*sustainability*

Article

# Bioeconomic Clusters—Background, Emergence, Localization and Modelling

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Received: 15 July 2019; Accepted: 21 August 2019; Published: 24 August 2019

**Abstract:** Industrial Clusters, especially those based on biologically sourced materials and their derivative products, can play an important role in the global shift to more sustainable production methods and ecological economic systems. The concept of cluster, however, is difficult to define and study. This paper presents quantitative methods based on Input-Output and Operations Research analysis to establish and plan cluster operations and complement that with qualitative reflections on the nature of these clusters. The purpose is to bring together both dimensions and demonstrate their complementarity, with social and policy aspects being as important considerations as techno-economic-driven ones. Using a case study, hypothetical clusters using numerical methods are created; the clusters produced by numerical methods point to and raise important issues related to the need to utilize qualitative analysis in conjunction to pure economic motives while designing/planning industrial clusters.

**Keywords:** industrial symbiosis; input-output modelling; operations research; environmental economics

## 1. Introduction

The European Commission defines bioeconomy as "the part of the economy that uses renewable biological resources ( . . . ) to produce food, materials, and energy." (Bioeconomy. https://ec.europa.eu/research/bioeconomy/index.cfm. Accessed July 2019) It is considered part of the economic system of a region, nation or, if talking about the global bioeconomy, the world.

Considering Environmental economics [1], costs and benefits of alternative environmental (market-based) policies are key topics, particularly since such policies affect toxic water and air emissions, production of waste, climate change, etc. [2]. Among these policies, and of chief interest to us, are those incentivizing biotechnological advances and the ensuing design, creation and operation of industrial clusters [3], particularly those consisting of bioeconomic industries (BEIs). BEIs are characterized as being either primary industries that harvest, extract or capture biological raw materials (crops, livestock, lumber, fish, etc.), or industries that use these raw materials directly as part of their production process (food processing, biotechnological products, and so on.)

Clusters, by definition, should provide economic benefits such as lower transaction costs, knowledge sharing, ready availability of products and shared infrastructure [4]. Additionally, if organized and as effective circular economic systems, BEI clusters can improve resource efficiency, minimize emissions and waste, and provide wider social benefits to the cluster location, such as facilitation of sustainable resource use. It is then a key concern of cluster design and administration to achieve effective circular economic benefits if sustainability is a goal.

Found in Sweden and other Nordic countries, there are many examples of BEI clusters acting in what is called an Industrial Symbiosis [5,6]. Industrial symbiosis is a form of industrial organization characterized by an industrial ecosystem in which industries and businesses share natural resources, by-products like biowaste, and production infrastructures for mutual economic, social and environmental gains. Taken from this "Nordic perspective", governments strive to turn their economies into circular-and sector-based, rather than sector-specific, supporting environmentally sustainable transitions [7]. Collaboration is not only crucial at local, regional, and national levels, but across levels too. According to the Nordic Bioeconomy Programme, the Nordic bioeconomy should contribute to upgrading residues, by-products and waste to higher value products and services, and to optimize the utilization and value of biomass [8].

Bioeconomic clusters are discussed here: their various definitions, how they emerge; and how Input–Output (I–O) and operations research (OR) approaches can be used together with other cluster formation studies to find optimal composition and location. A case study based on quantitative data strategies to localize and design clusters is provided, and the results of said method are discussed from a qualitative point of view and then deliberate both viewpoints. The research question can be formulated explicitly as "How, and to what extent, can the analysis of bioclusters and their benefits to sustainable production be supported with Operations Research methods?"

This article is organized as follows: the qualitative and quantitative dimension in cluster analyses is continued to be discussed in the Introduction. The Methodology and Methods section discusses I–O and OR methods used for quantitative experiments. Said experiments, using empirical data from Norway, demonstrate in the Results section how this methodology might be used to identify cost-efficient locations and compositions of bioeconomy clusters. Numeric findings are examined and connected to the qualitative dimension in the Discussion section, finishing with some remarks in the Conclusions section.

## 2. Qualitative Dimension: Cluster Classifications

Cluster development is a global policy trend [9] that has its roots in theories about the benefits of industrial agglomeration; co-location provides a common, specialised labour market, low transport cost and industrial knowledge. Regarding economic theory, the benefits are described, for instance, as reduced emissions and waste, spill-over effects, infrastructure and knowledge-sharing [10].

Clusters can be characterised in several ways, depending on which are the focal properties. One cluster can be defined as a value chain or as a group of business relationships which can stretch out globally, nationally, or regionally; or it can be a clump of enterprises belonging to the same industry and located within a community [11]. This difference is important as critical views on clusters (and cluster-focused analysis) are derived from lack of a coherent definition of the term and the "many ambiguities, identification problems, exceptions and extraneous factors" that make measurement of effects and comparison between clusters complicated [12]. The term cluster can be used to refer to a handful of facilities located in a single industrial park, for example, or to describe industrial sectors at a national level, such as the Norwegian oil-and-gas or the Norwegian maritime clusters [10]. A combination of these interpretations is used for the purposes of the latter case study: a national scope, but with a focus on individual, interlinked industrial processes.

