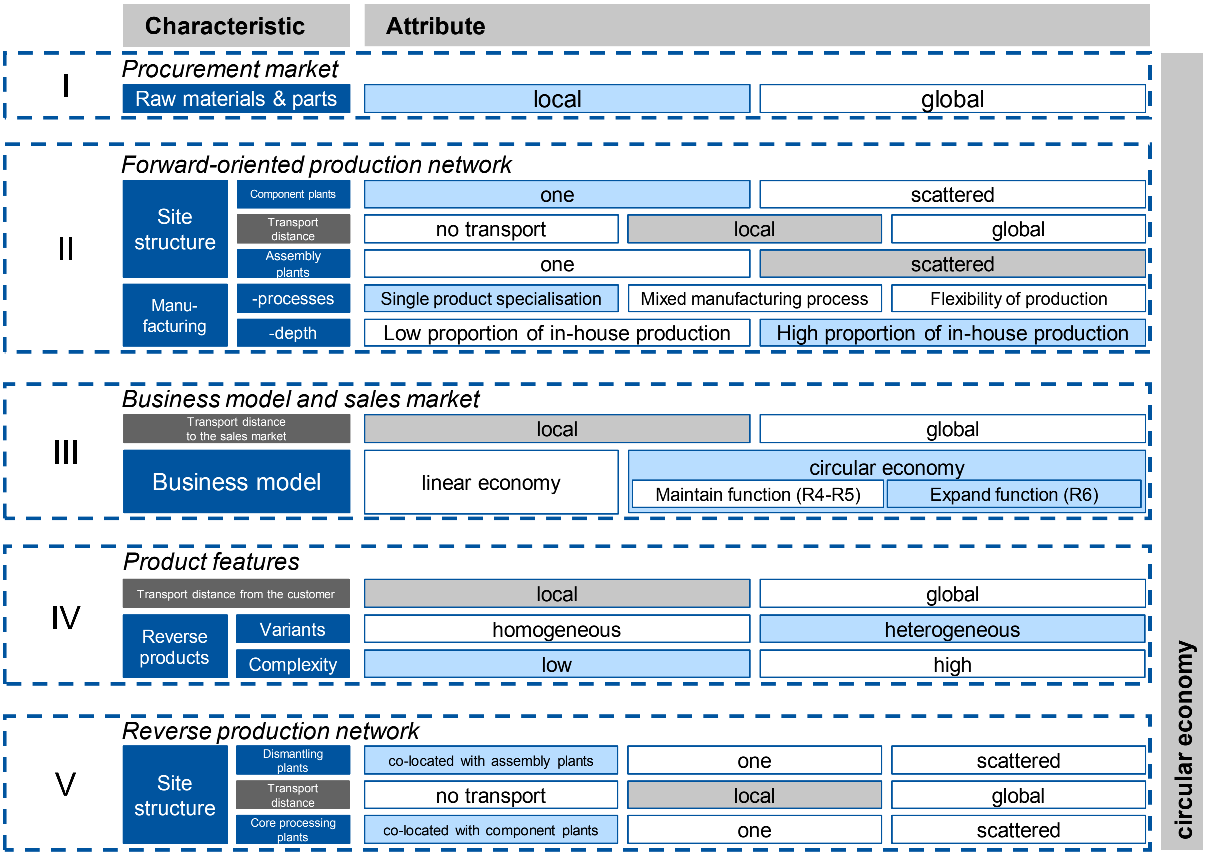

Illustration 5.18: The socio-economic phenotype in the circular economy

The sub-models (I - III) are identical to those of the linear economy.

The product characteristics are described in sub-model (IV): In the socio-economic model, the ease of manufacture and the qualification level of employees characteristics must be harmonised. Simple products are particularly suitable for automation processes. As the degree of complexity increases, so do the requirements for employee qualifications since complex products have a higher range of possible errors. An increasing number of possible errors combined with small batches makes automation more difficult. Conversely, this leads to a greater need for qualified personnel who can recognise and intelligently remove sources of error.

The reverse-oriented production network is described in sub-model (V): It is economically advantageous to concentrate the complexity in the core and keep the degree of complexity of the modules low. This creates efficiency effects in the core processing plant. Dispersed disassembly plants reduce transport distances to the sales market. Concurrently, a greater range of products can be processed in dispersed disassembly plants. For instance, individual plants may qualify their employees for the disassembly of specific product variants. This enables the processing of a greater variety of variants.

5.6.5 Phenotypes from a socio-ecological perspective (E)

The socio-ecological phenotype in the linear economy is first described below. Building on this, the socio-ecological phenotype for the circular economy is explained. Both phenotypes are hybrid forms that are derived from the phenotypes of the ecological perspective (cf. sub-section 5.6.3) and the social perspective (cf. sub-section 5.6.2).

Linear economy

In comparison to the models of the pure forms, there are no contradictions in the characterising features, so that these are adopted analogously to the pure forms. The result is shown in Illustration 5.19.

