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Industrial clustering as a barrier and an enabler for deep emission reduction: a case study of a Dutch chemical cluster

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ABSTRACT

Industrial clusters are considered more resource- and greenhouse gas-efficient than stand-alone industrial plants, but clustering may also act as a barrier to radical changes required for deep greenhouse gas emission reductions. Here we explore how clustering in an energy-intensive chemical industry cluster may influence attainability of the deep emission reduction targets. Chemelot, located in the southeast of the Netherlands, was willing to collaborate and we adopt a qualitative system dynamics approach based on expert interviews and group model building sessions. We found that clustering may hinder reaching deep emission reductions by three reinforcing feedback mechanisms, or ‘traps’, related to: incremental changes; short-term focus; and companies acting alone. The system dynamics analysis also identified potential mechanisms to escape from these traps, notably: (1) increasing cluster autonomy; (2) activating public support; (3) promoting changes in the supply chain; and (4) attracting long-term investors. The findings can inform policymakers on how to steer industrial clusters towards deep emission reductions, and support industrial cluster decision-makers on both internal and external strategies.

Key policy insights:

- Industrial clustering may offer opportunities to accelerate deep greenhouse gas emission reductions, but it could also cause carbon lock-in because of increased physical and organizational interdependency, which favours incremental changes, short-term focus, and solitary actions rather than collective actions, at the cost of deep greenhouse gas emission reductions.
- To fully exploit the potential benefits of industrial clustering for greenhouse gas emission reductions, policies need to take into account the causal relations that operate in a self-reinforcing way to lock the cluster into high greenhouse gas emissions, and that can help escape them.
- A coordinating authority operating across the cluster is necessary to ensure effective collaboration within a chemical cluster so as to escape carbon lock-in.
- Policies addressing emissions along the full value chain (i.e. to include scope 3) might be mutually beneficial with the circularity and low-emission ambitions of the chemical industry.

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1. Introduction

Research shows that industrial clustering can be effective as a strategy to increase resource efficiency, to mobilise and combine resources, to reduce waste and to lower production costs (Chertow, 2000; de Gooyert et al., 2019). An industrial cluster is not only a technological network, it is also a community in which participants share knowledge, experiences, excess organizational capacity and competences (Boons et al., 2011; Domenech & Davies, 2009; Walls & Paquin, 2015). In this social and technological context, this paper investigates whether industrial clustering can be helpful to achieve climate neutrality targets. It is based on the case study of Chemelot, a chemical cluster in the Netherlands.

This paper adds to the literature on industrial clusters. Research on industrial clusters typically focuses on drivers and barriers to realise industrial clusters, discusses and quantifies gains from such system integration (Chertow & Lombardi, 2005; Domenech et al., 2019) and describes clusters’ dynamics (Boons et al., 2017). Drivers of the emergence and future prospects of industrial clusters include physical proximity (Chertow & Ehrenfeld, 2012), government involvement to create supportive institutional conditions (Paquin & Howard-Grenville, 2012), economic and environmental factors (Walls & Paquin, 2015), common visions and beliefs among the firms (Behera et al., 2012), knowledge sharing and innovations (Lombardi & Laybourn, 2012), and a diversity of actors within the network to ensure opportunities for materials and energy exchanges (Chertow, 2000; Jensen et al., 2012). Power imbalance in resource dependence relationships (Casciaro & Piskorski, 2005), risk of the exit of a key actor (Walls & Paquin, 2015), perceived high risk and costs (Chertow & Miyata, 2011; Paquin & Howard-Grenville, 2012) and lack of goal alignment among firms (Boons & Spekkink, 2012) are barriers that have been identified in literature to the establishment and further development of industrial clusters.

The environmental and economic benefits of (energy-intensive) industrial clustering include saving virgin raw materials by utilizing recycled materials that would otherwise be wasted (Guo et al., 2016; Heeres et al., 2004) and reducing carbon emissions, e.g. by substituting fossil fuel raw materials with bio-based feedstock (Røyne et al., 2015). For instance, Taddeo et al. (2012) identified energy and material efficiency and cost reduction potential in logistics and external transport exchanges through revitalizing an existing chemical cluster in Abruzzo Region-Italy. Zhang and Wang (2014) concluded that industrial symbiosis-induced inter-firm collaboration in Chinese industry and the access to cluster resources play important roles in both the economic and environmental performance of the firms studied and overall carbon emission reduction in the value chain. While these studies shed light on the potential of industrial clustering to incrementally increase efficiencies and reduce environmental footprints in energy-intensive industrial clusters, they do not address how clustering would help or hinder radical change, such as what would be needed to achieve ambitious climate change targets in such clusters.

Implementing climate change commitments, such as the net-zero greenhouse gas (GHG) emission targets in the EU (European Commission, 2020), will require industries to change radically over the next decades (IPCC, 2018). As many high emitters are in industrial clusters, it is relevant to examine how industrial clustering impacts the ability to reach deep GHG emission reductions. There are few studies that have investigated deep mitigation scenarios involving radical change for industrial clusters. Examples include Schneider et al. (2020), who developed four scenarios for decarbonizing the Rotterdam industrial cluster and identified risks and opportunities associated with each, and Janipour et al. (2020), who investigated different sources of carbon lock-in in the chemical industry and identified cluster integration as one of the sources of such lock-in. Carbon lock-in has been defined as a path-dependent process whereby reinforcing feedback mechanisms favour incumbent technologies and thus inhibit development, innovation and implementation of low-carbon alternative technologies (Arthur, 1994, 1989; Seto et al., 2016; Unruh, 2000). This study builds on Janipour et al.’s (2020) findings by scrutinizing the dynamics leading to such carbon lock-ins, or escaping them, in the context of a chemical industrial cluster.

