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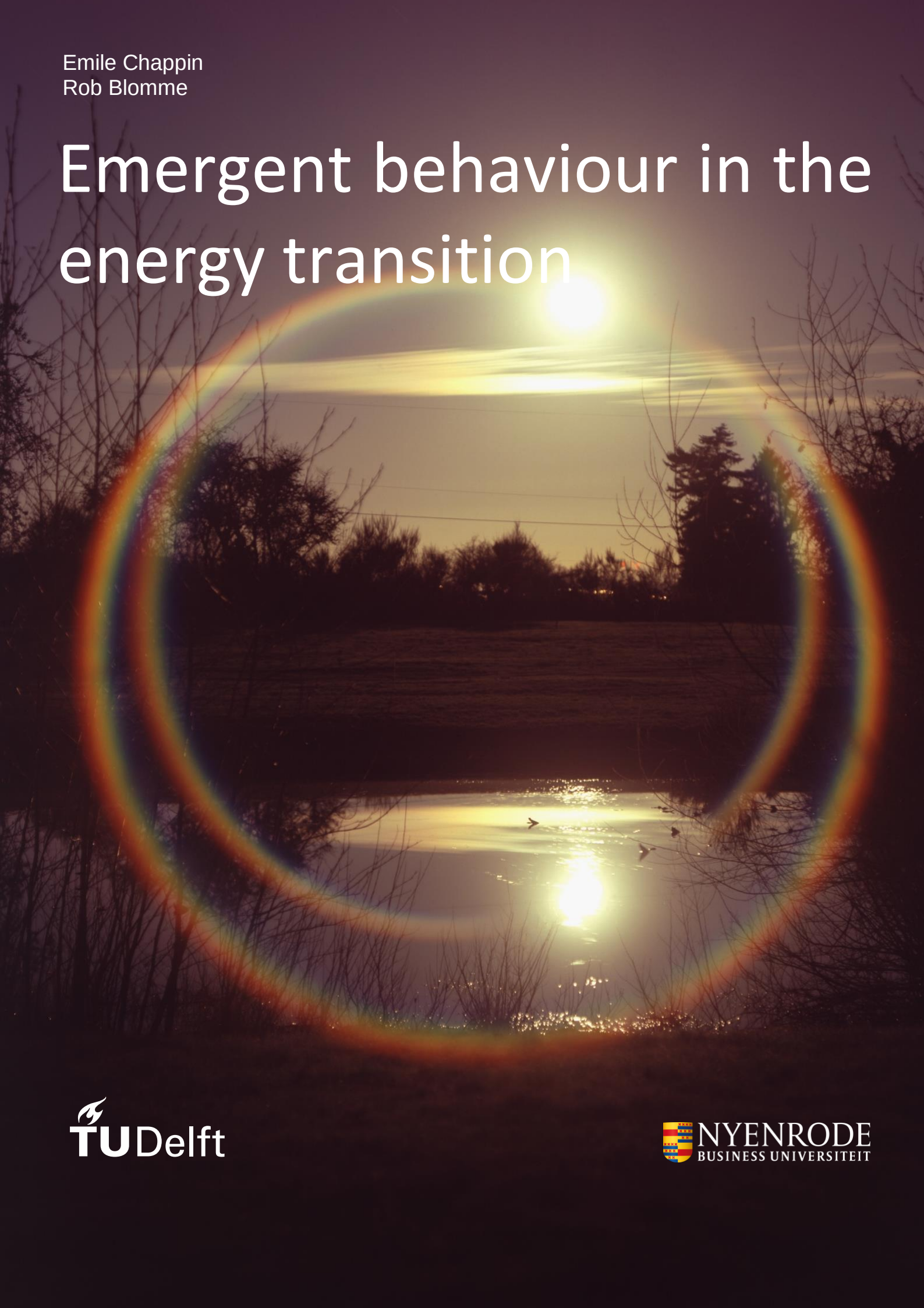

TU Delft
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Emergent behaviour in the energy transition

By

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Executive summary

Mitigating the adverse effects of climate change requires us, globally, to speed up the energy transition: to decarbonise energy supply while maintaining the security of supply and the affordability of energy services. This is an unprecedented challenge. The energy transition seems to have moved into a phase of scaling up: technologies are becoming competitive; more and more of the public will have to be involved in the energy transition in the coming years.

In this report, we outline the opportunities that come from studying so-called 'emergent behaviour' in the energy transition. Emergent behaviour are trends or patterns observed on the aggregated/system level that are not a simple sum of the individual actions. What drives behaviour is hard to anticipate, but understanding it is crucial for a successful energy transition – to avoid lock-in and delays. As such, this report outlines what the concepts emergence and complexity theory can entail for the energy transition, what approaches there are to study this, and how to translate this into action. We focus on how we may be able to anticipate how such behaviour (i.e., opinions, choices and using) of larger societal groups may promote or hamper progress in the energy transition. And, at the end of the day, how to affect those processes to scale up a fair, inclusive energy transition robustly.

Based on literature and interviews, we provide five perspectives: 1) behaviour in the energy transition, 2) the transformation of large systems, 3) emergent behaviour and marketing, 4), modelling emergent behaviour, and 5) intervening to shape complex systems.

There are substantial opportunities to better develop, study and integrate concepts from complex systems and energy systems research and modelling into decision-making processes for the energy transition. We present a research agenda including a concrete action plan for the following research challenges: behavioural theory and modelling of the energy transition, 2) anticipating emergent behaviour to scale up the energy transition, 3) developing transition narratives, and 4) embracing key/change agents and emergent leadership. The action items vary between quick wins and fundamental research ideas that may, together, help us to better shape the energy transition.

Contents

1. Introduction

Mitigating the adverse effects of climate change requires us, globally, to speed up the energy transition: to decarbonise energy supply while maintaining the security of supply and the affordability of energy services. This is an unprecedented challenge. The energy transition seems to have moved into a phase of scaling up technologies are becoming competitive. Climate change and the terms sustainability energy transition have become a central topic of discussion throughout societies globally.

In this report, we outline the opportunities that come from studying so-called 'emergent behaviour' in the energy transition, which can be defined as *patterns and developments on the system level that come about from actions of individuals and stakeholders during the transition process.* Such emergent patterns are difficult to anticipate and difficult to steer. Nevertheless, for the energy transition to accelerate, we need to anticipate how behaviour (i.e., opinions, choices) of larger societal groups may hamper or promote progress in the energy transition. And, at the end of the day, how to affect those processes to scale up a fair, inclusive energy transition robustly.