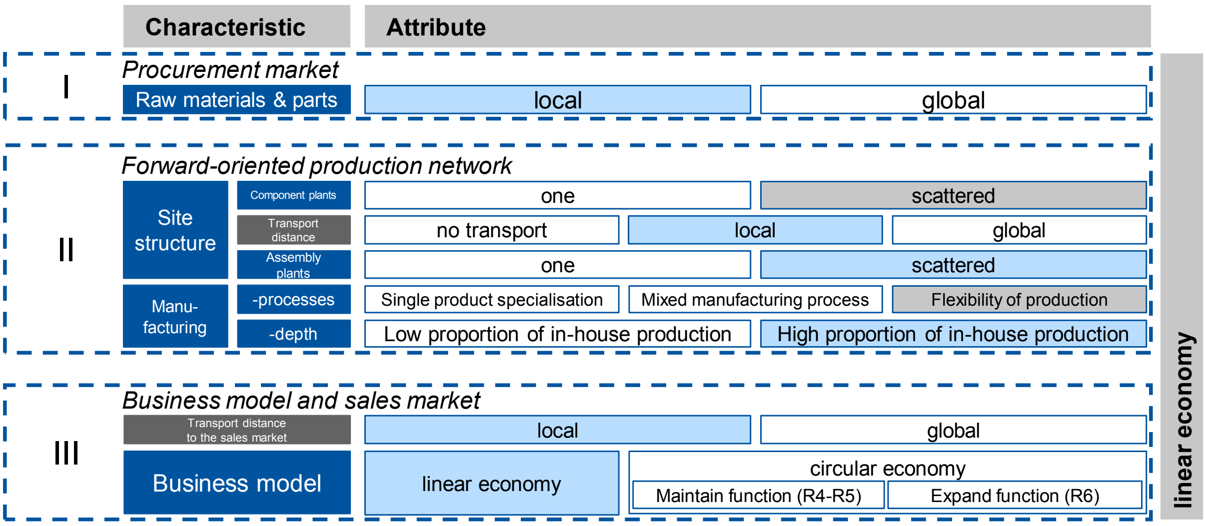

Illustration 5.19: The socio-ecological phenotype in the linear economy

Regarding the procurement market (I), the choice of the attribute *local* is a characteristic feature for both the social and the ecological perspective.

Sub-model (II) describes the forward-oriented production network: From an ecological perspective regarding the location structure, dispersed assembly plants and the associated short transport distances are characterising features. Dispersed component plants are ideally suited to benefit from short transport routes. From a social perspective concerning vertical integration, a high proportion of in-house production is a characterising feature. Flexible production is advantageous from both an ecological and a social perspective (cf. pure models).

With regards to the sales market (III), localisation is a characteristic feature from an ecological perspective.

The micro-production network according to RAUCH ET AL. serves as an example of the socio-ecological phenotype in the linear economy (cf. sub-section 3.2.5). Its local focus on the procurement and sales market is supported by a network that is spread across both process steps. The high proportion of in-house production and the strong local focus result in an allocation to the socio-ecological phenotype in the linear economy.

Circular economy

Influences primarily by the ecological phenotype, functional conservation is selected as the business model. In comparison to the characteristic features of the pure forms, there are no contradictions in the characterising features, so that these are adopted analogously to the pure forms. Illustration 5.20 shows the final model.

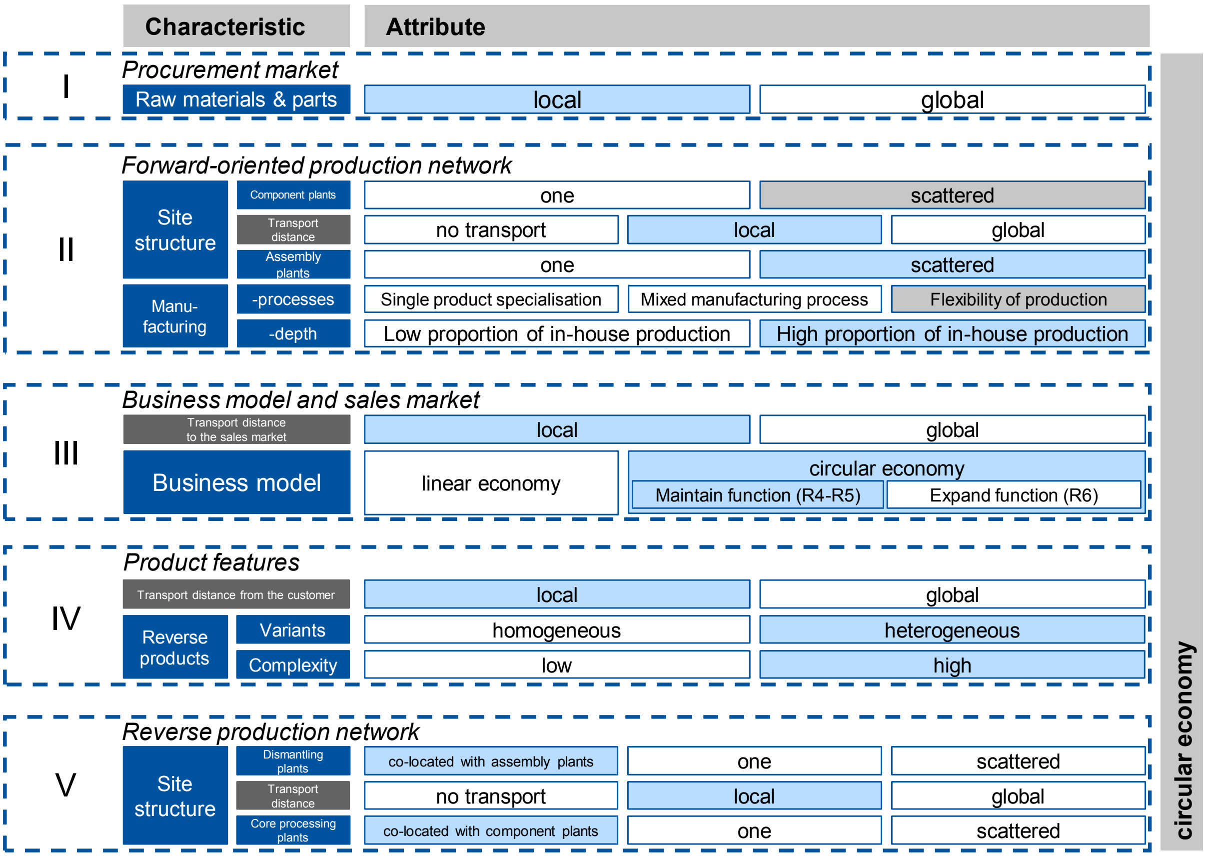

Illustration 5.20: The socio-ecological phenotype in the circular economy

The sub-models (I - III) are identical to those of the linear economy.