Historically, clusters have grown in a geographical area through the development of collaborating and competing enterprises, specialised in a field, and linked by common technologies, skills and value chains. A well-known example of these "organically grown" clusters is Silicon Valley, whose initial enterprises were spin-offs from NASA and the aviation research sector [13]. Conversely, there are "supported clusters": enterprises linked together through an organisation administered by a cluster manager, often initiated as an innovation policy tool [14]. The management of these clusters is partially or fully supported by public funding and usually includes enterprises, public bodies for industrial support and development policy, and academic institutions. This "triple helix" structure of industry, public policy and science and is intended to promote regional innovation and development.

The cluster manager aims to build networks and trust in the project and facilitate collaboration and flow of knowledge, thus stimulating innovation. Examples of supported BEI clusters in Norway are the Norwegian Centres of Expertise (NCE) Seafood Innovation Cluster and NCE Heidner.

Another relevant categorisation of clusters is based on dominant policy rationale. Discussed in [15,16] the authors identify three groups of cluster policy models, each prioritising different aims [17]. First, there is the "Mega Cluster", prioritising industry competitiveness. National clusters such as the Norwegian Oil-and-Gas Cluster mentioned above is one example. There is then the "Local Network Cluster", which is based on regional industrial density. This category is arguably the one most targeted by regional innovation policies, and the public support system aiming to develop "triple helix" structures and smart specialisation processes [9]. Looking at Norway, the development of Arena and NCE clusters (Figure 1) are examples of Local Network Clusters.

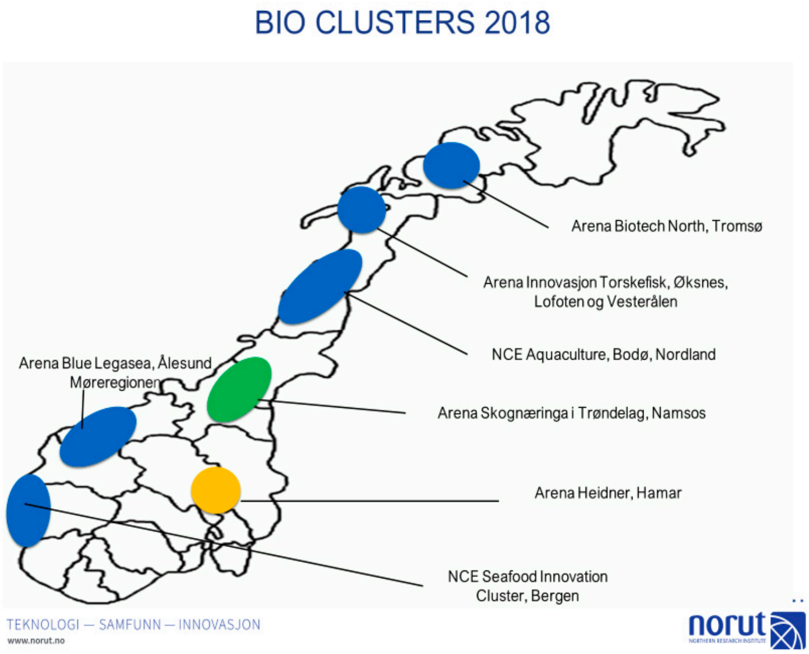


**Figure 1.** Bioclusters in Norway, October 2018.

Finally, the "Knowledge-Based Cluster" prioritises innovation. An example of this kind of cluster is the GCE Blue Maritime (GCE vision statement, https://www.bluemaritimecluster.no/gce/the-cluster/our-blue-vision) cluster, which defines itself as a knowledge-based cluster aiming to be world leading and the most innovative knowledge and competence cluster in advanced maritime operations.

The classifications above, however, are admittedly not clear-cut. According to several studies, most clusters evolve organically, from spontaneously generated clustering and are then followed by policy-support efforts; i.e., they evolve from natural to supported clusters. Political promotion of clusters can mean very different things in different contexts and cluster policy can be regarded as a form of "umbrella policy" including a combination of different policy instruments [17]. According to the Norwegian cluster program, membership in a cluster stimulates collaboration [18]. This experience, however, is not universal: studies of European clusters indicate that there is less interaction between businesses located in the same area than cluster theory assumes, and that non-local networks are more important for flow of knowledge [19,20].

Nevertheless, the concept of BEI clusters has become a key focus of analysis in urban and regional economic development, and it attracts a broad range of interest groups, from academics and consultants to policymakers concerned with promoting regional growth [21]. The concept, while not without its critics, is still today a significant part of regional development for both academics and practitioners.

Cluster-based policies have been adopted by a broad range of organizations as an integral part of industrial and regional policies.

To understand the functioning of regional bioeconomy strategies, policies, and activities, it is important to analyse how the regional BEI clusters are structured. Regarding [22] an illustration of the organisational structure of a biocluster is seen, in which bioeconomy entrepreneurs, policy makers willing to support the bioeconomy, and bioeconomic R and D institutes, have been considered as main actors. These are complemented with provisions on biomass resources and competitive bioeconomy products ([23], adapted from [22]).

The classical [11] definition describes clusters as geographic concentrations of interconnected companies and institutions within a particular economic sector. According to [24], industrial clusters can be described by way of several other concepts, chief among them that of "Eco-industrial Parks". Industrial clusters then, as long as they can be identified with such eco-industrial parks, have their roots in Industrial Ecology, which has as basic characteristics (a) a holistic view of the system, (b) an emphasis in the biological and material flows within and outside the system, and (c) a consideration of technology dynamics and future development.