This first chapter introduces the topic and provides an outline for the remainder of the report.

1.1. The energy transition

The challenge in achieving a successful energy transition is in its urgency and complexity, of which key aspects are outlined here:

Goals, urgency, action

Our energy transition goals are urgent: delays have serious consequences. The urgency is not necessarily experienced by the general audience (yet), and it is challenging to connect global and local climate emergencies to local actions in the energy transition. Recently, the sense of urgency has increased because of the war in Ukraine. This is a key example of an emergent phenomenon: the discussion on switching away from Russian natural gas and oil is now a key part of the societal debate on the energy transition. While it has been impossible to anticipate this specific development, the question that comes with this development is *how* to use this momentum to increase the chance of a timely energy transition.

Technologies

All activities and sectors require energy, and the energy transition aims to transform the backbone of society. There are technological options, each with its properties, pros, and cons. None of them is the silver bullet for the energy transition. This includes electricity generation, transmission, energy storage, hydrogen, decentral technologies. The technological system performs different functions and the infrastructure system as a whole, together with all the stakeholders that invest and operate them, needs to function together at any stage in the energy transition, for a functioning society.

Scenarios, assumptions, behaviour

Many technological scenarios for the energy transition that are feasible and economically sound. All these scenarios could be considered 'optimal' to various sets of assumptions in costs developments and behaviour of a wide range of actors. At the same time, any choice for a technological option requires other decisions throughout energy value chains and appropriate policy support, regulation, and actions by a wide range of actors (including the public). A key challenge

to accelerate the energy transition is the uncertainty that comes from this: what scenario(s) do we desire/anticipate for and can we align all stakeholders' actions to contribute accordingly, and to play their part.

Policy intervention

Looking at all the complications above, the question 'what policies are needed for success?' is not straightforward. There are already many policies that affect energy investments and behaviour; those themselves interact in complicated ways. They may vary in scale and scope (which technologies, which regions, which types of incentives). Any additional intervention that aims to speed up the energy transition needs to consider the existing policy scope, both nationally and on the European level.

1.2. Emergent behaviour

One of the areas in energy transition research that, so far, has been somewhat left behind is the consideration of behavioural aspects. What drives behaviour is hard to anticipate, but understanding it is crucial for a successful energy transition. For long-term iterative processes such as the energy transition, it is vital to consider emergent patterns in behaviour. Such patterns emerge out of the actions of individuals as well as companies, system operators, governments.

The public gets involved

Now we are reaching a phase of scaling up, the public will be affected directly by regional and local actions, e.g., through regional energy strategies and local initiatives (e.g., energy cooperatives). It is long overdue to consider carefully how to avoid behavioural barriers hampering the progress in the energy transition.

What drives human behaviour

Understanding what drives human behaviour is complicated. Many (psychological) processes play a role, decisions are often habit-driven/non-deliberate, they can be influenced by others, by perceptions, and by earlier behaviour. In other words, decisions are not made in isolation. Because of all these interacting processes, what dominates in a specific situation is hard to anticipate.

Decisions-making is multi-topic, multi-stakeholder, and multi-level

Decisions made with respect to the energy transition are diverse: it is about the adoption of technologies, about habitual behaviour, about energy in the built environment, but also about public perception of each technology, about infrastructure development and about developments abroad. There are decisions made by individuals and households, but also those by companies, by utilities, by commercial parties, by network operators, by governments. And those act on multiple levels (local, regional, national, supranational).

System-level behaviour is *emergent*

Figure 1 shows that out of all the decisions made, by all these stakeholders, system developments emerge. It also shows that exogenous events may be a key driver. Vital to the success of the energy transition is that we are adequately able to shape the developments in desired, emergent, patterns in a timely fashion. Understanding the behaviour of individuals, groups of individuals, companies, and other stakeholders is impossible by excluding the systems they are part of. And understanding systemic change is impossible without understanding the behaviour of those stakeholders.

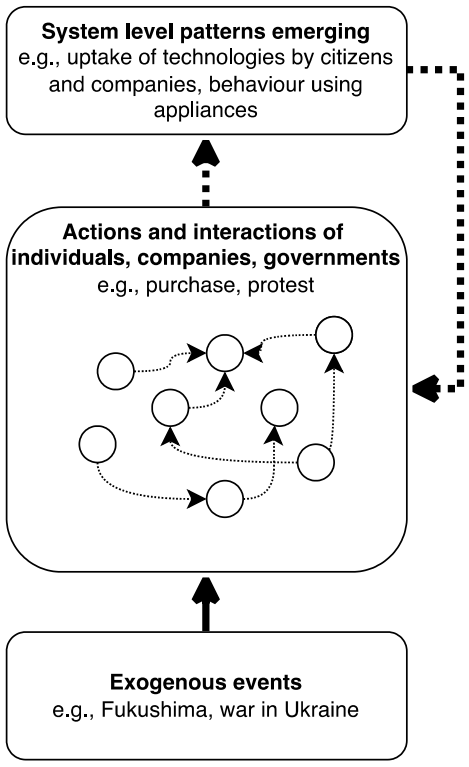

Figure 1. Emergent system-level patterns, and examples. On the system level, patterns can be observed that emerge out of the actions and interactions of individuals and others. These actions, in turn, may be driven by exogenous events. Over time, system-level patterns can also affect local actions.

1.3. Objective

This report sketches the challenges and opportunities concerning emergent behaviour in the energy transition. We discuss what has been done and outline essential opportunities for further research.

1.4. Outline

This report is structured as follows: Chapter 2 discusses the approach used and distributed tasks. Chapter 3 discusses literature on how emergent behaviour in the energy transition has been studied so far, including a synthesis from interviews held during this project. Chapter 4 presents a research agenda with 8 research challenges, an action plan for each of the challenges, and the potential impact of that action plan. The report contains an appendix with interview reports.

2. Approach

This chapter presents the approach used to develop this report. Important points, caveats and notes are listed as red flags (symbolized with ⚠).

2.1. Literature review and interviews

Literature review

Critical literature is evaluated from five perspectives: 1) behaviour in the energy transition, 2) the transformation of large systems, 3) emergent behaviour and marketing, 4) modelling emergent behaviour, and 5), intervening to shape complex systems. Each of these perspectives is sketched, critical assumptions are explained, as well promising contributions; combined with results of the interviews, these findings are in Chapter 3.