The product characteristics are described in sub-model (IV): From an ecological perspective regarding the product characteristics, local transport routes are a characterising feature. The characterising features listed for the social perspective complement those of the ecological perspective. Regarding the variants, a heterogeneous product structure and a high level of complexity are favourable. As explained in sub-section 5.6.2: "With increasing complexity, it can be assumed that employees perform a broader range of changing activities. It can also be assumed that automation of the process is less lucrative, which increases the value of the employees' expertise for the company."

Sub-model (V) describes the reverse-facing production network: With regard to the location structure, dismantling and core processing plants should be located "at forward locations". These are characterising features from both a social and an ecological perspective. As component and assembly plants are scattered in the forward-oriented production process, disassembly and core processing plants will also be scattered. As already described in chapter 5.6.4

the following applies: "Scattered disassembly plants reduce the transport distances to the sales market. At the same time, a greater variety of products can be processed in dispersed disassembly plants, for example by individual plants qualifying their employees for the disassembly of individual product variants. This allows a greater variety of variants to be served."

5.6.6 Phenotypes from the eco-efficient perspective (F)

First, the eco-efficient phenotype in the linear economy is described below. Building on this, the eco-efficient phenotype for the circular economy is explained. Both phenotypes are hybrid forms that can be derived from the phenotypes of the ecological perspective (cf. sub-section 5.6.3) and the economic perspective (cf. sub-section 5.6.1).

Linear economy

In comparison to the models of the pure forms, contradictions occur in all sub-models in the characterising features. Following the presentation of the overall model in Illustration 5.21, the sub-models are discussed.

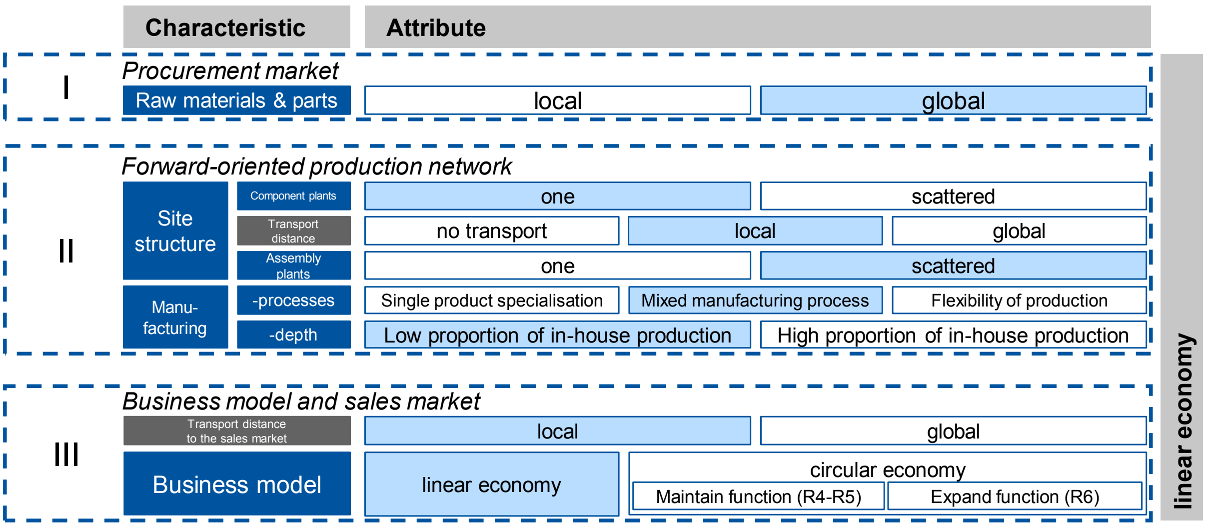

Illustration 5.21: The eco-efficient phenotype in the linear economy

There is a conflict of interest regarding the procurement market. From an environmental perspective, transport routes should be as short as possible, and the sourced materials should be produced in the most environmentally friendly way possible. In order to also include the global search for suppliers a potential compromise could be to accept global transportation distances under the premise that the most CO_2 -neutral means of transport are selected.

Sub-model (II) describes the forward-oriented production network: With regard to the location structure, there are conflicts of interest at both component and assembly plant level. From an economic perspective, opting for a single product specialisation combined with a single co-located plant for both stages would result in efficiency effects through economies of scale. From an ecological perspective, scattered plants should be favoured at both levels in order to achieve flexibility in production. A good way of addressing both interests is to select either a diverging or a converging location structure. By choosing one of these structures, for example, specialisation can take place in the component plant and flexible production in the dispersed assembly plants. Consequently, in this perspective, a mixed production form is therefore preferable. Individual components can be outsourced by deliberately choosing a nearby partner company that operates ecologically, so that a low proportion of in-house production is achieved.

Sub-model (III) describes the sales market: The sales market with a divergent location structure is supplied over short transport distances using the most CO_2 -neutral means of transport possible.

The hub-and-spoke type according to MEYER and JACOB serves as an example of the eco-efficient phenotype in the linear economy (cf. sub-section 2.1.3). As a divergent process, it combines economies of scale at the component plant level with the possibility of achieving a high degree of local flexibility.

Circular economy

Based on the economic phenotype, functional expansion is chosen as the business model. From an ecological point of view, function maintenance is better than functionality expansion, but both business models are better than linear economy business models in the context of a circular economy. When comparing models of pure forms, there are no contrasts between the characterising features in the circular economy. The characterising features from the pure models can therefore be adopted here. Illustration 5.22 shows the resulting final model.