The objective of the work presented in this paper is thus to understand how industrial clustering influences attainability of deep emission reductions. To this end, we examined one large industrial cluster, Chemelot, that was willing to collaborate and learn at the start of its effort to reach deep emission reductions before 2050. To perform the research, we interviewed experts and organized group discussions with key actors of the Chemelot cluster. Drawing on information from these interviews and discussions, we were able to develop a qualitative,
participatory system dynamics model. Our model describes feedback mechanisms that enable or limit (Repениng & Sterman, 2002; Walrave et al., 2011) the possibilities of Chemelot’s transformation into a cluster with zero GHG emissions. By means of a participatory system dynamics approach, we invited the participants to explore the potential feedback mechanisms of industrial clustering that are relevant to the implementation of deep emission reduction options in the Chemelot cluster. Our research is novel as, to our knowledge, there has been no study done on possible dynamics arising from feedback mechanisms of industrial clusters undergoing transformative change.

This paper proceeds as follows. After a description of the case of the Chemelot cluster in Section 2, we explain the methods we applied in our research in Section 3. In Section 4, we present results on how clustering, and feedback mechanisms due to clustering, may enable or hinder Chemelot’s achievement of a deep GHG emission reduction target. In Section 5, we discuss our findings and provide policy recommendations as well as the limitations of our research and suggestions for future research. Finally, Section 6 provides our conclusions.

2. Chemelot cluster case description

The Chemelot cluster, situated in the southeast of the Netherlands close to the German and Belgian borders, covers an area of 800 hectares and comprises 150 companies and 8 plants, including several large GHG emitting industrial plants and several smaller ones. The annual GHG emissions of Chemelot in 2019 were about 2% of the total Dutch GHG emissions (Chemelot, 2020a). About 6100 people are directly employed within this industrial cluster (Chemelot, 2018a), and another 8000 indirectly (Chemelot, 2018b). Until 2002, Chemelot was the main chemical complex for DSM, a chemical company that arose from a Dutch government coal mine closure programme in the 1970s. This background has resulted in a high degree of integration, even though most assets previously owned by DSM are now in the hands of different firms, headquartered in different countries.

In the Chemelot cluster, several entities handle different organizational aspects. Since 2016, the Chemelot Executive Director is responsible for communication, sustainability, acquisition of new companies and the cluster’s response to climate policy. The organization under the administration of the Chemelot Executive Director (hereinafter referred to as the ‘Chemelot authority’) is financed by and reports to the Board of Directors of the Foundation Chemelot. The Board consists of the cluster’s five largest users, DSM as the landowner and Brightlands Chemelot Campus, an organization that aims to spur innovation.

Chemelot has a Utility Support Group (USG), co-owned by the large energy users on the cluster. USG delivers utilities such as electricity, steam (different pressure levels), nitrogen, power, industrial gases, air and water to the Chemelot plants (Chemelot, 2020a). Pipelines supply the Chemelot cluster with naphtha and natural gas, used as feedstock or energy carrier. Naphtha serves as feedstock for the petrochemical plants to produce polymers and other plastics. Natural gas is used to obtain hydrogen and ammonia for fertilizer production (Chemelot, 2018b). In 2019, Chemelot’s total natural gas consumption was about 1200 million m$^3$ (about 3% of the Netherlands total natural gas consumption), of which roughly 600 million m$^3$ is used as feedstock for the ammonia production by OCI Nitrogen. In 2019, Chemelot emitted 4.1 Mt (Megatonne) CO$_2$ and 3.6 kt (kilotonne) N$_2$O. The largest CO$_2$ emitters at the Chemelot cluster are SABIC, a chemical building blocks producer, and OCI Nitrogen, producing fertilizer and melamine. Fibrant company, a caprolactam producer, was the main emitter of N$_2$O, but these emissions are expected to be reduced by 75% by mid-2021 (Chemelot, 2020b). Fibrant has announced that it will invest 42 million euros to reduce its N$_2$O emission. The Dutch government also will help Fibrant to reach its goal with an interest-free loan of 30 million euros. To realise the N$_2$O emission reduction goal, Fibrant will produce low-carbon caprolactam (called ecoLactam) from pyrolysis of plastic wastes or oily by-products of the wood and pulp industry (Processcontrol, 2020).

In response to the 2019 Dutch Climate Law, which stipulates a 95% GHG reduction below 1990 levels by 2050, Chemelot has developed a cluster plan to reach deep emission reductions (‘climate neutrality’) in 2050 (Chemelot, 2020c). For CO$_2$ emission abatement, five categories of emission reduction measures were already mentioned in an earlier Chemelot document: (a) Electrification based on green energy, (b) Sustainable
greening of raw materials, (c) Circularity, (d) Process improvement and optimization, (e) Carbon Capture and Storage (CCS) and Carbon Capture and Utilisation (CCU)' (Chemelot, 2018b).