Interviews: numbers

In total, we have held 9 interviews. Of these, five were with researchers with a diverse set of perspectives on emergent behaviour and the energy transition. Furthermore, 4 interviews were held with stakeholders in the energy transition from different areas of energy value chains. The interviews were held in January/February 2022 and were 30-60 minutes each.

Interview format, themes, and reporting

The interviews were open; only the topic had been mentioned before the discussion started. At the beginning of the interview, the project was shortly introduced.

The questions mentioned below were used as a guideline during the interview. We started with a question to clarify what emergent behaviour is according to the interviewee, allowing us to explain more in case this was necessary. We have structured subsequent interviews to identify central themes and synthesise them. We report on each interview with the main points, we informed the interviewee of our summary and provided the opportunity for feedback.

Interview questions

- What is **emergent behaviour** in the energy transition?
- What **critical challenges** do you see in the energy transition and which ones do you work on?
- What **methods** can be used to study progress in the energy transition, particularly on the topic of emergent behaviour?
- What **kinds of behaviour** do you consider relevant, belong to your focus? I.e., adoption, use, accepting, forming an opinion, discussing, protesting. What methods can you use for what kind of behaviour?
- What is the most significant **contribution**, in your view, based on your work? Understanding, policy, implementation, methodological, and so on.
- What are critical strengths and weaknesses, including the limitations of the methods you use/know?
- To what extent is the **predictability** of behaviour in the energy transition important and limited?
- To what extent can results on emergent behaviour **be generalised?** (E.g., to other regions, appliances/devices/energy functions, etc.)
- What are **vital resources** (methods, reports, scientific papers) as examples of how emergent behaviour in the energy transition can be studied and affected effectively? (E.g., consumer behaviour, marketing, complex systems, simulation models, empirical research, hybrid/interdisciplinary research.)

- What are **knowledge gaps** for studying emergent behaviour in the energy transition? What is the next step?
- Are there things we **missed** in our discussion?

Findings from the interviews are integrated in Chapter 3 and reported individually in Appendix A.

2.2. Research agenda and action plan

As a synthesis of the literature review, a review agenda is de developed with key research challenges, as well as a prioritization, and what may be expected in terms of accelerating the energy transition. The research agenda is in Chapter 4. For each research challenge, the challenge is compactly described. Afterwards, an action plan with various items is determined. For each item, the suggested approach is given as well as the market-readiness level. The potential impact is described.

2.3. Tasks and responsibilities

The responsibilities in this project were divided as follows:

Table 1. Tasks and responsibilities.

Section	Title	Reponsible author
1	Introduction	Emile Chappin (TU Delft)
2	Approach	Emile Chappin (TU Delft)
3	Perspectives on emergent behaviour and the energy transition	Emile Chappin (TU Delft)
3.1	Energy systems and behaviour in the energy transition	Emile Chappin (TU Delft)
3.2	Transformation of large systems	Rob Blomme (Nyenrode)
3.3	Emergent behaviour seen from different academic areas	Rob Blomme (Nyenrode)
3.4	Modelling emergent behaviour	Emile Chappin (TU Delft)
3.5	Intervening to shape the energy transition	Emile Chappin (TU Delft)
4	Research agenda and action plan	Emile Chappin (TU Delft)
4.1	Behavioural theory and modelling of the energy transition	Emile Chappin (TU Delft)
4.2	Anticipating emergent behaviour to scale up the energy transition	Emile Chappin (TU Delft)
4.3	Developing transition narratives	Rob Blomme (Nyenrode)
4.4	Embracing key/change agents and emergent leadership	Rob Blomme (Nyenrode)
Appendix	Interviews	Emile Chappin (TU Delft) & Rob Blomme (Nyenrode)
All	Report layout	Emile Chappin (TU Delft)

3. Perspectives on emergent behaviour and the energy transition

This chapter contains results from literature review and interviews on energy systems and behaviour in the energy transition (3.1), on transformation of large systems (3.2), emergent behaviour in different academic disciplines (3.3), modelling emergent behaviour (3.4), and intervening to shape the energy transition (3.5).

3.1. Energy systems and behaviour in the energy transition

In this section, we describe the context in which behaviour in the energy transition takes place: the energy systems, objectives for the energy transition and types of energy behaviour.

Objectives for the energy transition

The 'energy transition' has, in the Dutch context, explicit objectives. A process is in place to achieve those objectives. The goals translate from the Paris agreement that aims to limit (the impact of) global warming, European targets to decarbonise and green the economy, to national objectives for 2030 and 2050. And in the Netherlands, there is a vital role for regions: 30 RES regions have been established[1] in which all key stakeholders (municipalities, network operators, knowledge partners, energy companies, cooperatives) work together to develop scenarios and, at the end of the day, make all local changes required.

This context is vital for how the energy transition may be perceived, and in turn, for what can be expected. But all these developments are embedded in existing, interconnected, and interdependent energy systems, providing the backbone of society.

⚠ Different objectives for the energy transition interact: decarbonisation may be achieved through renewable energy, and reducing energy demand also contributes to lowering environmental impact.

Because a plurality of scenarios may fit with the energy transition objectives and because of the interdependent nature of energy systems, developing scenarios, and translating objectives to responsibilities and actions is not straightforward.

⚠ The multi-stakeholder aspect is crucial for in the energy transition: outlining responsibilities within envisioned transition scenarios.

What are energy systems?

Energy systems connect energy suppliers and consumers; they enable generation, conversion, storage, and transmission/distribution of all energy required to fuel societal sectors, allowing for a wide diversity of energy functions (Emile J L Chappin, 2011). They are large, interconnected and *socio-technical* (see Figure 1). This makes energy systems complex.

[1] https://www.regionale-energiestrategie.nl/

The technical subsystem includes physical infrastructures (pipelines, power lines), power generators, devices, appliances, storage, etc. Through these physical infrastructures, energy generation facilities are connected to appliances/technologies which consume energy.

Additionally, the social subsystem contains all stakeholders affecting investment and operation/use of the physical system as well as all the rules (laws, codes), markets, and policies. Any change in the physical portion of energy systems is due to the decision of (one or more of) the stakeholders. Behaviour may be organized/structured through markets (e.g., wholesale markets for electricity). And decisions are affected by energy policies. Some stakeholders have specific roles related to the functioning of energy systems: the TSO and DSO, for example, are responsible for maintaining and developing the power grids (resp. the transition and distribution grids) and for safeguarding that their functioning is safe and secure.