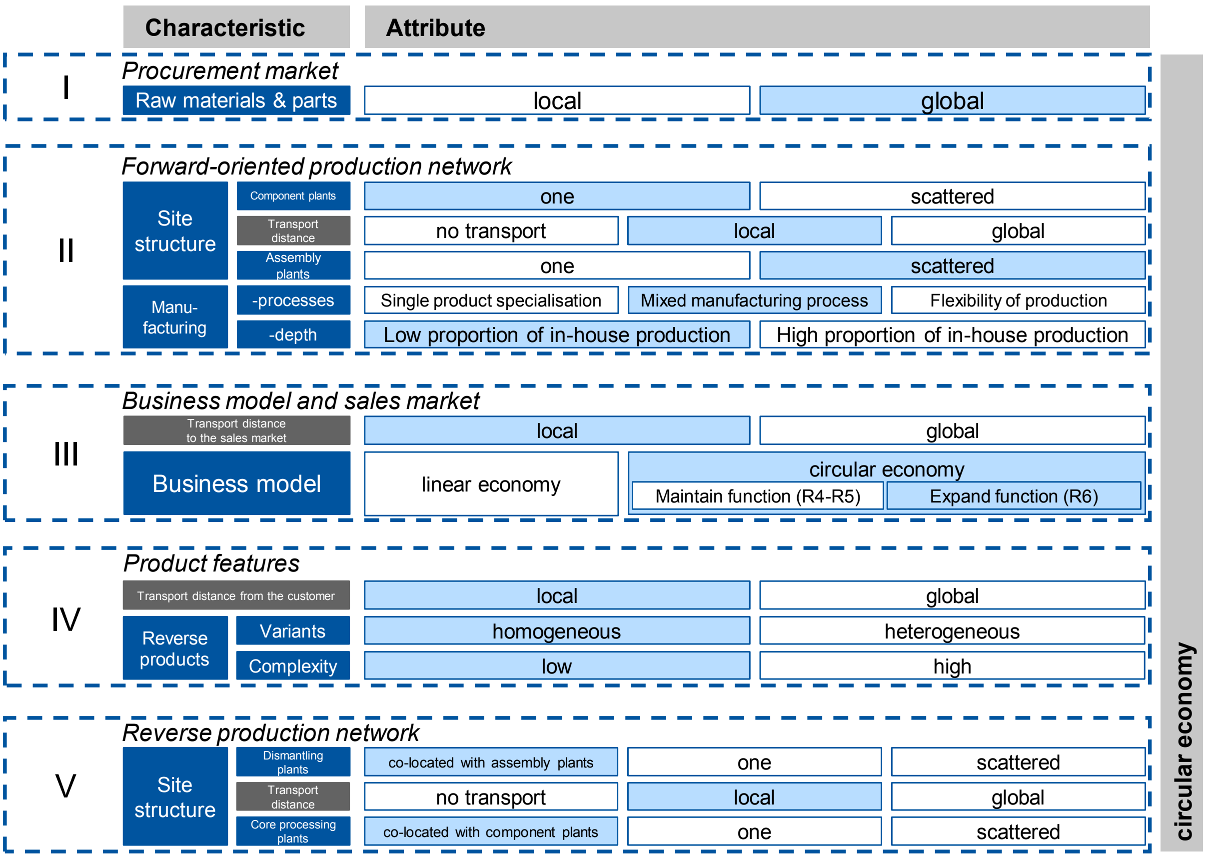

Illustration 5.22: The eco-efficient phenotype in the circular economy

The sub-models (I - III) are identical to those of the linear economy.

Sub-model (IV) describes the product characteristics: With regard to product characteristics, local transport routes are a characterising feature from an ecological perspective. As explained in sub-section 5.6.1: "Uniform products with low complexity also lead to economies of scale in the dismantling process. They are therefore preferable to those with high complexity and many variants."

Sub-model (V) describes the reverse production network: Just as the forward-oriented manufacturing network, the reverse process also necessitates a choice of converging or diverging structures. To reduce transport emissions and costs it is advised to co-locate both production stages with existing sites from the forward-oriented production network. In choosing the business model of expanding functions, as is the case here, new components are installed in the forward-oriented production network.

5.6.7 Phenotypes from a holistic sustainable perspective (G)

In the next section, the holistically sustainable phenotype of the linear economy is analysed. Expanding upon that foundation, the holistically sustainable phenotype of the circular economy is explained. Both phenotypes are mixed forms formed from the socio-economic perspective (see sub-section 5.6.4), the socio-ecological perspective (see sub-section 5.6.5) and the eco-efficient perspective (see sub-section 5.6.6).

Linear economy

The results of all previous phenotypes are used to describe the holistically sustainable phenotype. In contrast to the analysis of the perspectives (D - F), it is not the pure forms that are used for the comparison, but the mixed forms. The mixed forms already contain the results from the three pure forms. The result is shown in Illustration 5.23.