Further, ref. [24] also includes mentions to industrial clusters characterized as a either a community of businesses cooperating to gain higher benefits that they would by themselves [25,26], or as systems in which resources are exchanged considering efficiency of operations [27,28]. Both these definitions choose to interpret "benefits" and "efficiency" as wide-raging concepts, consisting of more than economic profits, but rather as social, environmental and economic gains from the cooperation/coordination of the activities of the members of the cluster. This leads to the concept of Industrial Symbiosis (IS).

Considering the literature on IS, scholars use the following main categories to describe possible models of IS emergence (although in practice these categories can overlap): (1) self-organization; (2) facilitation by organizations or individuals; and (3) top-down planning [28]. It can be assumed that these models of IS emergence could be applied to emergence of bioeconomy clusters, too.

There is a variety of studies on industrial clusters, as discussed in [29]. While some studies focus on already established clusters and the extent to which they fulfil their objectives (economic or otherwise), others present more quantitative analyses. The studies in [29], as well as others named here, often present several different theoretical approaches, including systems theory, philosophy, ecology, sociology, and economics.

## 3. Quantitative Dimension: Economics and Optimization

Just as there are many ways to define and classify clusters, there are also different analytical tools to study their economic performance and logistical organization. Here, some background on the methods the authors have chosen to apply is given—I–O analysis and OR—both of which are widely used in logistics and production planning.

### *3.1. Input–Output and Cluster Analysis*

I–O analysis uses accounting tables for predictions on large, usually heavily interconnected economic systems. They are straightforward and easy to compute: each intersection of a column/line in a table represents an economic transaction between economics sectors. The level of aggregation varies considerably but typically follows some national or international standards.

I–O tables are derived from macroeconomic supply-use tables, based on the assumption of fixed product sales structure and production patterns. The table's entries in each column and row corresponds to every industrial sector in an economy. Hence, a column shows how much money is paid to a sector, and the row correspondingly shows how much money is paid from that sector.

Ref. [30] describes a process for identifying existing clusters in a reduced input–output network, based on economic I–O tables. The full network is reduced by way of cut-offs, first removing weak links and then restricting the network to significant sectors. Information from I–O tables is used to identify optimal location and composition for new clusters to be established in the approach used here.

Ref. [30] also shows how I–O methodologies can be applied to cluster analysis. It must be said, though, that the application of I–O tables made here, using NACE classification codes, is only one of many ways to obtain conversion matrices to model production process. National I–O tables provide good starting points for a case study like the one herein presented, but real-life studies no doubt have to rely on more precise information on production processes, likely specific to the type of facilities considered for a cluster.

### 3.2. Clusters Analysis with OR Methods

OR models can be summarized as the mathematical relations between available resources (raw materials, time, workload, capital, energy) and the constraints imposed on those resources (technical production processes, conservation/sustainable farming), working to optimize a given objective (minimize emissions or transportation time, maximize synergic interactions etc.) Specifically, in this work Mixed–Integer Linear Programming is applied, which combines continuous and binary (yes/no) decisions, to model both the operation and strategy of clusters.

According to [31], OR methods for the natural resource sector have evolved into a complete and new field of study. The authors describe OR methods applied to the BEIs agriculture, fisheries and forestry. Despite rather different time scales, objectives and resources, these applications all have in common considerations for the environment and multi-criteria approaches. Linear and non-linear programming approaches are used, e.g., in a multi-objective LP model for forest management in [32], and a cost-efficiency model linking farming nutrients, livestock, land use and water quality [33].

The works in [29,34–36] deal with water exchange and pollution. Pollution and emission reduction are also key topics in [34,37–40]. Conversely, refs. [4,41] focus on economic indicators using OR and economic analyses. Economic feasibility of a cluster is also the main concern in [36,37,40,42]. Finally, ref. [29] discuss OR applications for cluster design and allocation.

## 4. Materials and Methods

OR approaches such as optimization models help to find optimal locations and compositions of industrial clusters, based on information about available resources, potential interactions and exchanges between industrial actors, demands for the sectors' products and other model parameters such as purchase and sales prices, operational and transportation costs, capacities. Typically, this data is gathered from different sources and might, therefore, be represented in various formats, levels of aggregation and units. This means some effort often is needed to harmonize all information. To describe product exchange between actors in an industrial cluster, information can be obtained by either collecting on-site data from existing facilities, or by deriving data from statistics with a national perspective. Like [30], the latter approach is followed here, and industrial exchange relationships are quantified by way of publicly available national I–O statistics. To facilitate data gathering and sharing of results, standardized sector aggregations such as the NACE standard are used. Hence, their aggregation level should be adapted to the analysis at hand, also balancing against availability and granularity of other data and the complexity of the analysis model. Obviously, for analyses focusing on bio-economics, I–O data should be more detailed on such industry sectors, while they can be aggregated more heavily for the rest of the economy.

Prior to being parametrized for the OR model, the I–O tables and other data-sources used in the case study presented below, need to be pre-processed according to the following steps:

1. Sector and location definition. Determine a suitable aggregation level of bioeconomic BEI sectors and potential cluster locations and define the according sector division based on the aggregation level in the I-O statistics to be used.
2. Data collection, which involves the aggregated I–O tables, resource availability in each location, suitable conversion data from monetary values to volume units, and import/export considerations

3. I–O data adaptation. Based on the chosen sector definition, aggregate the I-O statistics and derive relative values or shares describing economic exchanges between the sectors and conversion between products. It is assumed, for simplicity, that facilities of each type in all clusters have similar production ratio of inputs to outputs
4. Economic value conversion. Estimate the economic value of each sectors' output available for use by the sectors at each location, based on the physical and economic values determined in step 2.
5. Demand estimation. Estimate demand for each sector's products at each potential location in economic terms.