3. Research methods and design

3.1. Qualitative system dynamics model

To identify the causal relationships and feedback mechanisms that are enablers and barriers for Chemelot’s 2050 deep emission reduction targets, we built a qualitative system dynamics model based on expert interviews and group discussions. A system dynamics approach is typically applied in situations where information from various stakeholders with different perspectives needs to be synthesized (de Gooyert et al., 2016). This approach considers relevant variables and the network of inter-dependencies between those variables to explore any potential indirect and non-linear effects at play. When causal relationships between variables form a closed loop, a feedback mechanism emerges. Two types of feedbacks are distinguished: The label ‘R’ in the centre of a closed causal loop means a reinforcing feedback mechanism and a ‘B’ sign indicates a balancing feedback mechanism. A balancing feedback mechanism is a stabilizing mechanism, resisting change in one direction by generating change in the opposite direction. Balancing feedback mechanisms keep the system steady. A reinforcing feedback mechanism generates prompt system growth or collapse by driving change in one direction with increasing change in the same direction. Table 1 shows the legend of the symbols that are presented in the Results section.

A plus sign on an arrow indicates change in the same direction, which means that if variable A increases (decreases), variable B increases (decreases) too. A minus sign indicates a change in the opposite direction: if variable A increases (decreases), variable B decreases (increases).

To jump-start the conversation for the group discussions, we prepared a seed model (Richardson, 2013) in collaboration with three members of the Chemelot Sustainability Team (a committee consisting of the

Table 1. Legend of the system dynamics model.

<table>
<thead>
<tr>
<th>Name</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stock</td>
<td></td>
</tr>
<tr>
<td>Flow</td>
<td>![Flow Symbol]</td>
</tr>
<tr>
<td>Source and Sink</td>
<td>![Source and Sink Symbol]</td>
</tr>
<tr>
<td>Existing causal relation</td>
<td>![Existing Causal Relation Symbol]</td>
</tr>
<tr>
<td>Potential causal relation that is not realized yet</td>
<td>![Potential Causal Relation Symbol]</td>
</tr>
<tr>
<td>Time delay</td>
<td>![Time Delay Symbol]</td>
</tr>
<tr>
<td>Balancing feedback loop</td>
<td>![Balancing Feedback Loop Symbol]</td>
</tr>
<tr>
<td>Reinforcing feedback loop</td>
<td>![Reinforcing Feedback Loop Symbol]</td>
</tr>
</tbody>
</table>
sustainability managers of the Chemelot emitters). Our seed model (Figure 1) consists of a limited number of key stocks, flows and variables that play a key role in the Chemelot deep emission reduction plans and the causal relationships between these variables. In system dynamics modelling, stocks symbolize states of the system that are changed through in- and out-flows over time. Clouds represent the sinks and sources that fall outside the scope of our study. The seed model shows the different sources of GHG emissions (energy consumption, process emissions, products in use, and waste) and provides an overview of the various options for reducing emissions (electrification, process improvement, sustainable raw materials, plastic recycling, CCS and CCU). The ‘extent of clusterisation’ was also mentioned in the model to encourage discussion on the enablers and barriers that clustering creates for deep emission reduction.

3.2. Interviews and group discussions

We conducted eight semi-structured interviews with key actors involved in the climate transition of different Chemelot companies, and a number of various-sized group discussions with experts from various Chemelot companies. The individual interviews took place in February 2020 and the duration of the interviews was around one hour. The interviewees were selected in collaboration with the Chemelot Sustainability Team based on their role in the sustainability transition of the cluster companies. All interviewees were either high-level managers or senior engineers. Five interviewees worked at Fibrant, USG, SABIC, OCI Nitrogen and ARLANXEO, companies that are significant GHG emitters of the Chemelot cluster. Fibrant, SABIC, OCI Nitrogen and ARLANXEO are also shareholders of USG (utility provider). The other three interviewees were from the Brightsite centre (a regional research collaboration located at Chemelot) and Chemelot authority. We asked the interviewees about potential advantages and disadvantages that the Chemelot cluster creates for individual companies to reach the deep emission reduction target (see Supplementary Material, Appendix 1 for the interview guide). All interviews were recorded and transcribed. The transcripts were sent to the interviewees for review. All interviewees reviewed the transcripts, and five interviewees gave additional information. This additional information was included as an addendum to the transcripts.

In January 2020, in a preparatory discussion with three members of the Chemelot Sustainability Team, a seed model (Richardson, 2013) was developed to jump-start the conversation for the first full-group discussion. The full group discussion included four advisors of the Sustainability Team, two advisors of the Brightsite centre and
eight senior advisors and engineers of the individual cluster users, including the high-emitting companies. This meeting took about 2.5 h.

In the first full group discussion that took place early March 2020, we presented our seed model and asked the 14 participants to reflect on it. Then, we asked them to provide insights to identify those variables that they expected to play important roles in achieving deep emission reductions for the Chemelot cluster, and the causal relationships between those variables. Seven out of eight interviewees also participated in the group discussion and the meeting took 4 h. The results of this first full-group discussion provided input to the initial version of our system dynamics model. Both the preparatory and the group discussion sessions were recorded and transcribed to be used for later analysis.