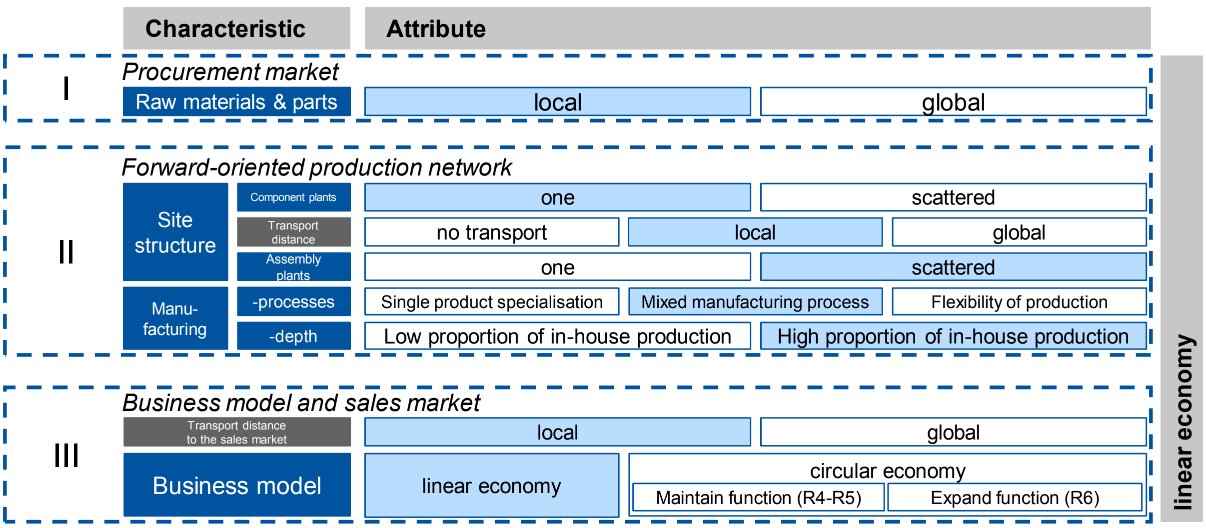

Illustration 5.23: The holistic sustainable phenotype in the linear economy

With regard to the procurement market (I), the local attribute is a characterising feature from a socio-economic and socio-ecological perspective. The choice of characteristic follows the argumentation from sub-section 5.6.4 on the socio-economic perspective: monitoring transparency is more difficult than monitoring prices, as it is more complex and cannot be easily quantified. The local focus enables the company to concentrate not only on the economic benefits, but also to take social and environmental aspects into consideration. This enables the establishment of a procurement model that considers not only the potential for short-term economic benefits, but also the long-term reliability of supplier partnerships and the associated reputational effects on end consumers.

Sub-model (II) describes the forward-oriented production network: Depending on the geographical distribution of suppliers, this leads to either a converging or diverging location structure. Analogous to the argumentation for the eco-efficient phenotype, this means that a mixed form of production should be selected. Meanwhile, a high proportion of in-house production guarantees full compliance with all environmental and social objectives. With regard to the location structure, local transport routes are the characterising feature from an ecological perspective.

From an eco-efficient and socio-ecological perspective, localisation is a characteristic feature of the sales market (III). Dispersed assembly plants are ideally suited to benefit from short transport routes.

Circular economy

In congruence with the eco-efficient phenotype, a functional expansion business model is selected. Compared to the models of pure forms, there are no inconsistencies between the characteristic features when considering the circular economy. These can therefore be adapted from the models of the pure forms. Illustration 5.24 shows the final model.

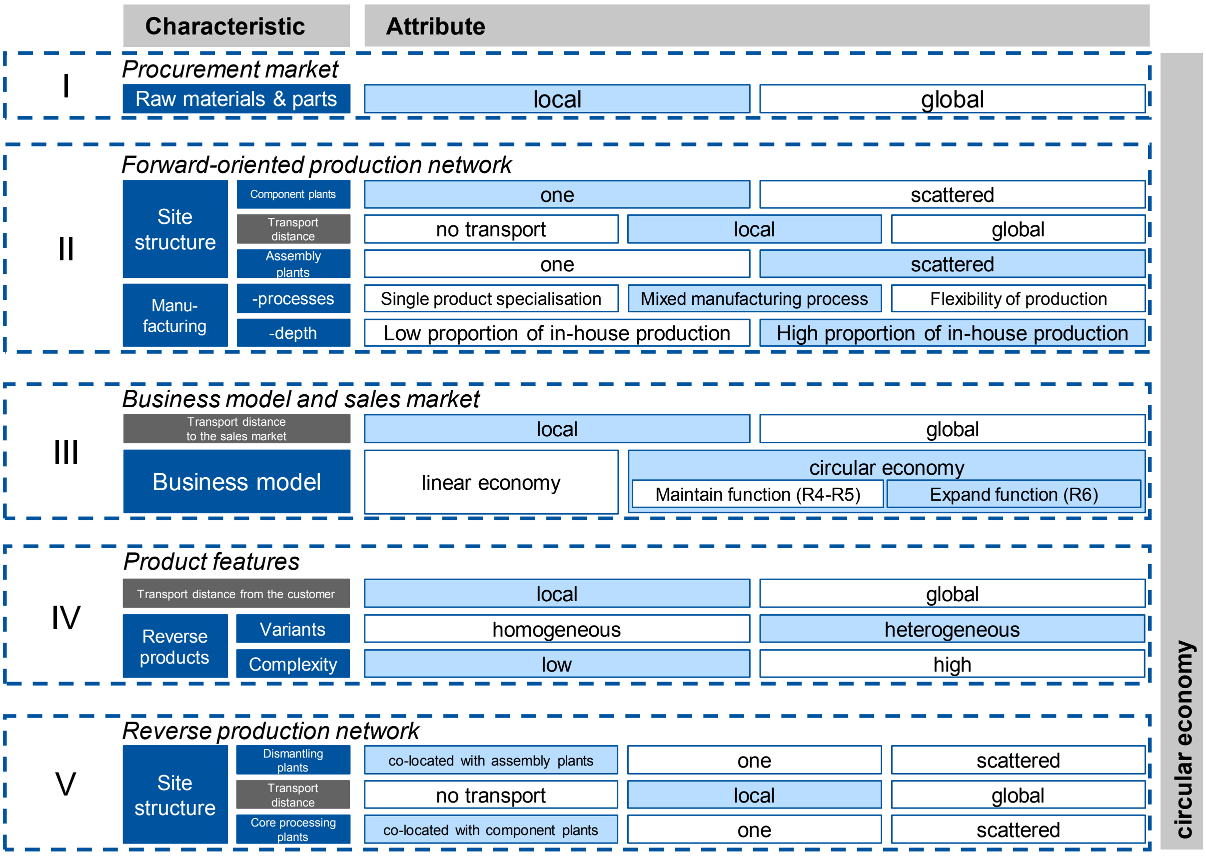

Illustration 5.24: The holistic sustainable phenotype in the circular economy

The fact that three mixed forms are considered means that there is at least a two-thirds match for binomially distributed characteristics. Theoretically, it would be possible to find differing attributes with more than two selectable characteristics for each mixed form. However, this is not the case in the model presented here.