Because of the ongoing systemic changes, the energy transition, some roles are changing. Figure 2 shows some of these relatively new roles: energy conversion and storage may now also occur on a local level, where end users become prosumers with their own solar panels, and storage owners with batteries in electric vehicles. New roles are emerging, due to these and other changes. Specifically, a new role emerges to invest and operate large energy storage. Rules and regulations need to follow new and changing roles in order for the infrastructure to keep functioning adequately.

⚠ Energy systems are large, include many stakeholders and large infrastructures.

Energy systems also interact with the environment through the extraction of resources (both directly and indirectly) and through the emissions and other waste that come from these systems.

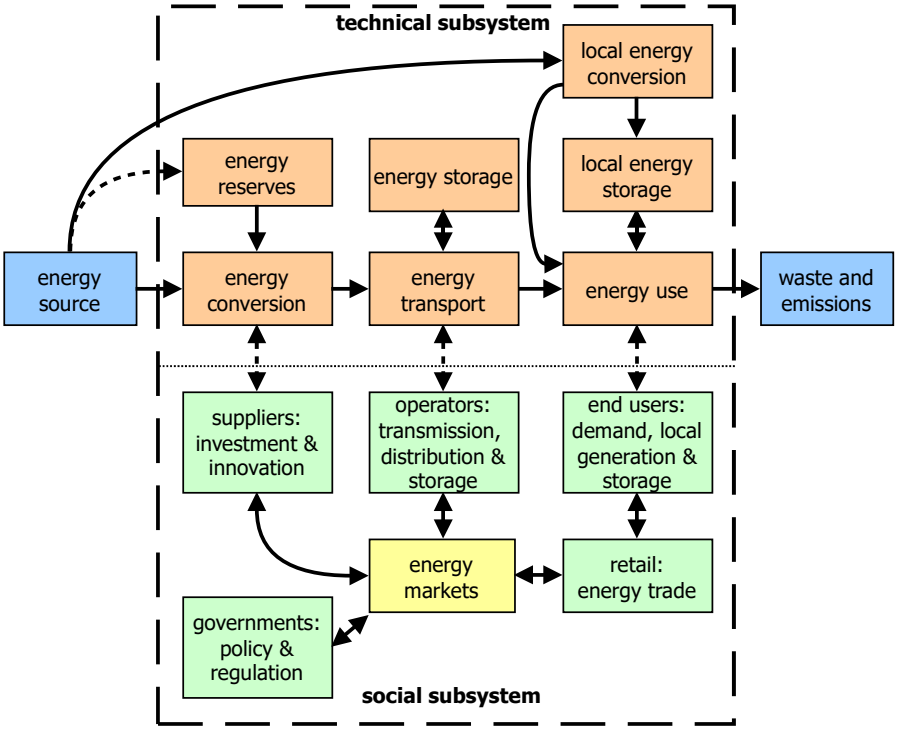

Figure 2. Energy systems are socio-technical systems. Expanded from (Emile J L Chappin, 2011). *This is a stylized representation; systems for specific energy carriers (may) have more connections and roles. For varying geographic scopes, other functions may be relevant.*

Interdependencies in and between energy systems

Because of various interdependencies – between carriers, functions, infrastructures, policies, and scales – energy systems are hard to study in isolation, which affects studying emergent behavioural patterns.

- **Energy carriers** connect. Different energy infrastructures are interdependent, with many physical connections between energy carriers. One key example is that natural gas is used to produce electricity.
- **Energy functions** connect. New energy functions create new connections and, as a result, new interdependencies: electric vehicles have related power to the energy function personal mobility.

- **Energy infrastructures** evolve. A new hydrogen infrastructure as a new energy carrier is envisioned/implemented rapidly to (partially) replace the natural gas infrastructure, i.e., the hydrogen backbone[2]. This also relates to district heating, e.g., the Warmte Koude Zuid-Holland[3].
- **Energy policies** affect both global developments and local actions. CO_2 prices in the EU ETS have climbed from under 10 to over 90 €/ton in a couple of years[4]. This was unexpected for many, although it was anticipated in our simulation studies which allow for emergent investment patterns (see Fig. 3 in (E.J.L. Chappin et al., 2017)). A complicating factor is that multiple policies affect each other (targeting the same local decisions, influencing each other's effectiveness).
- Energy systems interact **on various scales**. Unexpectedly high natural gas prices are another example, which affects geopolitical processes, national strategies as well as the local decision context (Mulder et al., 2021).

⚠ Energy and electricity are often used interchangeably, but energy is the generic term for all energy carriers. Energy systems, therefore, includes a much larger scope (compared to electricity), e.g., including natural gas-based heating.

⚠ Studies that do not specify assumptions regarding all relevant interconnections must be interpreted with care. The context to which results are valid may be unclear/unidentified. This includes assumptions about other energy carriers, related energy functions, developments in infrastructure, and the policy context.

Energy decisions and behaviour

Energy behaviour takes place in the context of these enormous energy systems. Systems provide the context, e.g., by affecting which options are available, the relevant decision criteria, perceptions about technologies. And after actual decisions are made, it means a change in the same energy system. Consumers may exchange information, perceptions, opinions and respond to each other's observed behaviour. Consequently, depending on what specific decisions are made, and when, particular patterns in emergent behaviour come about and the energy system as a whole evolves (Emile J L Chappin, 2011). Consequently, in view of anticipating patterns in emergent behaviour, it is vital to be aware that decisions take place in complex socio-technical systems.

⚠ Energy systems evolve through emergent patterns in behaviour.

The **types of decisions** made can be very diverse. Energy behaviour includes many kinds of decisions ranging from investment decisions to emotional responses to local energy projects. To provide structure, two important dimensions (observability and focus), are indicated in Figure 3, with typical examples.

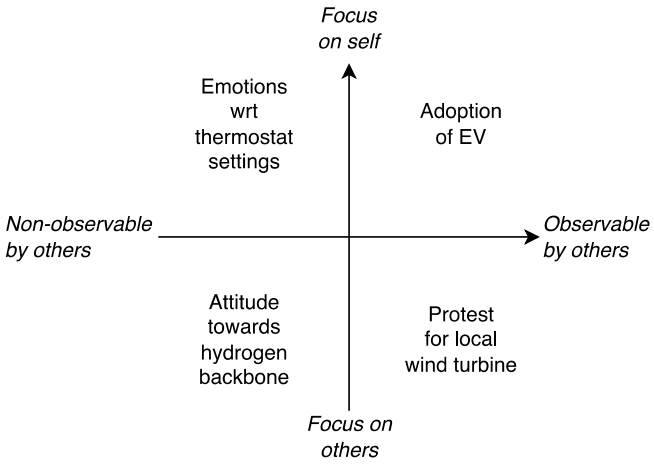

Figure 3. Typology of energy attitudes and behaviour, differentiating the focus on self and others (vertical) and decisions that are observable or non-observable by others (horizontal).