At that moment, the COVID-19 pandemic caused a lockdown which meant that we had to change the initial plan to hold a second and potentially third group session. Instead, we completed the model in a model finalization session with two members of the Chemelot Sustainability Team who had also attended the preparatory session where the seed model was developed. This session was not recorded, but the participants sent their written remarks and rationales for the topics discussed. Excerpts of those written comments were used for the analysis. The meeting took place in May 2020 and the duration was about 2.5 h.

We then decided to hold a second full-group discussion, that also took place online, to present the finalised model to the group of cluster users and invite feedback. Half of the participants of the first group discussion participated and no objection was raised. This session took place in June 2020 and took about one hour.

Finally, in June 2020, two high level strategic managers of the Chemelot cluster and two experts of the Chemelot Sustainability Team (who both also participated in the seed model and the model finalization session) were invited to discuss the validity and value of the model. In the meeting, the main results were presented to the participants, who were asked to reflect, particularly to comment on the feedback mechanisms and causal relationships that addressed strategic decision-making. These participants confirmed validity of the results presented in the model. Appendix 2 (see Supplementary Material) displays a graphical presentation to clarify the group model building process.

3.3. Data analysis

The preparatory discussion and the first full-group sessions were coded by one of the researchers to extract the excerpts related to the causal relationships in the system dynamics model that had been built by the participants in the group model building session. We revised the model based on the coded quotations: for instance, if there were overlaps between the variables, we merged them. Then, we coded all the interviews to identify the quotations related to the existing causal relationships in the model. We also coded the interviews for excerpts describing any new causal relationships relevant to the potential effects of clustering on attainability of the deep emissions reduction target, and based on those excerpts, we added new causal relationships to the model.

To address any biases in the coding process and create an agreed template for coding, two of the interviews were coded by two researchers, and then the codes were discussed among the researchers to reach consensus about the coding strategy. The remaining six transcripts were coded by one of the researchers based on the same coding strategy.

To translate the interviews’ textual data into the system dynamics modelling language, we followed the words-and-arrows diagramming method that Kim and Andersen (2012) and Janipour et al. (2021) applied. In

<table>
<thead>
<tr>
<th>Cause</th>
<th>Effect</th>
<th>+/-</th>
<th>Words-and-arrow diagram</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of per tonne of CO2</td>
<td>Carbon leakage</td>
<td>+</td>
<td><img src="#" alt="Cost of per tonne of CO2" /> + Carbon leakage</td>
</tr>
</tbody>
</table>

Figure 2. An example of words-and-arrows diagram derived from the analysis of the textual data.
this method, we extracted causal links from various coded data segments (the interviewees’ arguments + the supporting rationales). Then, we transformed the data segment’s text into words-and-arrows diagrams. An example is shown in Figure 2.

Data segment: ‘the cost of per tonne of CO2 also increases carbon leakage’ (Interviewee number 6)

We compiled and merged all the words-and-arrows diagrams into the intermediate stock and flow diagrams to map the whole detailed system’s structure and dynamics. Appendix 3 (Supplementary Material) displays illustrative examples of the intermediate stock and flow diagrams. The whole model (combination of the intermediate models) consists of more than 60 variables and causal relationships among them. Those variables and relationships between them helped us identify core issues and separate them from issues that are also relevant but not key to the objective of this research. In the last step, we generalized the model and extracted the main feedback mechanisms that emerged from the mapped dynamics and that are expected to have a substantial impact on the climate transition in the Chemelot cluster.

4. Results

In this section, we present our findings in the form of feedback mechanism diagrams. Via an iterative process between the raw data and the analysis, we identified the main feedback mechanisms hindering and helping action; these are listed in Table 2. In Sections 4.1, 4.2, and 4.3, we explain three different ‘traps’ identified, i.e. the incrementalism trap, the short-termism trap and the solitariness trap (that is created in the absence of a reinforcing feedback mechanism between cluster collaboration and development of a shared sustainable cluster strategy), respectively, as well as associated mechanisms to escape them.

We describe views of the interviewees and the participants of the group discussions (respondents) and refer to one, several (2-6), about half (7-11), most (12-16) and all (17) respondents expressing a similar view on a certain topic.

4.1. Incrementalism trap

4.1.1. Clustering reinforces itself and locks into incrementalism trap

One of the key variables discussed by all the respondents was the synergies that the Chemelot cluster offers to the cluster users. About half of the respondents explained that via incremental process improvements, the cluster has obtained resource efficiencies. In Chemelot, these efficiencies are mainly realized for utilities such as steam exchange. This has resulted in lower energy consumption and lower GHG process emissions for the Chemelot companies compared to standalone factories. As a result of synergies, Chemelot reduced its emission intensity (CO2-eq) per tonne of product from 0.68 to 0.62 between 2010 and 2019. It was highlighted by several respondents that the cluster synergies only remain if none of the factories engaged in the network shuts down and leaves the cluster. Several respondents explained that incremental improvements have resulted in more integration within the cluster, and that firms depend upon each other for further incremental improvements. This resulted in an incrementalism trap displayed in Figure 3, showing that clustering reinforces itself and locks the cluster into an incrementalism path.

