

What lock-in factors shape the energy transition of the distribution grid-which could be leveraged?
Interview Data Coding (1)

1) Material Lock-ins Mechanisms

| Raw data | Second-order codes: First- order codes | Aggregate code | Interaction with other Lock-ins | Consequences |
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| <p><i>"SDE+ subsidy schemes stimulated even solar panels for low-voltage customers, brought down the cost price of PV, now we are second in the world the solar panels per capita" (Int#5)</i></p> <p><i>"Clients is always faster than us especially when activities are subsidized" (Int#4)</i></p> <p><i>"Customers started to buy solar panels, electric vehicles, or heat pumps.. We don't the exact number. And when the sun shines, it shines for all roofs" (Int #11)</i></p> | <p>Economies of scale: favourable business case; unit cost decreased when output increased;</p> | <p>Material Lock</p> | <p>With Institutional Lock-in: Previously established subsidy schemes</p> | <ul style="list-style-type: none"> Exponential growth of the distributed (decentralized) energy demand Locked-in technologies (Consolidation on specific sustainable technologies, especially in high-medium voltage grid) Lack of grid capacity |
| <p><i>"We assumed most solar installations would be on rooftops, but instead, large solar farms are being placed in rural areas. This mismatch between production and demand has caused grid problems... Additionally, our organization is significantly affected by the rapid rise of data centres, especially in North Holland." (Int#7)</i></p> <p><i>"Like International Energy Agency we assumed linear line of solar energy produced, but I guess with uncertainties getting lower for people, it becomes exponential quickly" (Int#5)</i></p> | <p>Technological learning: in time know-how increased about renewables, uncertainties decreased for solar installations, self-reinforcing loop for further adoption</p> | <p>Material Lock-in</p> | | <ul style="list-style-type: none"> Lack of grid capacity Delays of grid development |
| <p><i>"low voltage grids, they were never designed for people also charging their cars and heating their homes are electrically and all having solar panels on their roof. " (Int#5)</i></p> | <p>Sunk Costs- Long-life Physical Infrastructure: Existing energy grid capacity, 100-years old grid, grid that never designed for decentralized energy sources, full-spatial space</p> | <p>Material Lock-in</p> | | <ul style="list-style-type: none"> Need for adapting existing grid, Delays in grid development |

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| <p>“..but our grid was designed around a centralized model. Now, we’re trying to adapt it to a decentralized setup” (Int#9)</p> <p>“In the Netherlands—and this happens in other countries too—wind and solar farms are often located in rural areas with limited grid capacity.” (Int#10)</p> <p>“hard to find space and get permits to expand the grid as quickly as needed.” (Int#10)</p> | | | | |
| <p>“No, I don’t think congestion will end anytime soon. For the next 10 to 15 years, it’ll likely persist. Right now, we’re facing congestion as a DSO, but also the TSO has major congestion problems. They’re talking about reinforcing their grid by 2035—over 10 years from now. That doesn’t even account for future demand growth. (Int#9)</p> <p>“Well, there are many reasons, but the fundamental problem is the imbalance between the speed of growing demand and the pace of grid expansion. The demand is increasing rapidly, but building or expanding the grid takes much longer.”(Int#6)</p> <p>“Due to the grid constraints, as all of my colleagues talks about we almost risking the energy transition. We can continue with the energy transition if the grid isn’t accommodating it”(Int#8)</p> <p>“In 15 years we will still be working on grid expansion, not just for local congestion but also creating high-voltage interconnections with other countries that will help also the intermittency problem of renewables.., But grid scarcity will likely remain a long time...there will be always push for more electrification”(Int#10)</p> | <p>Locked-in Congestion- Grid Scarcity: Imbalance between the speed of growing demand and pace of grid expansion, need for reinforcing the grid, congestion will remain for years, grid development takes time, increasing demand for electrification, already integrated renewables</p> | <p>Material Lock-in</p> | <p>With Institutional Lock-in: Growing market for large-scale distributed renewable sources, uncertainties of previous demand assumptions/investment plans</p> | <ul style="list-style-type: none"> Delays in grid development, Grid Scarcity (Congestion) |