The product characteristics are described in sub-model (IV): All three mixed forms favour the use of local transport routes for the product characteristics. With regard to heterogeneous variants, there is a consensus from both a socio-economic and a socio-ecological perspective. From an eco-efficient and socio-economic perspective, low product complexity is favoured.

Sub-model (V) describes the reverse-oriented production network: All three mixed forms exhibit identical characterising features. Consequently, dismantling and core processing plants should be situated in close proximity to the existing manufacturing sites, forming part of the forward-oriented production network. Transport distances between the plants should be kept to a minimum.

6 Summary, conclusion, and outlook

This chapter summarises and critically reflects on the results of this master thesis. Firstly, section 6.1 summarises the findings based on the structure of the previous chapters. Subsequently, section **Fehler! Verweisquelle konnte nicht gefunden werden.** reflects on the results of the work and section 6.3 gives an outlook on future research topics.

6.1 Summary

The aim of this work was to develop a system of network phenotypes taking into account the holistic sustainability dimension.

To this end, the initial situation was presented in the first chapter. Based on this, the motivation and objectives of the thesis were derived. The approach and structure of the thesis were then presented chapter by chapter.

In the second chapter, the theoretical foundations and concepts of global production networks were explained. Particular attention was paid to environmental and social sustainability. It was established that companies need to adapt the configuration of the production network due to the growing sustainability requirements of various stakeholders. As idealised network structures, phenotypes, are particularly well suited for this purpose.

The third chapter analysed the state of the art. Five approaches from the literature were presented for this purpose. These were compared with regard to six previously defined requirements. As a result, it became apparent that none of the approaches met all the set requirements. One specific research deficit that emerged was that none of the approaches took into account the business model of a circular economy, which is described in section 2.3 as an essential building block for sustainable GPNs. The structure of the methodology was adopted from the approaches to GPNs. In conjunction with the approaches from the supply chain perspective, holistic sustainability was thus described.

The concept for the solution approach was presented in the fourth chapter and described in detail in the fifth chapter. This was derived from the combination of practical and research deficits. The practical deficit resulted in the requirement to model GPNs with the inclusion of the circular economy. As idealised network structures phenotypes were to be used. However, this required an adaptation of the constituent characteristics. The building blocks for the rough concept were developed by analysing the relevant research literature. Firstly, a general description model for network phenotypes was developed on the basis of the building blocks. In the second step, a system was developed in order to relate the phenotypes to each other. The final third step was a description of all network phenotypes derived from the combination of description model and classifications. Fourteen sustainable network phenotypes were developed.

6.2 Conclusion

To summarise, it can be said that the approach developed is a good starting point for the investigation of sustainable network phenotypes. It presents 14 new phenotypes that include both existing network configurations from the linear economy and network structures in the context of the circular economy. In order to assess the extent to which the here developed approach provides answers to the questions posed in section 1.3 two test criteria are used: In the first criterion, the approach is analysed on the basis of the criteria described in section 3.1 As a second test criterion, the two building blocks of the solution approach from section 4.2 are analysed.

There were requirements regarding sustainability, classification & implementation as well as the object area. With regard to *sustainability,* the new approach ensures the comparability of phenotypes using a comprehensive concept of sustainability on the basis of the literature that covers the ecological, economic and social dimensions. The three dimensions are incorporated into the description model and form the basis for the structure of the developed system. In terms of *classifications & implementation,* the approach presented here allows an existing GPN structure to be intuitively recognised using the description model. However, although the 14 developed phenotypes provide a target structure, an explicit guideline for implementation is still missing. Furthermore, while the starting point and goal are defined, the necessary process steps still need to be determined in future research. Regarding the *object area*, the 14 newly developed phenotypes are clearly differentiated from one another, provide a target structure and are generically applicable.

When considering the second test criterion, the focus is on the description model and the system. By choosing a morphological box, the *description model* includes the entire solution space. The subdivision of the description model into the sub-models described in chapter 5.4 leads to a reduction in complexity. It is also easy to add further characteristics to the description model. The *system* is based on the well-known and well-researched sustainability triangle. The structure of the sustainability triangle clearly illustrates synergies between the linear and circular economic processes.

6.3 Outlook

Building on the findings of the present thesis, this section will present a perspective on the necessity for further research in this area.

The necessity for sustainable network phenotypes was previously discussed as part of the critical reflection in the preceding chapter. With regard to the implementation guideline, it was observed that it is currently only partially available. This gap must be addressed in the context of application-oriented research.

In this paper, it was assumed that in a circular economy, all products are always returned to the feedback production network. However, this assumption neglects goods for which transport is either not economical or which are permanently installed. An extension of the methodology is required here. In this context, the influence of mobile production facilities as described by RAUCH ET AL. (cf. sub-section 3.2.5) on the network configuration should also be analysed.

In this thesis the transportation distances are decisive for the assessment of the ecological sustainability perspective. Given the long-term planning horizons of global production networks, it is necessary to reassess this assumption as the electrification of means of transport and the generation of electricity from sustainable sources progresses.

In addition, the influence of new production processes on the structure of network phenotypes must be analysed. In the context of cloud production (cf. sub-section 3.2.5), it is possible to concentrate all production at one location without being restricted by the procurement market. This would mean a fundamental reorientation of GPN research.

7 Links to the UPV curriculum

The focus of this thesis is on the study of sustainable network phenotypes and represents the synthesis of two master's degrees. The industrial engineering degree from RWTH Aachen is comprised of a major in production engineering combined with a minor in corporate development and strategy. The Máster Universitario en Ingeniería Avanzada de Producción, Logística y Cadena de Suministro at the Universitat Politècnica de València (UPV) has a somewhat different focus. Topics covered include macro-level strategies for the design and enhancement of supply chains, as well as detailed knowledge on how to apply these strategies through the utilisation of a diverse array of tools. Thereby, the two degrees complement each other through their differing viewpoints.