About half of the respondents indicated that implementation of GHG emission reduction innovations is currently complex and difficult within the cluster as there are different decision making units (DMUs)

<table>
<thead>
<tr>
<th>Feedback mechanism (trap or escape)</th>
<th>Hindering the Chemelot deep emission reduction target</th>
<th>Self-reinforcing escapes enabling Chemelot deep emission reduction target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incrementalism trap</td>
<td>Attracting sustainable raw materials companies</td>
<td></td>
</tr>
<tr>
<td>Short-termism trap</td>
<td>Actively seeking long-term investors</td>
<td></td>
</tr>
<tr>
<td>Solitariness trap</td>
<td>Increasing autonomy of cluster authority</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Active public support</td>
<td></td>
</tr>
</tbody>
</table>
involved in the decision-making process. The respondents explained that the DMUs, often situated around the world, have different sustainability policies and priorities, which are not always in line with the collective interests of the Chemelot cluster. An example of such conflicts of interests has recently emerged in purchasing a new boiler for the utility provider company of the cluster. For this technology replacement, extra investment is required that should be approved and paid for by the six Chemelot companies that are the shareholders of the utility company. A lengthy coordination process was needed before the purchase was approved as some of the shareholders do not directly benefit from that investment. If the new boiler is bought and implemented as a part of the cluster, demanded steam would be produced with a lower GHG footprint. This case is also an example of interdependency among the cluster users. In this case, steam users of the cluster are dependent on the decision of other actors (the shareholders of the utility company) to receive steam with a lower GHG footprint. As displayed in Figure 3, clustering increases decision-making complexity, which at least in some cases is likely to hinder or at least slow implementation of deep emission reduction measures.

4.1.2. Attracting sustainable raw materials companies could break the incrementalism trap
Several respondents explained that Chemelot should create and promote new sustainable value chains to break the incrementalism trap within the two existing value chains based on naphtha and natural gas. In the longer run, circular feedstock (such as plastic and biomass wastes) may substitute fossil fuel-based raw materials in the cluster. Several respondents indicated that Chemelot cluster can be attractive for new companies to establish a new sustainable supply chain as the cluster can provide better accessibility and connectivity between the cluster logistics infrastructure and external future suppliers of sustainable raw materials. The same respondents flagged that some of the existing DMUs may need to be convinced to support the new value chain as it does not match their sustainability priorities or product portfolios.

Figure 4 expands upon Figure 3 to include the reinforcing feedback mechanism of a new supply chain of sustainable raw materials that can compete with the existing reinforcing mechanism of incrementalism and break the incrementalism trap. It is expected that the new supply chain of sustainable raw materials

![Figure 3](image-url)
will reinforce clustering in the future and can become a low-carbon lock-in (as opposed to a high carbon lock-in).

4.2. Short-termism trap

4.2.1. The short-termism trap reinforces incrementalism

Most respondents agreed that having a shared sustainable cluster strategy is a determining factor for deep emission reductions by the Chemelot cluster. Such a shared sustainable cluster strategy, however, has not yet been realized. One of the main reasons is that DMUs of the companies have different sustainability priorities. Several respondents stated that implementation of alternative technologies with lower or zero emissions bears high costs and lower short-term returns, depressing revenues for the companies’ shareholders. About half of the respondents indicated that there are various uncertainties around the public opinion on the climate measures that Chemelot is planning to take. Given examples of uncertainties were the side effects of new climate technologies and the end products, governmental climate policies and the NIMBY (Not In My Back Yard) effect. The respondents argued that the uncertainties may persuade the shareholders to favour investments with short-term returns and a high-value track record. Investments in incremental improvement deliver such short-term returns. Figure 5 expands upon Figure 3 and shows how short-termism pushes financiers towards more investments in incremental measures with short-term returns. Such a short-termism trap can inhibit more radical innovation needed for deep GHG emission reductions.

4.2.2. Actively seeking long-term investors could offer a way out of the short-termism trap

To break the short-termism trap, several respondents stated that Chemelot should attract long-term oriented investors by actively engaging in attractive projects of (inter)national and regional interests (e.g. producing sustainable raw materials which replace the current fossil fuel-based feedstock). Several respondents explained that the government more and more encourages and supports (industrial) regions to take the lead for developing projects that can help multiple sectors to reach deep emission reductions. Therefore, if Chemelot engages in such regional projects, more long-term investments can be brought into the cluster. As shown in Figure 6, it is envisaged that the more Chemelot gets involved in projects of (inter)-national and regional interests, the longer term-oriented investors will be enticed to invest in the Chemelot

Figure 4. Clustering can attract new companies that establish a new supply chain of sustainable raw materials and break the incrementalism trap created within the existing fossil fuel-based value chains.

Figure 5. The short-termism trap pushes financiers towards more investments in incremental improvements, inhibiting more radical innovation needed for deep GHG emission reductions.

Figure 6. Actively seeking long-term investors can break the short-termism trap by attracting more long-term oriented investors for climate projects.
deep emission reduction projects. This will reduce attractiveness of the cluster for short-term financiers and lower the pressure on the cluster to focus on short-term incremental projects. This is a policy/strategy that Chemelot can take to attract long-term investors. The reinforcing feedback mechanism of long-term
investment competes with the existing short-termism reinforcing feedback loop and strives to phase-out the existing short-termism trap.