[2] https://www.gasunie.nl/expertise/waterstof/waterstofbackbone
[3] https://warmopweg.nl/warmterotonde/
[4] https://sandbag.be/index.php/carbon-price-viewer/

The first distinction is between behaviour that focuses on the self from decisions that focus on others. Behaviour regarding owned appliances (e.g., a gas heater, or a car) are different to technologies in the local vicinity or further away (a local wind energy project, the electricity infrastructure, gas extraction in Groningen (for people that do not live elsewhere)).

The second distinction is from behaviour that can be directly observed or measured by others (e.g., purchase of a heat pump and organizing or joining a protest) versus behaviour that cannot be directly observed or measured (attitudes, opinions). Although the latter can be indirectly measured, e.g., through interviews or surveys, they cannot easily be noted because of the tacit, implicit nature. Despite the fact that attitudes and opinions may not be considered as behaviour, they are included here because they may be key drivers of (later) observable behaviour.

Energy behaviour includes *adoption* decisions: what equipment/technologies do individuals/households, companies, and industry invest in? One example for households is installing PV panels on roofs (Alipour et al., 2021). It also includes decisions with respect to *use*: how often and in what manner are technologies used. Furthermore, it includes behaviour related to external technologies (opinions, protests with respect to technologies that are perceived in the environment).

⚠ 'Energy behaviour' typically is the observable outcome of decisions made by individuals about their energy consuming appliances.

Most day-to-day decisions are habit-driven (simply because they are low interest, repetitive decisions). During the energy transition, energy behaviour may have to become more planned, more deliberate. Many factors influence such planned decisions (Ajzen, 1985; E J L Chappin et al., 2020; Gerdien de Vries et al., 2021; Hesselink & Chappin, 2019). Actual decisions are complex: many criteria may play a role in decisions, e.g., financial, greenness, image, status, reliability, comfort, perceptions, and innovativeness. And these may differ between consumer groups and product types. The following are important factors:

- Who is perceived to be **responsible** for certain decisions? (This can be a household, the municipality, the government, the infrastructure owner, the tenant or owner, an energy cooperative).
- Perceived **knowledge** and **attitudes** affect whether decisions are deliberate, or whether current habits continue.
- The **opportunities** for making changes are infrequent. There may be 'unplanned' windows of opportunity (e.g., when you move house or when your CV breaks down).
- Some choices may **depend** on other changes throughout energy systems. Some options exclude others. Some options are not being available unless something else happens. Examples are that charging infrastructure in the street is required before an electric vehicle is an option, and that a heat pump is only a valid option if other measures are taken/conditions are met (e.g., proper insulation, required physical space).
- Not all options are **comparable** (district heating uses a shared infrastructure, while a heat pump can be privately owned, this affects the relevant criteria, timeline, and scope for the decision)
- For large **investments** (from the perspective of the investor), perceived uncertainties play a significant role, as well as the investment climate and opportunities for financing.
- **Hassles,** even small ones, may significantly hamper behavioural changes.
- Decisions may show **rebound effects**: (1) Now I have already done *y*, I do not have to care anymore about how I use *y*; (2) I'm already doing *y*, so I don't have to do *x*; (3) Stakeholder *q* should do *y* before I do it.

⚠ Extrapolating behaviour from one group to another is often not valid because of the context-specificity that applies (e.g., from one region to another, from one consumer group to another, from one type of appliance to another).

3.2. Transformation of large systems

Scientific and societal interest in societal change has been awakened the last decade due to converging and persistent global crises and problems, including climate change, resource depletion and widening social inequality. In the

Netherlands these global crises have been transferred into more defined societal changes including the energy, agriculture transition and more inclusivity within organizations and society. Societal change has been often addressed as transition and transformation which are often used interchangeably to express the ambition to shift from analysing and understanding problems towards identifying solutions and roads for wanted environmental and societal change (E.J.L. Chappin & Ligtvoet, 2014). Although a variety of research approaches have been developed to understand, analyse, and support societal transitions or transformations, a macro-economic perspective is mostly used as an input for the development of policies and legislation. However, there is a growing number of publications which claim that the traditional (macro-)economic mainstream paradigms fall short in approaching and comprehending big real-world events which impact societal change and transitions. These models include for example rationality, representative agents and a perfect market equilibrium in the long-term, which are deviant from the real-world characteristics of society (cf. Stiglitz, 2018). Economic researchers emphasize the importance of societal characteristics such as complexity, feedback loops, path-dependency, uncertainty, and multiple heterogeneous interacting agents which are not included in the traditional macro-economic models (Mercure et al., 2016).

⚠ A macro-economic perspective falls short in the design of interventions for the energy transition.

As such, for a further comprehension of big societal events there is a growing number of economic literature which calls out for approaches which emphasizes the complexity of societies and its economics, characterized by non-linearity, non-ergodicity, and deep uncertainty (Hafner et al., 2020). This approach stresses the society and its economics as evolving and complex adaptive systems, which are strongly interconnected (R. J. Blomme, 2012). Henceforth, theory on emergence and complex system approaches may provide new avenues to explore the conditions and potential success of societal transition.

⚠ Societal systems are evolving complex socio-technical systems.

Emergence

The central idea of emergence is that the order of behaviour is emergent (Drazin & Sandelands, 1992). Structure or order emerges from the actions and interactions of agents – stakeholders, participants, companies, individuals – within a system. Social structure is a mental construct as displayed by categorization schemes used by agents as a means to make sense of their flow of experience. Emergence is not a static property of a system but is an evolving process. This logic exists as rules played out by the agents. The process of emergence can also be explained as the process of structuration; structure or order is not an omnipresent force that continuously reproduces itself but a process in which the agents are empowered by the logic provided to act. Moreover, with their capacities and inclination agents are able to change that logic when interacting with other participants and with the establishment of a new logic, a new related structure emerges.