Further, it is assumed that the single industrial actors considered for cluster formation are representative for their according industrial sector. The share of inputs acquired by a facility from another facility is assumed to be the same as the share of these goods exchanged between the corresponding sectors, measured in economic terms, and converted into relative numbers, in other words. This way, the magnitude of potential goods exchanges in a cluster formed by industrial actors from several sectors can be estimated. These economic estimates are later converted to absolute quantities and volumes using production statistics, to relate the potential exchanges to production capacities and other physical characteristics in an optimization model.

*Optimization Model*

The optimization model used is a Mixed Integer Linear Program that provides optimal solutions by defining, of all possible locations, which ones will have a cluster built, and what facilities of what size will be included in each.

The model is based on a network of geographical locations, or nodes, which can be either harvesting nodes (where raw materials are harvested/caught), cluster nodes, (where facilities might be built), or costumer nodes (where products are sold to end-users). A single location might have one, two or all three types of nodes. Elements of dynamic facility location problems [43] are incorporated, in combination with a supply chain network design problem where investments, resource availability and costs, and transport affect each other.

Refer to [44] for a detailed mathematical description and analysis examples demonstrating model capabilities on a finer scale, the main decision variables include:

- Cluster establishment in any given (cluster) node
- Facility establishment in any given established cluster
- Harvesting volumes in each (resource) node
- Transport volumes and costs between nodes

Values for these variables are obtained by solving the set of equations aimed at maximizing the combined profits for all the clusters, defined as the difference between revenues and costs. The latter consists of investment, harvest, transportation, purchase and operational costs for the clusters and facilities in them, while the former assumes everything which is harvested or produced is sold for its monetary value.

The model's constraints concern harvesting, transportation, production and consumption. Production and conversion from input to output products is formulated as a linear combination of product volumes, derived from the I–O tables. Finally, consumption at consumer nodes must match sales, bounded by demand limits given at national or local levels.

## 5. Results

To illustrate the methodology, we have performed a case study based on Norwegian data. These results will then be compared with former experiences on cluster formations in the country in the discussion chapter.

### *5.1. Input Data Preparation*

Below, the information for this case is organized according to the steps described above:

The definition of sector aggregation (step 1) is done following [45]: the industrial sectors listed in NACE are grouped according to whether they are BEIs, closely connected to BEIs, or other. This is shown in Table 1 below.

**Table 1.** Sector aggregation used in this work.

| Sector | Type | NACE Classification |
|---|---|---|
| 1 | Agriculture | 1 |
| 2 | Forestry | 2 |
| 3 | Marine industries | 3 |
| 4 | Processing, agriculture and marine industries | 10, 11, 12 |
| 5 | Processing, forestry | 16, 17 |
| 6 | Other related processing industries | 13, 14, 15 |
| 7 | Biotechnology | 20.14, 20.59, 21, 22, 71.20, 72.11, 72.19, 77.40 |
| 8 | Production of machines and equipment for bioeconomy processing industries | 28.93, 28.95 |
| 9 | Energy production and distribution | 35.113, 35.114, 35.21, 35.3 |
| 10 | Recycling | 38, 39 |
| 11 | Trade | 46.2, 46.3, 46.61, 46.692 |
| 99 | Non bio-economic related | All Others |

Detailed data for Norway is often given at county level. Regarding the case study, therefore, a total of 18 potential cluster locations are used, roughly corresponding to the counties and represented by the counties' administrative centres.

Data collection (step 2) uses supply volumes data in physical terms based on [46] for the primary bioeconomic resources. Transport distances and costs between the potential locations are based on data from the National Road Database (https://www.vegvesen.no/en/Professional). This database contains data for each road segment, both regarding its physical properties and its regulations (e.g., maximum speed, total weight, length and height of timber trucks). The road data is aggregated to a network with a node for each municipality centre and road links to all neighbouring centres based on the shortest path using national and county roads. The I–O tables were obtained from the more recent tables from Statistics Norway [47]; because the values will be used in relative form, the mismatch in dates is not considered a problem.

To adapt I–O data (step 3) the I–O tables are aggregated according to this study's classification. Table 2 shows an abbreviated version of the table, highlighting the first three (i.e., primary) sectors, with the complete table in Appendix A. These values will be transformed into relative values to create conversion matrices for use in the optimization model's production functions.

**Table 2.** National Input–Output table for primary bioeconomic sectors (MNOK).

| | 1 Agriculture | 2 Forestry | 3 Marine Industries | Total (All Sectors) |
|---|---|---|---|---|
| 1 Agriculture | 1386 | 27 | 33 | 42,739 |
| 2 Forestry | 221 | 1661 | 2 | 5604 |
| 3 Marine Industries | 46 | 0 | 5096 | 27,894 |

When it comes to converting physical to economic values (step 4), combining the aggregated I–O table with information on the sectors' total supply in physical terms allows us to derive factors stipulating how much each tonne of a sectors' output product mix is worth in monetary terms. Then, it is possible to estimate the economic value of each sectors' output at each potential location (columns 3, 5, and 7 in Table 3).