4.3. Solitariness trap

4.3.1. Collaboration requires a shared strategy, and a shared strategy requires collaboration
Cluster collaboration was highlighted by most respondents as the key factor to develop the shared sustainable cluster strategy that could facilitate a collective Chemelot deep emission reduction plan. Currently, Chemelot does not have a shared sustainable cluster strategy as collaboration among the cluster users for climate goals has not taken place yet. At the same time, the required cluster collaboration is not happening because there is no shared cluster strategy to guide it. This together forms what we call a ‘solitariness’ trap as opposed to collective GHG reduction actions that are hindered in the absence of a reinforcing feedback mechanism between cluster collaboration and development of a shared sustainable cluster strategy. Several respondents indicated that lack of a shared cluster strategy is a main barrier to deploy any collective climate actions at the Chemelot cluster. About half of the respondents also agreed that if Chemelot manages to reach a shared sustainable cluster strategy, the existing and new cluster stakeholders will make more investments for sustainability, including budget for shared R&D that can lead to projects with benefits for multiple cluster users, as well as projects of (inter)national and regional interests. Figure 7 shows how cluster collaboration and development of a shared sustainable cluster strategy can create a reinforcing feedback mechanism. However, as each of the variables are waiting for the other one to happen, it is not happening, forming the solitariness trap.

4.3.2. Increasing autonomy of cluster authority could offer a way out of the solitariness trap
Several respondents expected that if the Chemelot authority would gain more autonomy to make decisions, cluster collaboration will be fostered and better organized, leading to faster progress in developing and

Figure 7. A solitariness trap is created in the absence of a reinforcing feedback mechanism between cluster collaboration and development of a shared sustainable cluster strategy.
implementing the shared sustainable cluster strategy. Several respondents indicated that the shared sustainable cluster strategy is likely to attract long-term oriented investors that can reinforce the autonomy of the Chemelot authority. Figure 8 expands upon Figure 7 and shows how increasing autonomy of the Chemelot cluster authority can better facilitate cluster collaboration. This reinforcing mechanism is in competition with the reinforcing mechanism of the solitariness trap.

### 4.3.3. Active public supports enable deep emission reductions by Chemelot

Having a shared sustainable cluster strategy was indicated by most respondents as essential to foster a shared public affairs strategy and department for communicating with external players in the cluster surroundings, including the general public and the government. About half of the respondents explained that positive public opinion on sustainability and climate actions would increase the cost of financing for fossil fuel-based investments, which in turn would encourage the companies’ owners to direct their decisions towards sustainable investments. Several respondents explained that positive public opinion on climate plans would also increase customers’ willingness to pay for more expensive but sustainable products. This may further motivate the companies’ owners to advance their sustainability and climate policies.

Several respondents also stated that there are uncertainties about the governments’ climate policies for industrial clusters, including the Chemelot cluster. This makes the companies hesitant to make collaborative efforts within the cluster on the Chemelot climate projects, because there is a risk that those projects may not be supported by future climate policies. The participants explained that Chemelot chemical companies produce building blocks and inputs for other manufacturing industries. Efforts to reduce the GHG emission footprint of the production output of the Chemelot cluster would have positive effects on scope-3 emissions reduction of Chemelot itself and other sectors. About half of the respondents expressed their dissatisfaction with the national government and the EU policies (at the time) that do not appreciate such efforts. Indeed, only scope 1 and partly scope 2 are covered by the EU Emissions Trading Scheme. The same respondents explained that such climate policies, that do not reward the scope 3 efforts, are discouraging action by a number of Chemelot companies. About half of the respondents explained that Chemelot is using its collective lobbying for the interests of all Chemelot companies to influence the national government and the EU policies to broaden the scopes covered by policy. Several respondents stated that if the policies include scope 3 emissions reductions, incentives will likely be put in place for the production or use of sustainable raw materials,
leading to lower carbon leakage risk and fewer negative consequences of climate transition for the regional economy. One interviewee indicated that a just climate transition of the region, including the Chemelot cluster, would be supported by the general public, and that this could influence the governmental policies to focus more on the long-term projects. Figure 9 expands upon Figure 8 and shows the reinforcing feedback loop of developing a shared sustainable cluster strategy that may reinforce the shared public affairs for the cluster. This is important because it improves communication with the general public to gain legitimacy for the climate plans of the cluster. This will also help to increase the public desire for sustainable production and the appetite for better financial instruments to implement the cluster climate plan.

5. Discussion

5.1. Academic significance

Our research contribution comprises a dynamic and empirically grounded discussion of positive and negative consequences of clustering for deep emission reductions, based on a chemical industrial cluster case. The incrementalism and short-termism traps that we found are in line with earlier academic work on path dependency (Seto et al., 2016), forming a lock-in situation that has been discussed in the industrial symbiosis literature (Jacobsen, 2007; Posch et al., 2011). The solitariness trap and its remediation strategies are to the best of our knowledge not discussed earlier in the literature.