2) Institutional Lock-ins Mechanisms

| Raw data | Second-order codes: First- order codes | Aggregate code | Interaction with other Lock-ins | Consequences |
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| <p><i>“We have a system where network operators are incentivized for efficiency. It was challenging to make substantial investments in this system because the way it was structured discouraged significant upgrades.” (Int#3)</i></p> <p><i>“.. their investment per customer was lower.. so they were more efficient in their operation. That means we have to pay money excess, we won’t be the one getting the bonus, we get a penalty” (Int#5)</i></p> <p><i>“the kind of regulation is actually forcing us to be late as possible” (Int#5)</i></p> <p><i>“regulation says we need to be cost effective as possible.. with other DSOs we are benchmarked against each other, whether we have unused grids or not” (Int#6)</i></p> <p><i>“ In the past, we didn’t build excess grid capacity.”(Int#6)</i></p> <p><i>“It wasn’t prohibited, but the incentives were just against it. Right. Because if you do that and we are being compared, they introduce like kind of pseudo-competition between the grid operators, you know right I think in existing state and then our DSO and they get compared to each other and the one that’s most cost-efficient will get the most benefits, kind of a bit of financial reward. So there was a real, from the regulation side, it was the steering mechanism towards being more cost-efficient, and then it doesn’t make sense to pre-invest.” (Int#8)</i></p> | <p>Collective Action-Regulatory Rule: structure of discouraging significant upgrade, bonus vs. penalty, regulation based-on pseudo competition- “regulative captives”</p> | <p>Institutional Lock-in</p> | <p>With Behavioural Lock-in: Collective risk avoidance on proactive grid development among grid operators.</p> | <ul style="list-style-type: none"> • Limiting timely investments, • Delays of extending grid on time for energy transition |

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| <p><i>“That way of thinking may have existed 25 years ago as well, but the major hurdle is that we’ve been keeping each other hostage over regulations. This structure dictates how much a DSO can invest and earn annually, reinforcing the regulatory rule” (Int#6)</i></p> | | | | |
| <p><i>“The grid is always thought of as being a copper plate and capacity should be available anywhere at any time”. (Int#5)</i></p> <p><i>“we are bound by the regulations.. and it created the common expectation, we have to provide any client with any capacity they asks.. we have to provide it 24/7, for instance they ask for 2 megawatts but at the end use only 1 we still need to ensure that they can use 2 when they needed” (Int#6)</i></p> <p><i>"There is enough physical space, but we have to reserve capacity on the energy grid for companies and other users based on the contracts we make with them. We are obligated to guarantee the contracted capacity, and when you add up all these agreements, the grid appears full on paper—even though, physically, it isn't." (Int#1)</i></p> <p><i>“We are still approaching, to highly demanding issue as if were a free-market solution” (Int#7)</i></p> <p><i>“Another issue is that, while we’ve scaled up, the regulatory framework hasn’t adapted accordingly. In the Netherlands, we still operate under the “copper plate” principle, meaning any customer has complete freedom of connection, regardless of congestion. This approach is inefficient, as congestion costs fall solely on the grid operator. It might be more reasonable for some of that burden to shift to grid users.” (Int#7)</i></p> | <p>Institutional Learning- (Copper Plate Rule): “always thought to be”, common expectation, complete freedom of connection (demand) thought and adapted in time among different institutions (customers, regulative body, grid operators, renewable energy projects)</p> | <p>Institutional Lock-in</p> | <p>With Material Lock-in: The reserved (requested) capacity in contracts reduce the ‘space’ for using the grid for flexibility in future.</p> | <ul style="list-style-type: none"> • Grid scarcity- Congestion |