**Table 3.** Primary bioeconomic sectors' supply per county.

| | 1 Agriculture | | 2 Forestry | | 3 Marine Industries | |
|---|---|---|---|---|---|---|
| | Supply [1000 Tonnes] | Economic Value [MNOK] | Supply [1000 Tonnes] | Economic Value [MNOK] | Supply [1000 Tonnes] | Economic Value [MNOK] |
| Østfold | 441 | 3191 | 564 | 610 | 0 | 0 |
| Akershus and Oslo | 420 | 3039 | 564 | 610 | 0 | 0 |
| Hedmark | 793 | 5738 | 2309 | 2497 | 0 | 0 |
| Oppland | 798 | 5775 | 1002 | 1084 | 0 | 0 |
| Buskerud | 270 | 1954 | 772 | 835 | 0 | 0 |
| Vestfold | 274 | 1983 | 232 | 251 | 0 | 0 |
| Telemark | 124 | 897 | 430 | 465 | 0 | 0 |
| Aust-Agder | 63 | 456 | 251 | 271 | 0 | 0 |
| Vest-Agder | 109 | 789 | 176 | 190 | 0 | 0 |
| Rogaland | 776 | 5615 | 107 | 116 | 304.19 | 1928 |
| Hordaland | 219 | 1585 | 145 | 157 | 264.25 | 1699 |
| Sogn og Fjordane | 274 | 1983 | 142 | 154 | 340.81 | 2138 |
| Møre og Romsdal | 430 | 3112 | 178 | 193 | 602.48 | 3639 |
| Sør-Trøndelag | 547 | 3958 | 338 | 366 | 205.42 | 1361 |
| Nord-Trøndelag | 701 | 5073 | 467 | 505 | 104.09 | 779 |
| Nordland | 338 | 2446 | 141 | 153 | 705.41 | 4230 |
| Troms | 116 | 839 | 6 | 6 | 483.62 | 2957 |
| Finnmark | 51 | 369 | 7 | 8 | 285.68 | 1822 |
| Total | 6744 | 48,802 | 7830 | 8470 | 3625.53 | 20,553 |

Finally, demand at cluster locations (step 5) need to be estimated., Demand for the sectors' output products can be specified on a national level or regionally, by county, in the model. Considering regional demands, the authors estimate them by taking the national demand as a starting point, and distributing it among each country according to its population, as indicated in Table 4.

**Table 4.** Population and economic value of primary bioeconomy sectors' demand per county, year 2016.

| County | Population | | Demand for Sector Products [MNOK] | | |
|---|---|---|---|---|---|
| | Absolute | Relative | 1 Agriculture | 2 Forestry | 3 Marine Industries |
| 01. Østfold | 289,867 | 5.56% | 48,201 | 6993 | 38,940 |
| 02. Akershus | 594,533 | 11.40% | 2680 | 389 | 2165 |
| 03. Oslo | 658,390 | 12.63% | 5496 | 797 | 4440 |
| 04. Hedmark | 195,356 | 3.75% | 6086 | 883 | 4917 |
| 05. Oppland | 188,953 | 3.62% | 1806 | 262 | 1459 |
| 06. Buskerud | 277,684 | 5.33% | 1747 | 253 | 1411 |
| 07. Vestfold | 244,967 | 4.70% | 2567 | 372 | 2074 |
| 08. Telemark | 172,494 | 3.31% | 2265 | 329 | 1830 |
| 09. Aust-Agder | 115,785 | 2.22% | 1595 | 231 | 1288 |
| 10. Vest-Agder | 182,701 | 3.50% | 1070 | 155 | 865 |
| 11. Rogaland | 470,175 | 9.02% | 1689 | 245 | 1364 |
| 12. Hordaland | 516,497 | 9.91% | 4347 | 631 | 3511 |
| 14. Sogn og Fjordane | 109,530 | 2.10% | 4775 | 693 | 3857 |
| 15. Møre og Romsdal | 265,290 | 5.09% | 1013 | 147 | 818 |
| 16. Sør-Trøndelag | 313,370 | 6.01% | 2452 | 356 | 1981 |
| 17. Nord-Trøndelag | 136,399 | 2.62% | 2897 | 420 | 2340 |
| 18. Nordland | 241,906 | 4.64% | 1261 | 183 | 1019 |
| 19. Troms | 164,330 | 3.15% | 2236 | 324 | 1807 |
| 20. Finnmark | 75,758 | 1.45% | 1519 | 220 | 1227 |
| Total (national) | 5,214,000 | 100% | 48,203 | 6986 | 38,932 |

### *5.2. Case Analysis and Results*

To test how different assumptions underlying the model affect cluster formation, the optimization model was applied to the six scenarios described in Table 5. These scenarios varied in their demand specification (national or regional) and how resource availability was bounded by sustainable, minimal or benchmark values. Bounds on resource utilization should, ideally, be calculated with emphasis on sustainable utilization, although, in this example historic production figures from sustainable-managed regions are used. Additionally, transport costs were particularly difficult to estimate when considering different sectors, therefore, scenarios with reduced transportation costs were considered also.

**Table 5.** Six scenarios for case analysis.

| **Scenario Definition** | | **Scenarios** | | | | | |
|---|---|---|---|---|---|---|---|
| | | **1** | **2** | **3** | **4** | **5** | **6** |
| Consumption is specified/demanded regionally, rather than nationally. | | x | | | x | x | x |
| Harvesting of resources at resource points: | Upper bound on harvesting | x | x | | | | |
| | Lower bound on harvesting | | | | x | x | |
| | Harvesting is penalized if deviates from benchmark | | | x | | | x |
| Transportation costs are halved to test sensitivity | | | | | | x | x |

Legend: x designated whether a particular consideration has been taken in an scenario.