We hypothesized, based on earlier work, that incrementalism and short-termism are prevalent in a deeply integrated industrial cluster, given that not only investments into a single plant, but also the shared infrastructure and therefore investments by other stakeholders, are linked with one another. Earlier work (Janipour et al., 2020) had found this, based on interviews, alongside other sources of carbon lock-in and barriers. However, this earlier study did not identify feedback mechanisms responsible for creating carbon lock-in. Such dynamics in energy-intensive industry had been identified by Wesseling and Van der Vooren (2017), who studied the technological innovation system of deep decarbonization in the Dutch cement industry; they concluded that lock-in in this sector emerges when a set of interdependent systemic problems and vested interests reinforce each other in one or more closed feedback cycles. Our study confirms their finding that vested interests, reflected in short-termism and incrementalism, lead to incremental improvements to core process technologies over
the past decades (Skoczkowski et al., 2020; Wesseling et al., 2017). Finally, Söderholm et al. (2019) find that the continuous investment in incremental improvements have deterred participation on the part of the forestry, pulp/paper and chemical industries in more forward-looking, transformational Swedish bio-refinery development projects. This corresponds to our findings about the negative effect of incrementalism to attract long-term financiers for deep emission reduction projects.

The application of our qualitative participatory system dynamics modelling method in the industry sector is novel; no studies could be identified that took a similar approach for this sector. The closest example is Wesseling and Van der Vooren (2017), who developed a system dynamics diagram by connecting interviews with a qualitative modelling, and identified causal relationships between seven technological innovation system functions (Hekkert et al., 2007) to identify systemic problems. Qualitative participatory system dynamics modelling has been used in other sustainability studies, for instance, in sustainable urban planning research (Eker et al., 2018; Pineo et al., 2019), electricity production (de Gooyert et al., 2016, 2021) and sustainable farming and food security (Lane et al., 2012; Stave & Kopinsky, 2015). The contribution of qualitative participatory system dynamics modelling includes its ability to structure the systems’ complexities and long-run, non-linear effects of the decisions, in combination with viewpoints from practitioners (de Gooyert et al., 2017). This is demonstrated by the finding of the solitariness trap in the Chemelot industrial cluster, that had not been found by earlier work.

5.2. Policy implications

We identified four escape routes to address the ‘traps’ found in the feedback mechanisms present in an industrial cluster: (1) increasing cluster autonomy, (2) activating public support, (3) promoting changes in the supply chain, and (4) attracting long-term investors. For each of these escape routes, the literature suggests possible policy interventions by both public and private actors, which are briefly discussed here.

First, our findings imply that a more autonomous cluster authority could improve and advance cluster collaboration to develop the shared sustainable cluster strategy to facilitate action towards deep decarbonization. At Chemelot, the current landowner of the Chemelot cluster is DSM, which is no longer a large emitter in Chemelot. The Chemelot authority is dependent on various companies’ approval for making decisions to the collective interest of the Chemelot cluster to achieve deep emission reductions. Different sustainability priorities and timings of relevant investments of the cluster company owners have made it difficult to reach agreement on collective deep emission reduction actions and strategies. In some other Dutch industrial clusters, such as the Port of Rotterdam, the Port Authority is the landowner of the cluster and also coordinates the plans and activities related to their deep emission reduction objectives (Climate Strategies, 2021; Schneider et al., 2020). In such a situation, when there is an independent authority interested in the transition, activities and collaboration for deep emission reductions could be facilitated and more effectively organized. A cluster authority with a mandate to achieve deep emission reductions could usefully have its own resources to invest in knowledge and low-emission infrastructure, bearing in mind the collective interest of the cluster.

Second, according to our findings, if such a cluster has a mandate or requirement to address climate change, and it designates a climate authority to represent it, the companies could meaningfully engage with regional stakeholders, the general public, local inhabitants and government, and the cluster’s approach could receive more local support. This could serve to reduce the resistance to some low-carbon infrastructure options, such as CCS, with stakeholders in the immediate surroundings (Batel et al., 2013; Terwel et al., 2011), and increase their ‘social license to operate’ (Terwel et al., 2011). Such a change could also help increase the political support for further-reaching government climate policies and measures.

Third, policymakers, at EU, national and regional levels, could support advancing sustainable value chains by combining policy instruments to incentivise efficient raw material use and substitution (Agora Energiewende and Wuppertal Institute, 2021; Chiappinelli et al., 2021; Neuhoff et al., 2019); this would allow chemical industrial clusters to green supply chains, and also to make their downstream businesses more sustainable (Wood et al., 2020). Other policies within this area could include a variety of instruments to promote the market for secondary raw materials and to facilitate transboundary transportation of waste for recycling, as well as policies to support development of waste exchange and infrastructure across the value chain (Gerres et al., 2021; Milios,
Our findings suggest that focusing on the whole value chain of sustainable raw materials in chemical industrial clusters is important. These findings are in line with life cycle assessments indicating that environmental impacts of chemical clusters go well beyond their on-site processes (e.g. Royne et al., 2015) and also with policy studies noting the need to encompass the entire value chain in mitigation policy (Grubb et al., 2020). This also applies to non-clustered heavy industry. Both Chiappinelli et al. (2021) and Bataille et al. (2018) researched policy pathways for deep decarbonization of energy-intensive industries; they concluded that in order to accelerate the commercialization of the decarbonization technologies, a mix of precise innovation and market uptake policies along the value chain are needed. This includes prioritizing research into supporting institutions and business models, deployment subsidies (contracts for difference), a carbon price and border protection, all integrated into a comprehensive industrial policy framework aiming at the deep emission reduction goals (Nilsson et al., 2021). Building on this, making policy that captures both up- and downstream (i.e. scope 3) emissions, in particular for chemical companies, would support the companies in an industrial cluster to collaborate on deep emission reductions. However, given that the institutional and governance settings differ substantially across clusters, tailor-made policies and interventions are also needed for different clusters (Costa & Ferrão, 2010).