Hence, bringing about the energy transition will have the consequence the breakdown of an old logic and structure and the establishment of a new logic and related structure. However, this requires new patterns of behaviour by the agents. The environment functions as an important input for emergent change. Exogenous change exerts pressures on the behavioural system, which determines its own emergent actions (Mezias & Glynn, 1993). These actions are then further shaped by internal and external forces with a further continuation of the cycle. Emergent change will take place when exogenous change leads to a decrease in the system's performance, and agents are aware that the current logics are no longer working effectively. Hence, emergent change can be defined as the structuration process of agents in which the structure and underlying logics are perceived as unworkable and in which agents make sense of new logics and related structures that will eventually work. As such, the society can be considered as an emerging system in which compliance with the energy transition has the consequence that new logics will emerge.

⚠ Transition is a process of change of the social structure which is emerging from the behaviour and interactions of participants within a system.

Influencing institutions

If we examine the role of institutions which try to fuel transition within the society by policy making and direct interventions, the emergent perspective maintains that there is no fundamental difference between these institutions

and the society as such. How can institutions change a social system such as a society if they themselves are part of it? All the events in a social system are embedded in a social context. How people act in such a context is the result of the experiences and artefacts which people have accumulated in the past. Transformation and transition are often seen as the opposite of the stable societal systems. In the beginning society is stable; change is then induced in the societal systems. The change process is brought to a halt once the appropriate ultimate state of organizing has been achieved. As such, change and social systems are not opposites: the social system itself is precisely where changes continuously take place. Therefore, such an institution does not transform societal systems directly. The operate through change in agents actions, shaping the emergent system behaviour

⚠ Institutions that want to bring about the energy transition in society are a part of the societal system they intend to change.

First, we will address the incremental aspect of emergent change. In contrast to transformational perspectives of change and transition in which influencing institutions redefine structures and policies, emergent change passes through small steps unfolding new logics and structures as it does so. We could also argue that change and transformation are unplanned processes, which contradicts the theories of planned change, such as those found in the institutional perspective or in the resource-based value perspective. Emergent change is a reaction to the perceived exogenous changes by the system's agents. We could also conclude that from an emergent perspective, change is remedial rather than developmental. Emergent change will take place when the underlying logics cannot help in dealing with an exogenous change which might impact the existential needs of agents (R. J. Blomme & Lintelo, 2012). Without this exogenous change, agents are inclined to instantiate their own logics. This is different from the developmental change perspective in which agents are willing to change their logic without there being an exogenous threat. As such, emergent change can be characterized as incremental, unplanned, and remedial.

⚠ Emergent change is affected by the way how agents perceive and respond to exogenous events.

Emergence (R. J. Blomme, 2012) is increasingly becoming an important concept in understanding the dynamics of social systems and has a strong connotation with concepts like spontaneous change, autopoiesis, complexity theory and self-organization. A considerable number of studies on behavioural dynamics share the same premise: that emergence is the result of self-organizing processes in a social system that can be considered to be closed, that it is free of external interventions, and that it produces unpredictable outcomes. The degree to which systems are closed is that emergent processes are confined to the system itself; exogenous events can be observed but are not a part of the emergent process itself. The process of emergence suggests that a social system is evolving from one state of behaviour into another state of behaviour. The outcome of this evolution, a state of behaviour, is unpredictable. Emergence is an important characteristic of a complexity approach to social systems. The use of complexity theory has not restricted itself to the hard natural sciences only. Since roughly the mid-1990s social sciences have become increasingly interested in complexity theory as a way to approach behavioural and social dynamics) and has been expanded to the theory on transition processes and societal change.

⚠ Emergence is the result of self-organizing processes in a social system that can be considered to be closed, that it is free of external interventions, and that it produces unpredictable outcomes.

3.3. Emergent behaviour seen from different academic areas

Complexity theory in the social sciences

Complexity theory is a system theory (see for example, Uhl-Bien et al., 2007). In a system theory the delineated entity (system) is the focal point from which we attempt to comprehend the order of behaviour and the behaviour of the agents. The connection with the outside world is determined by the input – the 'things' which the system needs to display a particular behaviour – and the output – the 'things' which result from behaviour. In complexity theory, the nonlinear comparison is important when describing the behaviour of the system. This comparison is a mathematical model of relationships in which the effect of a cause is not proportional and in which a cause has more than one effect (Blomme, 2012). This nonlinear relationship between input and output can be found especially in the supplementary positive feedback loops, in contrast to the negative feedback loops, which form the basis of a linear comparison of

system behaviour (the cybernetic approach). In principle, the nonlinear relationships are deterministic, that is, the relationships themselves do not change or evolve. Nonlinear systems may display different types of temporal patterns depending on the balance between positive (deviation-amplifying) and negative (deviation-reducing) feedback loops over a particular period of time. Nonlinear systems can attain stable equilibrium, either static or cyclical, over a certain period of time. Nonlinear systems, however, may also show behaviour which can be characterized as states of bounded instability and explosive instability. Nonlinear behaviour depends on the interaction between positive feedback, which leads the system towards instability, and negative feedback, which ensures that variations in behaviour are damped. Positive feedback ensures that a system is destabilized, whereby existing patterns of behaviour in the system are no longer followed. The feedback loops consist of the responses of the social groups outside the system boundaries. This could be the behaviour of people outside the system boundaries, physical resources and information, for example

An example of how positive feedback loops work when these exceed the impact of negative feedback loops can be displayed with the process of a bank run. Normally a bank has as a primary task to collect savings from its customers and invest this money in ventures. A negative feedback loop consists of the number of customers who are willing to deposit their money; the more deposits there are, the more quickly the bank will grow. Take a bank that acts professionally as an example. One bad day a large number of customers come to the bank at once without any exact reason. Some customers, being confronted with so many others at the bank, start to worry. Their worry starts to fuel false rumours that something is wrong with the bank. Hearing these rumours, other customers rush to the bank to tyro get some of their money out. The number of customers at the bank increases, as do their excitement and nervousness. This fuels the false rumours of the bank's insolvency and impending bankruptcy more and more, with an effect that more customers come to the bank and try to withdraw their money while they still can. At the end of the day the rumour of insolvency has caused such a sudden demand by too many customers asking to withdraw their money, which the bank could not comply with. The bank run ends with the bank becoming insolvent and as a consequence declaring bankruptcy. If we apply the theory of complex adaptive systems to this case, we can address the false rumours about the instability of the bank as positive feedback loops. Over a period of time we see that the customers' withdrawal of cash enforces new withdrawals, which in turn produces new positive feedback loops and results in the bank's bankruptcy (Blomme, 2012).