Network phenotypes exist within the context of global production networks (GPNs). As Chapter 2 explains, the objective of network phenotypes is to describe, direct and optimise the coordination and configuration of a multinational company's production facilities within the context of its supply chain. Consequently, to conduct a comprehensive investigation of network phenotypes, it is essential to possess a dual understanding of both supply chain strategy and the intricacies of a production network.

A further example may be found in section 2.1.1, which outlines the theoretical background of GPNs. The section explains that there is no uniform scientific agreement on the definition of a GPN. Nevertheless, all definitions agree that a network consists of nodes and links. RUDBERG and OLHAGER highlight that, although a GPN should be regarded as a unified entity, its genesis can be traced back to two distinct sources: (i) The manufacturing network describes the internal company network, focusing on the nodes. In contrast, (ii) the supply chain describes the external network, focusing on the links. Consequently, any reference in this thesis to links, transportation, and the supply chain is directly influenced by the courses studied at Universitat Politécnica de València. The following excerpts will provide a more detailed examination of the connections between the ideas developed in thesis and the UPV curriculum.

7.1 Designing a supply chain strategy

Course: Supply chain strategy

The course on supply chain strategy presents five types of network configurations from the field of logistics. Similar to how network phenotypes describe GPNs, these configurations describe different routes between suppliers and regional warehouses. The most rudimentary of these is the direct shipment, wherein a single warehouse is supplied by a single supplier. More intricate configurations employ consolidation to achieve economies of scale. These five configurations may also be observed in the context of global value chains, where a direct shipment corresponds to the local-for-local phenotype, whereas a consolidation of shipments at the supplier's side corresponds to the hub-and-spoke phenotype.

A central element in designing a supply chain strategy is choosing a suitable production network. Once a company has made the decision to sell a specific product, it must consider the optimal design of its supply chain. The supply chain strategy course names several decisions which need to be made. An integral part to this is the make-or-buy decision. It determines which product components are to be manufactured internally and which are to be sourced externally (for further details, please refer to the section 5.4.2 and the variable "manufacturing depth"). A high degree of manufacturing depth entails an increased complexity within the supply chain. A further pivotal strategic decision in the contemporary business context is the manner in which the new product is positioned in terms of sustainability. Once these decisions have been made, a review of the 14 sustainable network phenotypes developed in this thesis can facilitate a further streamlining of the decision-making process. As only a small number of network phenotypes satisfy both criteria, this provides management with a framework for identifying which options remain viable. The management must then determine which network phenotype is most aligned with the company's long-term strategy. This network phenotype represents the objective that the company is striving to achieve. MEYER and JACOB propose an analysis of the existing production network, which can then be integrated into the universal framework. Choosing this approach provides a clear visualisation of the steps required to achieve the set goal.

7.2 KPIs

Courses: Business process management & Performance management system

Another objective of this thesis is to develop a universal framework capable of being applied by all production companies, independent of their specific business sector (for complete framework, please refer to section 5.5). To achieve this objective, the literature review draws upon sources from a number of different industries, including the automotive, remanufacturing, pharmaceutical and high-tech electronics industries. Section 5.4 provides a detailed account of the specific characteristics, including the options available within each sub-model. In order to encompass such a diverse range of products within a unified, universal framework, required creating a set of binary characteristics.

To maintain an objective external view, the variables in this model have been designed as key performance indicators (KPIs) in accordance with the principles set out in the business process management course. An illustrative example of this approach is the manufacturing depth, which is characterised by a *low proportion of in-house manufacturing* and a *high proportion of in-house manufacturing*. A global production network is comprised of multiple locations, resulting in a complex supply chain. In order to create KPIs for a supply chain, the performance management systems course recommends extrapolating from KPIs for an individual company.

7.3 Warehouse location issue

Course: Supply and distribution logistics

In determining the optimal location for warehouses and distribution centres, it is crucial to analyse the type of provisioning required. Just-in-time provisioning allows setting up operations further from the final customer than just-in-sequence provisioning. The method of provisioning must be taken into account when employing concepts such as weighted factors in a multi-criteria analysis, the centre of gravity method or the coverage method. Nevertheless, in order to ensure the sustainable provisioning of resources to production facilities, it is necessary to extend the existing quantitative analysis concepts to encompass all three sustainability factors. As previously stated in section 3.2.4, the normalisation of social sustainability factors across different companies is a challenging process, making objective comparisons of scores a difficult task. This makes it all the more important to establish a set a KPIs in this framework, to track sustainability goals.

7.4 Information sources on location planning

Courses: Supply chain strategy & Supply and distribution logistics

Theoretical concepts on network phenotypes offer a comprehensive overview and a framework for the design of GPNs. However, the real world presents decision-makers with an imperfect distribution of both information and resources between countries, regions and even municipalities, which must be taken into account. Accordingly, the course on supply chain strategy presented tools such as the Ease of Doing Business report, the Global Competitive report, and the Logistics Performance Index, which provide a concise overview of how countries compare internationally. The supply and distribution logistics course further highlights the necessity of considering additional factors at the municipal level, including the availability of transport infrastructure, the cost of labour, the attractiveness of a location to draw skilled workers from abroad, and the availability of sufficient space for potential expansions, before selecting a location.

7.5 Transportation

Course: Supply and distribution logistics

A key feature of the universal framework developed in this thesis is the factor *transportation*. It is represented by a binary variable, whereby distances of less than a certain threshold are classified as local, and distances exceeding this threshold are classified as global. It is based on an overview of the four primary modes of transportation presented in the supply and distribution logistics course. The observed trends are contingent upon the distance travelled and the weight shipped.