Finally, more public support, better cluster coordination and consistent policy interventions working both upstream and downstream in the supply chain could lead investors oriented to the longer term to gain confidence around investment in the low-emission projects of the chemical company clusters. This could, in turn, lead to a relative decrease in the short-term investments that compete with deep GHG emission reduction investments. Both the attention to scope 3 emission accounting and mitigation actions, and to attracting long-term investors, would entice innovative, circular or more resource efficient companies to settle in such a cluster, transforming the cluster to one that operates on low-emission and circular, resource efficient business models.

While each trap individually could prevent deep GHG emission reduction measures, the traps that share variables in their feedback mechanisms (e.g. ‘realized incremental improvements’ in both the incrementalism and the short-termism trap) are interrelated and could therefore be mutually reinforcing. This interrelation, however, also applies to the feedback mechanisms to escape the traps, meaning that combining the different escape mechanisms could be a more promising way to make the Chemelot climate transition happen. Hence, we recommend that policymakers engage with the specific characteristics and the feedback mechanisms in the systems they are trying to change, and tailor their policy instruments and strategies to the features of industrial clusters.

5.3. Research limitations and suggestions for future studies

We identified several limitations to our research, on the methods, the generalisability of our results, and translation into policy recommendations. First, due to the COVID-19 pandemic, we could not organize more than one in-person and one online discussion session for our participatory system dynamics model. As a result of this limitation, the participants’ engagement in the discussions to identify all influential variables and their causal relationships became more limited than originally envisaged. This increased the likelihood that we missed important components and dynamics of the system. The pandemic also limited the engagement of the participants in the analytical and full research process, and with that, importantly, their willingness to adopt the findings and turn them into actions.

Second, due to the complexity of any chemical industrial cluster, it is unclear to what degree the specific findings of Chemelot can be generalized. Each cluster has its own characteristics and differs from others on aspects such as type and diversity of companies, history, symbiotic links, infrastructure, location and other contextual elements. For example, the Port of Rotterdam cluster is larger and less integrated, but is more centrally organized than Chemelot (Climate Strategies, 2021). It is hard to say whether this would enhance the solitariness trap, for example, or weaken it. It would require multiple case studies to find under which conditions which elements of our findings could also apply in a robust manner to other industrial clusters.

Finally, the literature on converting the findings into policy recommendations is still limited. In general, there is a gap between the policy literature on climate change mitigation and the literature on closing material cycles...
and moving towards a circular economy in industry (Durán-Romero et al., 2020; Gallego-Schmid et al., 2020).
Given that the chemical industry is both a high GHG emitter and a key operator in the circular economy, this problem is particularly pronounced for this sector (Bauer et al., 2019).

Future research could apply the participatory system dynamics model building method to other industrial clusters, permitting to comparative studies so as to identify similar or divergent patterns of the impacts of clustering on achieving deep decarbonization in industry. In addition, where possible, quantification of the mechanisms hindering the industrial climate transition, including the causal relations, and testing the effectiveness of public policy, of business and broader societal solutions to the carbon lock-in, would be both conceptually interesting and policy relevant.

6. Conclusions

We investigated the implications of clustering for achieving deep emission reductions by the Chemelot chemical industrial cluster and identified the potential feedback mechanisms that could hinder or enable the feasibility of deep emission reductions in an industrial cluster. We applied qualitative, participatory system dynamics based on expert interviews and group discussions to identify potential and existing hindering and enabling feedback mechanisms related to the cluster character of the Chemelot cluster that may influence the attainability of its deep emission reduction targets. We found three reinforcing feedback mechanisms that we call the incrementalism trap, the short-termism trap and the solitariness trap. These mechanisms can ‘trap’ the Chemelot cluster or lock it in to high GHG emissions. We also identified four potential self-reinforcing escape routes or feedback mechanisms, namely: increasing cluster autonomy; activating public support; promoting changes in the supply chain; and attracting long-term investors. Each of these leads to policy recommendations. The feedback mechanisms that share variables are interrelated, but this also shows that their escape routes are mutually reinforcing to help enhance the transition of the Chemelot cluster toward low-emissions. Our results underpin that taking into account feedback mechanisms in planning interventions could help tailor and lead to more effective policy.

We recommend that policymakers look more into possibilities to escape carbon lock-ins, though we caution against generalizing. Each individual cluster faces its own challenges, operates its unique supply chain, and governs its own transition towards low-carbon production differently. A tailor-made approach is necessary, and governments can encourage creation of cluster coordination bodies so as to work with them to look specifically at the circumstances. In this way, they can work together to see what is necessary in terms of infrastructure, societal engagement, and incentives to attract innovative companies and long-term investors.

Yet, despite the traps and escape mechanisms being contextual, we would expect that our approach and some illustrative examples of feedback mechanisms may be similar across large and diverse industrial clusters. The research presented here may thus provide some inspiration to companies in other clusters and researchers.

Notes

1. DSM is derived from De Staatsmijnen, or The State Mines.
2. According to the GHG Protocol (www.ghgprotocol.org), Scope 3 emissions are all indirect emissions by a plant not included in scope 2 or 1. Scope 2 emissions are emissions from purchased energy. Scope 1 emissions are direct emissions from owned or controlled sources.

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