Localisations and structural properties of the clusters, rather than quantitative details such as product flows within and between clusters or economic performance, are the focus for the discussion below, thus mostly avoiding listing numerical results here. Table 6 shows which locations were found optimal for establishing a cluster and which industry sectors these clusters should comprise under the respective scenario assumptions.

There are some things which are immediately apparent from the data above. First, only a handful of counties are selected from among the options to have clusters built in generally all cases. Finnmark in the far north, Oppland and Hedmark in the central east, and many counties in the south and east, are absent from the cluster selections. Counties omitted from the cluster list include both small and large ones (in population terms), as well as some with large resources, such as Hedmark's forestry output, or Nord-Trøndelag's agriculture.

Second, food processing (sector 4) is present in all clusters, in all scenarios. This is plausible, as all clusters have access to either agriculture or marine biomass sources. It is also realistic, as Norway has some aspects of protectionism regarding its food-production industry.

It is interesting that processing of forest resources (sector 5), appears in a single cluster in just two scenarios, and never in all clusters. Despite the sizeable logging resources in most counties, scenarios 2 and 3 show only one facility belonging to sector 5. Again, this is arguably due to how transport costs are modelled and, in scenarios 2 and 3, the ease of getting products from sector 5 to consumers anywhere in the country.

Industries in sector 7 Biotechnology are also widely represented. Only in scenarios 2 and 3 are there fewer of them. Biotechnology thus arises as an important industrial sector, especially in Akershus and Oslo, Hordaland, and Sør-Trøndelag.

Generally, location-specified demand leads to more clusters being established; it is also the only case in which regions such as Troms get one cluster. Additionally, the lower the transport costs, the less clusters are achieved. While logical, this highlights the importance transport costs might have on the results.

**Table 6.** Suggested cluster locations and sector composition under different model assumptions. Sector codes are 1: Agriculture, 2: Forestry, 3: Marine industries, 4: Processing, agriculture and marine industries, 5: Processing, forestry, 6: Other related processing industries, 7: Biotechnology, 8: Production of machines and equipment for bioeconomy processing industries, 9: Energy production and distribution, 10: Recycling, 11: Trade.

| Scenario | Description | Suggested Cluster Locations | Sectors (Other Than Primary) |
| --- | --- | --- | --- |
| 1 | Regionally specified demand, resource statistics as upper limit | Akershus and Oslo | 4, 5, 6, 7, 8, 9, 10, 11 |
| | | Rogaland | 4, 5, 6, 7, 8, 11 |
| | | Hordaland | 4, 7, 8, 9, 11 |
| | | Sør-Trøndelag | 4, 6, 7, 8, 9, 11 |
| | | Nordland | 4, 5, 6, 7, 8, 9, 10, 11 |
| 2 | Resource statistics as upper limit | Akershus and Oslo | 4, 6, 7, 8, 9, 10, 11 |
| | | Sogn og Fjordane | 4, 6, 7, 11 |
| | | Møre og Romsdal | 4, 6, 8, 9, 10, 11 |
| 3 | Resource statistics as benchmark to adhere to | Akershus and Oslo | 4, 5, 6, 7, 8, 9, 10, 11 |
| | | Møre og Romsdal | 4, 6, 11 |
| | | Nordland | 4, 6, 7, 8, 9, 10, 11 |
| 4 | Regionally specified demand, resource statistics as lower limit | Akershus and Oslo | 4, 5, 6, 7, 8, 9, 10, 11 |
| | | Vestfold | 4, 6, 7, 11 |
| | | Rogaland | 4, 7, 8, 11 |
| | | Hordaland | 4, 5, 6, 7, 8, 9, 10, 11 |
| | | Møre og Romsdal | 4, 7, 8, 11 |
| | | Sør-Trøndelag | 4, 5, 6, 7, 8, 9, 10, 11 |
| | | Nordland | 4, 5, 6, 7, 8, 9, 10, 11 |
| | | Troms | 4, 7, 8, 11 |
| 5 | Regionally specified demand, resource statistics as lower limit, reduced transportation costs | Akershus and Oslo | 4, 5, 6, 7, 8, 9, 10, 11 |
| | | Rogaland | 4, 6, 7, 8, 11 |
| | | Hordaland | 4, 5, 7, 8, 9, 11 |
| | | Sør-Trøndelag | 4, 6, 7, 8, 9, 10, 11 |
| | | Nordland | 4, 5, 7, 8, 9, 11 |
| 6 | Regionally specified demand, resource statistics as benchmark to adhere to, reduced transportation costs | Akershus and Oslo | 4, 5, 6, 7, 8, 9, 10, 11 |
| | | Rogaland | 4, 6, 7, 8, 11 |
| | | Hordaland | 4, 5, 7, 8, 9, 11 |
| | | Sør-Trøndelag | 4, 6, 7, 8, 9, 10, 11 |
| | | Nordland | 4, 5, 7, 8, 9, 11 |
| | | Troms | 4, 7, 11 |

## 6. Discussion

The results obtained by the quantitative methodology, as presented in the Methods section, are looked at and discussed, first from a technoeconomic point of view, and then a qualitative perspective more akin to that presented in the Introduction.

The clusters suggested have a numeric/economic justification behind them, i.e., given the assumptions and data above, these clusters and their composition is the optimal. Using precise resource, transport and costs, as well as productivity estimations, one could argue there are no cluster strategies giving a better profit for the participants.