Road transportation is the exclusive means of transporting goods over short distances, irrespective of weight. For global distances, differentiation occurs between lightweight goods, which may be shipped via air freight, and bulky, heavy goods, which are primarily shipped via sea freight. The use of rail transport is less prevalent due to its unreliability, the necessity for double handling, and the restriction of a limited number of railroads. From an environmental sustainability perspective, both sea and air freight entail additional handling, rendering them less environmentally sustainable than local road transportation.

A further issue that arises in the context of supply and distribution logistics is that of sustainable packaging. The use of bulky, heavy, single-use packaging has an adverse impact on the sustainability of the final product. It is imperative that packaging be designed in accordance with the 10Rs, as outlined by POTTING ET AL. in section 2.2.5.

7.6 Bullwhip effect

Courses: *Supply chain strategy & Supply and distribution logistics & Supply chain simulation & Performance management system & Advanced management of production and inventory systems*

One of the most significant challenges in supply chains has been the phenomenon known as the Bullwhip Effect. Given the significance of this subject, it was incorporated into the majority of courses at UPV. The effect has multiple origins, but one of the fundamental causes is the absence of information sharing between business partners. One of the reasons for this is a lack of trust between the partners. In the context of sustainable network phenotypes, the sharing of information is of equal importance to ensure the comprehensive implementation of sustainability measures throughout the entire supply chain. Given that the OEM is the entity most closely aligned with the end consumer, it is therefore susceptible to a greater degree of reputational risk than that faced by the n-tier supplier. Consequently, multinational corporations that lack trust in their suppliers may be compelled to pursue a high degree of vertical integration in order to maintain control over all pertinent sustainability issues. As previously stated in section 5.4.2, the maintenance of trust between business partners is more readily achieved when the distance between them is minimal.

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VI Rúbrica para la evaluación de los TFM

Rúbrica para la evaluación de los TFM (a rellenar por el estudiante)- Ver instrucciones al final

Nombre Estudiante: Felix Benedikt Constanz Robiné   Curso: 2022/23

Resultado	Competencia Verifica	Aspecto		Excelente	Bien	Regular	Insuficiente
Elaboración	CB6	Conocimientos			x		
	CB10	Aprendizaje					
Estructura		Resumen		x			
		Índice					
		Desarrollo	Contextualización				
			Objetivos				
			Metodología				
	CB8 y CB9	Conclusiones					
		Bibliografía					
Redacción		Fluidez		x			
		Léxico					
		Referencias y citas					
Contenido	CB7	Originalidad		x			
		Aplicabilidad/Avances					
		Dificultad					
		Intensidad del trabajo					
Defensa	CB8 y CB9	Comunicación		x			
		Material empleado					
		Aportación					

Competencias Generales alcanzadas: Dejar sin rellenar las competencias no relacionadas con el TFM	Excelente	Bien	Regular	Insuficiente
5 Aptitud para la Identificación de Alternativas en la Logística, la Cadena de Suministro y sus Estrategias.	X			
6 Aptitud en la Definición y Evaluación de distintas alternativas para la Logística de Aprovisionamiento.		X		
7 Capacidad de desarrollar estrategias innovadoras para la Gestión de la Cadena de Suministro.	X			
8 Destrezas en el Modelado de la Cadena de Suministro mediante Arquitecturas y Marcos de Referencia.				
9 Destrezas en la gestión de procesos de negocio y sus herramientas para la gestión de la cadena de suministro				
10 Destrezas en la Definición de Sistemas de Medición del Rendimiento en la orientación a procesos de negocio. Metodología y herramientas.		X		
11 Conocimiento de la Gestión del Transporte, sus Infraestructuras y Medios en el contexto de la cadena de suministro.		X		
12 Capacidad para utilizar las tecnologías de la información y las comunicaciones para la mejora de los Sistemas Logísticos y de la Cadena de Suministro				

Competencias Específicas alcanzadas: Dejar sin rellenar las competencias no relacionadas con el TFM	Excelente	Bien	Regular	Insuficiente
13 Conocer e identificar el nivel de relaciones de interdependencia (colaboración) en los procesos de Planificación, Previsión y Reaprovisionamiento en la cadena de Suministro.				
14 Destrezas en el modelado avanzado de distribución y su gestión de inventarios (inventarios multiescalón), así como en los algoritmos de optimización y heurísticas.				
15 Capacidad de diseñar e implantar sistemas avanzados de producción en sistemas de producción e inventario.				
16 Destreza en la Identificación de las Relaciones entre actores de Cadena de Suministro y su implicación en cuanto a la interoperatividad de las TIC		x		
17 Aptitud en la Definición y Evaluación de distintas alternativas para la Logística Interna, con especial atención a la manutención y al almacenaje, así como a sus equipos.				
18 Conocimiento de las distintas tipologías de operadores logísticos en la cadena de suministro, mediante la identificación y la comparación de los operadores 3PL y 4PL.				
19 Aptitudes para la identificación y evaluación de distintas alternativas de transporte terrestre, marítimo y aéreo, con especial atención a su manutención y almacenamiento y procedimientos específicos.				
20 Conocimiento de la Economía de la Logística y el Transporte, y de las metodologías y herramientas para la evaluación de distintas alternativas logísticas y de transporte.				
21 Destrezas en el Modelado Cuantitativo y Resolución de los Problemas de Gestión en la Cadena de Suministro, con especial atención tanto a la planificación agregada como a la maestra en contextos centralizados y distribuidos.				
22 Destrezas en el análisis del funcionamiento de los sistemas productivos mediante su Simulación, a través de las correspondientes aplicaciones informáticas.				
23 Aptitudes en planificación y programación de producción en entornos distribuidos, mediante sus correspondientes modelos, algoritmos y metaheurísticas.				
24 Destrezas en la Secuenciación y Equilibrado Avanzado en sistemas de producción, mediante los correspondientes modelos y algoritmos de resolución.				