An example how negative feedback loops work is for example the tendency people have to manifest their routines.
Is the underground storage of CO2 in Barendrecht. Research in commission of the government by objections committees displayed no objections against the project. Henceforth, the government/parliament decided on the continuation of the CO2 storage in Barendrecht. The inhabitants of Barendrecht-Ziedewij were against the stories. The involvement of parties including the province Zuid-Holland and the municipal government were also against the CO2 storage and functioned as negative feedback loops to amplify the resistance against the storage. In the end, after the fall of the government the project was cancelled.

These two examples display that change is an emerging process which is evolving from within. In the bank run the change was ignited by agents from within the system, in the CO2 storage case change was imposed by external parties, and internal agents were looking for exogenous factors with which they could legitimate their ongoing resistance. It occurred that no agents from the city block were mobilized to start up emergent change initiatives.

As such, a complex social system such as a society has the following characteristics:

- The process of emergence is non-linear and henceforth not predictable.
- Exogenous events are represented by feedback loops which affect the order of behaviour in the system.
- Positive feedback loops lead to instability of the system by which a new order of behaviour can emerge.
- Negative feedback loops lead to further stability of the system by which the present order of behaviour is affirmed.
- Transition is the process in which the system is going to a new order of behaviour induced by positive feedback loops.

⚠ Complexity theory is a way how to understand the concept of emergence. It is the result of self-organizing processes in a social system that can be considered to be closed, that it is free of external interventions, and that it produces unpredictable outcomes. When considering a society as a complex system, society is

characterized as a nonlinear system which displays different types of temporal patterns depending on the balance between positive (deviation-amplifying) and negative (deviation-reducing) feedback loops over a particular period of time.

⚠ Nonlinear systems as societies can attain stable equilibrium, either static or cyclical, over a certain period of time. Nonlinear systems, however, may also show behaviour which can be characterized as states of bounded instability and explosive instability.

Sociology and Economic sciences: Complex Adaptive Systems

The concept of Complex Adaptive Systems is often used in Sociology and Economic Sciences to simulate behaviour of large groups of agents such as a societal system (see for example, Maguire et al., 2006). In a system interaction occurs between large groups of agents. Agents adapt their behaviour to other agents. This produces patterns of interactions. Another characteristic of these agents is that they each try to attain their own goals, which in turn allows them to obtain an independent relationship with some of the other agents. Agents also realize that success can be measured according to the actions performed by others. The patterns of interactions, the sharing of common goals, mutual dependence and the nature of that independence allows some agents to belong to the system but not others. The agents which belong to the system are referred to as a population. It is the aforementioned factors that produce a type of order in a complex adaptive system which is changeable and diverse, and which occurs spontaneously.

Therefore, the emphasis is more on the relations between the entities than on the individual constituents themselves (R. J. Blomme, 2012). This removes the central position the cognizant individual was once accorded by previous systems theories and contrasts with the viewpoint of the rational individual who acts upon the (financial) inducements provided by government and related institutions. Moreover, what has been newly created is essentially unpredictable. The position of an external, objective observer is problematic because the complexity theories argue that new forms develop spontaneously through the process of self-organization in which agents are participants. The following question remains: How does emergence occur in such a complex adaptive system? In a state of stability behaviour follows point attractors which represent the ordering of behaviour in the system (R. Blomme, 2003). Behaviour which is in line with the point attractors represents stability in the system. In a state of stability behaviour tends to adhere to the system order every time despite destabilizing influences from both inside and outside the system. Negative feedback will have a damping effect on these destabilizing influences, which causes unusual behaviour to conform with existing point attractors. However, if the influence of positive feedback is greater, instability will increase, and the point attractors will increasingly change into complicated, cyclical attractors.

⚠ Positive feedback loops will change the state of a societal system; a societal system will be brought into transition.

Organization sociology and anthropology: Complex responsive systems

The theory of Complex Responsive systems distinguishes itself from other Complexity theories because it argues that human behaviour systems are complex responsive processes rather than complex adaptive processes (Stacey, 2011). The theory of complex responsive systems is an interpretation of the general thinking on complex adaptive systems. The approach to complexity is based on the ideas put forward by the sociologists Herbert Mead and Norbert Elias. The basic idea behind complex responsive systems is that human experience is organised by themes, narratives, and interactions. The analogy with point attractors for human interaction is a recognisable pattern in the sequence of organizing themes, which in turn elicit other organising themes. According to the scholars in this discipline, the analogy between this approach and the thinking behind complex adaptive systems is human interaction itself. There is a considerable difference, however. Human interaction is certainly complex but describing it as adaptive would not be doing justice to the true meaning of complexity. People do not just simply ‘adapt’. It is therefore better to talk about human actions and interaction as being responsive, or as reacting or responding to something, and whether a behaviour may be adaptive in this responsiveness or not. Experiences, that is, the interaction between groups of people and between individuals, are therefore complex responsive processes which are similar to complex adaptive systems. Interactions lead to the ordering of behaviour. In an interaction, such as a conversation, a theme arises and the conversation develops around this theme until a turning point – a certain remark, for example – gives rise to another theme. New (discourse) attractors arise, patterns of themes which are brought about by certain self-organising

associations. These processes organise the experiences of a group of people who talk to each other, enabling individual and group experiences to arise simultaneously. Change only occurs if the pattern of conversation changes. Individual behaviour changes only if an individual, silent conversation changes and that can in turn, only change if the individual experience in a social relationship change. In this sense, change in a social entity and in an individual is the same; it happens simultaneously. This way of thinking about transition has significant implications both for government and society: in brief, it means that societies can only change if the people in the society begin to talk to each other in a different way. Transition means making different forms of conversation possible. This means that a society can no longer be thought of as an adaptive *thing-like* system or network, but as a series of responsive processes (R. Blomme, 2003). The self-organising agents are not individuals, but symbols arranged in propositional and narrative themes which connect them to each other. Themes organise the responsive experiences of individuals. In other words, it is the themes which bring about interaction, and not the individuals. Narrative and propositional themes are organised in conversations, both privately and publicly, which can assume different forms such as fantasies, myths, rituals, ideologies, culture, gossip and rumours.

⚠ Discourses and narrative themes determine the way how emergence is established. Narrative themes work as a way to order interactions, new narratives will introduce new themes by which new interactions and related behaviour will emerge.