It can be seen, for example, that while Norway has extensive forest resources, there is little activity in sector 5 (forest processing) in most cases. Once the economic values table is looked at, however, it is easy to see that sector 5 contributes very little, in absolute terms, to the overall profits, and will only do so when local demand and transport costs are ideal. This, however, does not mean that industrial activity in sector 5 is not profitable at all, but rather, that under the parameters in this study, the sector is not suitable for cluster inclusion.

Conversely, even though Norway has very little arable land, sector 4, Processing of food, is included in most clusters in most scenarios. The same applies to sector 7, Biotechnology. These sectors have a very high end-value and, thus, are preferred when it comes to investment in cluster facilities. Notice, however, that this analysis is a single period run of the model, which can say little about parameters which are sensitive to changes over long periods of time, such as population growth (and thus changes in consumption patterns) and changes in technology (possibly cheapening biotech products).

The results above focus on quantitative methods in analyzing bioeconomic clusters. Nevertheless, the latter two, taken the numerical results, highlight the need for further modelling, crucially, the inclusion of non-quantitative parameters. Argued already in the Introduction, economic performance is neither the only reason to have a biocluster strategy, nor is said strategy always a centrally defined plan. Organically created bioclusters might not be economically optimal, yet the reason they exist points to other concerns in their establishment and operation.

Many of these issues related to the analysis of clusters are, however, challenging to analyze with quantitative methods only, if not impossible. Trust among cluster actors is often cited as one key success factor of clusters (see for example [48]). The role of trust as a cluster success factor compared to e.g., location or physical infrastructure, is difficult to analyze without complementing the quantitative analysis with qualitative analysis. Taking the clusters above, for example, they show that industries 4 and 7, food processing and biotechnology are often placed together in a cluster, but while our model shows them as two variables, they actually represent potentially many biotech and food companies of varied types.

The quantitative recommendation is, parsed through a qualitative lens, to find X number of food processing and biotech partners, at both the institutional and personal level, all over the country which have enough trust (among other factors) to work together in a real cluster exchange, with common resources, multiple exchanges, and more. The quantitative result, while economically ideal in terms of this and many other common techno economical models, obviates things which might very well prevent the clusters from functioning at all, and so other disciplines, from process engineering, to political sciences and anthropology, need to be considered in a serious study.

Now, take a hypothetical existing BEI cluster, including facilities from sectors 4, 6, and 11 (trade), such as the one suggested by the OR model for Møre and Romsdal in scenario 3. The exact operational details of this cluster might be known, and it can be poor or excellent, in the context of resource exchange and utilization. The idea of adding a new facility to the cluster, focused on biotechnology development, can be a desire of the current owners, or a policy goal of the local authorities. Now, given enough data, we can propose recommendations on the performance of said facility inside the cluster, and judge whether its eventual success, or lack thereof, is due to the interactions of the cluster, the facility itself, both, or none. This implies that cluster establishment, extension, and planning can be a complementary activity between quantitative-based methods, and qualitative/policy intentions and realities.

Another aspect the numeric models do not easily represent is the cannibalization of hard-to-quantify resources, such as educated workforce, innovation, and other similar concerns. As a given facility grows, its labourers grow in experience and learning effects can be seen, and often measured. However, within a cluster, the possibility exists that individuals with experience can jump into other parts of the cluster, thus negatively, sometimes critically, affecting some of the members of the clusters in favour of others. Silicon Valley, once again, can be used as an example of this possibility. A similar case can be made with innovation. As mentioned above, while learning and innovation can be, to some extent, quantified, their ultimate effects on a cluster's dynamics are much more problematic for numeric algorithms, such as the one presented here but are suited for more quantitative studies like the ones cited above.

NACE codes have been used in this study's methodology to classify industries. As a European standard, NACE is a valuable tool to make results easily communicable to many. However, NACE classifies biotechnology in ways which could seem unintuitive. As such, we must caution against considering NACE classifications as the ideal when it comes to BEI cluster analysis. We also reiterate our advice to find other ways to obtain conversion rates for the production processes modelled in a cluster.

Finally, and going back to the research question, we can conclude that BEI clusters can be analysed, and decision support tools for localization can be developed using OR and I–O methods. However, the insight thus provided should then be complemented by qualitative analysis and expertise on the social and political sciences angles. Regardless of the scope assumed for the concept of cluster, it invariably involves a large number of people, products, and interactions, and its dynamics require more than pure economic analysis for a successful implementation and, therefore, a positive effect in reducing waste, emissions, and costs with a more efficient and sustainable production system.

## 7. Conclusions

The philosophy, formation and operation of industrial clusters, specifically, those involved directly in economic activities related to the use of biological raw products and their derivatives was discussed. Such clusters, we propose, are an important component in the transition into greener systems, as they reduce waste, transport distances, and promote economically and environmentally sustainable operations. The nature of a BEI cluster (and of course, of industrial clusters in general) can vary considerably, and its ultimate success is tied to economic, political and operational conditions.