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| <p><i>“for instance a windmill they are free to choose, free to demand and we should follow them.. copper plate principle we give everyone who’s connected to grid complete freedom” (In#8)</i></p> | | | | |
| <p><i>“we are separated from power generation from network operation.. how it’s been organized historically. To give some insight into the split’s impact, when network operators and electricity companies were separated, you could see...Well, with the rise of solar panels and renewable energy, the value of electricity companies dropped quite a bit. I think that if these companies had controlled the network, they might have tried to keep renewables out of the grid because they would have had incentives to protect their own interests.” (Int#3)</i></p> <p><i>“It’s challenging because we’re pushed to find solutions with our backs against the wall. As grid operators, we’re regulated strictly and are required to solve these issues...but the same regulations don’t apply to the customers and producers using the grid.” (In#7)</i></p> <p><i>"As a liberal country, I understand the reasoning behind the European law that separated production and distribution. Encouraging competition among energy companies helped lower prices for customers. However, many congestion issues today might not exist if the sectors had remained integrated. When we were one company, production planning could coordinate directly with distribution or transmission teams—asking, for example, 'Can the grid support this new power plant or solar installation?' (Int#9)</i></p> <p><i>“ I know we collaborate with other DSOs and TSO, and other energy market players. One thing we’d like in the control room is the ability to reduce input from solar</i></p> | <p><i>Institutional Learning- (Unbundling-Separation of Roles):</i> feedback on protecting own interests, historically organised, changing conditions same rules, divided expectations</p> | <p>Institutional Lock-in</p> | <p>With Behavioural Lock-in: The uncertainty (lack of power) around innovations reinforced the traditional company culture. Separation of interest, behaviour own protecting own interest</p> | <ul style="list-style-type: none"> • Lack of timely/informed grid development/investments |

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| and wind farms when the grid is overloaded. A system button to manage this would be ideal. This way, we could instantly lower input when needed, but energy companies say... they don't want us to do that.” (Int#11) | | | | |
| <p>“But it won't be easy because consumers are protected by law and have a lot of freedom. regardless of the reason, Parliament asked that we legally forbid DSOs from restricting household electricity use. But of course, that's impossible—the electricity grid would melt if such a rule were implemented.”” (Int#6)</p> <p>“Politically, it's undesirable to steer customer behavior too much, but I think we need incentives for customers to willingly cooperate with us” (Int#9)</p> | Power Asymmetries: freedom, protection by law, power inequalities-reinforced by the institutions, political power among actors | Institutional Lock-in | | |

3) Behavioural Lock-ins Mechanisms

| Raw data | Second-order codes: First-order codes | Aggregate code | Interaction with other Lock-ins | Consequences |
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| “In the Netherlands, money ultimately dictates decisions. While there may be green ambitions, people only act when there's a clear business case.. and that happened for renewables with subsidies and so on” (Int#5) | Habitation | Behavioural Lock-in | With Technological and Institutional Lock-ins: The decreasing uncertainty around renewables and incentives/agreements create business case for specific renewables | <ul style="list-style-type: none"> Exponential growth of the electricity demand |
| "Right now in the Netherlands, demand for electrification in mobility, housing, and industry is too high. Across all our investment scenarios, consumption keeps rising. The built environment must transition from gas to electricity, and the same applies to mobility. As more electric cars emerge and gas is phased out, electricity demand across sectors—industry, housing, and transport—will continue to grow, putting increasing pressure on the grid." (Int#2) | Consumerism | Behavioural Lock-in | With Technological and Institutional Lock-ins: The decreasing uncertainty around renewables and incentives/agreements create business case for specific renewables | <ul style="list-style-type: none"> Exponential growth of the electricity demand |

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| <p>"About 40 years ago, there were around 10 electrical devices in an average household. Today, that number has increased to about 90."(Int#1)</p> | | | | |
| <p>"There were aspects we didn't anticipate, such as the need to account for a broader range of scenarios than expected. Initially, we followed the 'low' scenario, as it seemed like the most prudent investment approach. However, demand quickly exceeded that forecast." (Int#3)</p> <p>Because we didn't do our investments soon enough, and we saw that the trend is exponentially rising, which we didn't expect. Also, the ACM, our law firm, didn't expect that to happen.'(Int#4)</p> <p>"Regulation, in a way, forces you to delay action as much as possible. In a steady-state system, this might be an efficient way to keep costs low. However, it does not encourage proactive investments to prevent grid constraints from emerging...It cannot be the case that we put everyone on a waiting list before making investments. While this approach might make sense financially or from a regulatory perspective, it is far from optimal for society."(Int#5)</p> | <p>Risk Avoidance</p> | <p>Behavioural Lock-in</p> | <p>With Institutional Lock-in: The regulatory rule relies on efficiency which reproduce the risk averse company behaviour</p> | <ul style="list-style-type: none"> • Delay of extending the grid/timely investments |