First a cluster-localization methodology based on I–O analysis and OR, applied to a case study on Norway, in which each county's capital is considered as a potential location for a BEI cluster containing one or more facilities is proposed. Three types of bio-sourced products (agriculture, forestry, and fish/aquaculture), or derivatives of these products, can be harvested, produced or sold in each cluster. Results show how the conformation of each of the proposed clusters differ as we vary demand, consumption, and transport cost parameters, but in general some counties are preferred over others by the optimization model. However, when other considerations are added, such as social or political conditions, the OR clusters can be seen in a different light and can prove to be difficult to operate effectively. This methodology then serves as a starting point for a decision-support analysis of real-life existing and potential BEI clusters, and we intend it to be used to explore economically sound alternatives and how can they be achieved after political and other considerations have been introduced, such as competition, political will, inter/company trust, and others.

Considering future works, we plan to address some of the weaknesses of the optimization part of the methodology, such as incorporating analyses based on future scenarios ("what if biomass usage were incentivized?"), as well as time series into the model so decisions on the clusters can be made across time according to expected production, demand, weather and price tendencies. Extending the analysis to other Nordic countries, which share similarities with Norway, is also a short-term objective. Additionally, we plan on investigating the parametrization of otherwise qualitative political factors, policies, and other situations which we have so far named as important to define the establishment and success of a cluster, but which we have not yet attempted to incorporate into our analysis. Finally, we plan on looking into the relevancy and application of environmentally-extended I–O analysis to improve the sustainability-assessment in the methodology.

**Author Contributions:** Conceptualization, V.S.N. and M.-B.E.; Formal analysis, G.A.P.-V.; Methodology, G.A.P.-V. and V.S.N.; Validation, J.T. and A.T.W.; Writing—original draft, G.A.P.-V. and V.S.N.; Writing—review & editing, G.A.P.-V., M.-B.E., J.T. and A.T.W.

**Funding:** This work was supported by the Research Council of Norway (project BioSmart, grant no. 244608) and the SINTEF Industri Publication funding project 102004770-59.

**Acknowledgments:** We would like to thank our colleague Ulf Johansen for his ideas on I-O analysis, and to Svein Olav Krøgli, Misganu Debella-Gilo, and Wenche Dramstad at NIBIO for their collaboration within the BioSmart project.

**Conflicts of Interest:** The authors declare no conflict of interest.

## Abbreviations

| | |
|---|---|
| BEI | Bioeconomic Industries |
| I–O | Input–Output |
| OR | Operations Research |
| NCE | Norwegian Centers for Excellence |
| IS | Industrial Symbiosis |
| NACE | Nomenclature Statistique des Activités Economiques dans la Communauté Européenne |

## Appendix A

Table A1 presents production ratios for the sectors in which we are interested. An entry in the intersection of column X and row Y means that sector X pays to sector Y the specified monetary amount as part of sector X's production process. It can be seen that sector 4 pays considerably large amounts to sectors 1 and 3, and comparatively little to sector 2. Due to the large aggregation we have used to reduce the sectors to 12, some of the diagonal entries are not only non-zero, but large, as industries classified in the same sector pay to each other as part of large and complex value chains.

To produce usable data for the optimization model, all entries in a row are divided by the column's total, which gives the relative amount of goods needed for the production of the sector.

**Table A1.** Industrial Conversion Matrix for the Bioeconomic Sectors. Source.

| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **Total** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 Agriculture | 1386 | 27 | 33 | 37,507 | 10 | 132 | 24 | 15 | 38 | 3 | 184 | 3378 | 42,739 |
| 2 Forestry | 220 | 1661 | 1 | 2 | 2912 | 0 | 362 | 35 | 6 | 0 | 45 | 357 | 5604 |
| 3 Marine industries | 46 | 0 | 5096 | 21,251 | 8 | 3 | 215 | 9 | 14 | 2 | 47 | 1203 | 27,894 |
| 4 Processing, agriculture and marine industries | 7483 | 2 | 15,400 | 48,839 | 381 | 163 | 808 | 1974 | 140 | 78 | 951 | 20,461 | 96,681 |
| 5 Processing, forestry | 226 | 1 | 532 | 708 | 6042 | 14 | 620 | 309 | 215 | 333 | 4729 | 40,321 | 54,050 |
| 6 Other possible processing industries (may be omitted): | 65 | 4 | 562 | 245 | 89 | 1011 | 260 | 138 | 158 | 396 | 644 | 11,055 | 14,628 |
| 7 Biotech | 3724 | 244 | 3316 | 3587 | 1507 | 394 | 18,052 | 2639 | 552 | 2341 | 7663 | 100,995 | 145,015 |
| 8 Other industry, machines for processing industries | 107 | 95 | 949 | 1084 | 615 | 63 | 463 | 25,732 | 191 | 251 | 4853 | 54,871 | 89,275 |
| 9 Energy production and distribution | 616 | 62 | 409 | 2041 | 1526 | 67 | 3205 | 368 | 2460 | 366 | 1284 | 29,417 | 41,819 |
| 10 Recycling (might be relevant) | 10 | 3 | 266 | 246 | 352 | 15 | 976 | 210 | 355 | 5345 | 2472 | 18,864 | 29,115 |
| 11 Trade | 987 | 113 | 1474 | 5293 | 1485 | 348 | 3662 | 5219 | 440 | 1572 | 8718 | 83,957 | 113,268 |
| 99 Other Sectors | 5407 | 707 | 9960 | 28,832 | 9881 | 1838 | 97,592 | 33,922 | 10,621 | 12,835 | 89,001 | 1,374,118 | 1,674,714 |
| Total | 20,278 | 2918 | 38,001 | 149,636 | 24,808 | 4050 | 126,239 | 70,570 | 15,190 | 23,524 | 120,592 | 1,738,997 | |

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