In this sense, themes organise complexity in society. Researchers who take Complex Responsive systems as a perspective draw attention to Herbert Mead's assumption about interactions (for example, Stacey, 2011), that is that each type of presence (social act) produces responses from others, which gives rise to interactions and conversations. They also argue that agents' attitudes have a considerable influence on interaction. In line with Mead's conception, a broad definition of attitude as the tendency to act can be used to comprehend these interactional patterns. Although scholars describe agents' attitudes in case studies in several publications, they do not specify how these attitudes develop. However, these attitudes refer to point attractors. The way in which attitudes are shaped determines the nature of interactions and these typify the extent to which the prevailing point attractors are followed.

⚠ The attitude of agents determines how agents respond towards each other and whether this as a positive feedback loop will bring the societal system into transition.

Marketing Sciences: a social network approach

A potential avenue for marketing efforts is to induce the energy transition as a starting point. Traditionally, the general viewpoint of marketing perceives society narrowly from the perspectives of business and consumers, who fuel the development of objectives, strategy and rationale of commercial organizations (Peattie & Belz, 2010). Also, the perception of society as markets by non-privatized institutions and organizations may constrain and influence the choice for policies and interventions to bring about societal transitions. We stress that are some problems with this perspective. First, this perspective is aimed at the rights and interests of the individual consumer. Second, this holds the premise that what the individual consumer wants has an unquestioned priority over those of other people, animals, nature and environment in particular. This can be conflicting with transitions which are applicable for the whole society such as the energy transition. Henceforth, in specific marketing areas such as sustainable marketing, researchers look for other paradigms which take the whole societal system into account. As such, one of the scholarly perspectives which are identified as an interesting avenue for marketing is complexity system theory.

⚠ Next to the traditional vision, the marketing discipline also wields other perspectives including the complexity theory

The starting point for this avenue is that societal outcomes are a function of the social relationships between organizations or individuals within a society (Connelly et al., 2011). A complexity system is a social network which holds a map of all the relevant ties between organizations or actors in society, though there may be many different types of ties. From a complexity perspective, agents are constituted by organizations, cliques of individuals and individuals themselves. In this approach, weak ties (e.g., acquaintances) and strong ties (e.g., close friends and family) carry different types of information and are useful in different ways. As well individuals and organizations make decisions based on information and influence that arise from the extent to which they are embedded in their social networks.

These embeddings are due to the number and type of their dyadic ties. Dyadic ties are pivotal for predicting how innovations and strategies and as such transition processes diffuse throughout a social network. This viewpoint incorporates the role of network structures to explain diffusion across networks. Whether through an organization's direct ties or owing to its structural position, scholars have found that a firm's social network plays an important role in determining the activities in which firms engage.

⚠ The nature of the social networks organizations and individuals develop determine the activities in which these parties engage.

This may hold an interesting theoretical perspective for the energy transition because strategic initiatives in organizations may diffuse throughout organizational networks. Once organizations implement a sustainable business practice, they may influence other organizations with which they hold alliances. One way the organization's social network affects the likelihood of implementing energy transition is by providing information and experience that reduce uncertainty. Many organizational and individual decisions are made under conditions of imperfect information, but the emerging nature of sustainability practices makes their implementation particularly uncertain and multifaceted. Approaches to sustainability vary considerably, and they often touch upon a wide range of organizational processes. Thus, key persons within organizations and society may find their social networks particularly important to identify and evaluate sustainability practices.

Furthermore, not all sustainability initiatives are successful. There is some evidence to suggest that ties to organizations with less emphasis on sustainability or with unsuccessful sustainability initiatives will have a suppressive effect on diffusion. In addition to the influence of direct ties on the likelihood of implementing sustainability initiatives, an organization's structural position in its social network is more important. Being connected to organizations that are themselves unconnected could offer advantages through the mediums of increased access to timely and novel information about sustainability practices, information, arbitrage (leveraging information about sustainability from one context in another context), and brokerage (connecting or mediating sustainability practices between disconnected organizations in the network).

⚠ The structural positions of organizations in society are important for the diffusion of information and knowledge on the energy transition.

Marketing scholars invoke the metaphor of echo to describe information acquisition in closed networks. Actors embedded in densely interconnected cliques are at risk of echo, which is the recapitulation, elaboration, and reinforcement of relatively isolated perspectives that become more homogeneous over time. Echo could filter and sanitize information, resulting in narrow points of view about how to implement sustainability. On the other hand, network positions rich of interconnections can provide access to a more cosmopolitan population of organizations that have a wider range of experience with sustainable business practices.

⚠ Densely interconnected cliques may suffer from echo which pertains to the development of an arrow mind in relation to the energy transition.

3.4. Modelling emergent behaviour

Social complexity in energy scenarios

The energy transition's goals (for CO_2 reduction, renewable electricity generation, energy efficiency, natural gas free heating in the built environment and so on) typically are key input to developing scenarios. Scenarios typically show what is possible, and, developed with techno-economic, technology assessment, and macroeconomic models optimal for minimizing societal cost while meeting those goals. They excel in their richness of in representing technology and can be used well as a starting point, or promising technological solution to (parts) of the energy transition challenge.

However, at the same time, energy scenarios lack a perspective of how to intervene in the transition process, to shape complex systems in such a way that the transition may come about through the actions of all key stakeholders required to see that technology-focused scenario to life (E.J.L. Chappin et al., 2017). The process towards intervention is not at

all captured in energy scenarios (at least not in operational/action-oriented terms). In some scenarios, policy effects are considered; primarily by means of expert's opinions about expected policy effects. Those are put in directly. However, this does not represent social complex policy responses, including realistic representations of stakeholders' actions and interactions.

⚠ Energy scenarios do not consider social complexity, e.g., emergent system-level behaviour.

Simulating emergent behaviour

The only modelling approach that explicitly studies emergent behaviour is agent-based modelling (Gilbert, 2007). Agent-based models are defined through their decision rules for individual agents. Agents follow these rules to make their own, autonomous decisions; agents may react to each other and interact (observing each other, communicating, cooperating, etc.). System-level behaviour emerges from all agents' decisions (Farmer & Foley, 2009). Agent-based models show a wide range of system-level patterns (Hofstede & Chappin, 2021).

⚠ Agent-based models simulate social complexity as emergent phenomena arising on the basis of modelled decision rules of individual agents.

Agent-based models vary widely in all kinds of aspects: energy transition is an important topic and models have been developed for many aspects of energy systems, including energy efficiency, insulation and heating, and investments in power generation (E.J.L. Chappin et al., 2017; Friege & Chappin, 2014; Hansen et al., 2019; Hesselink & Chappin, 2019). Agent-based models address how systemic complexities affect long-term policy and short-term actions (E J L Chappin & Dijkema, 2015; Holtz et al., 2010; Lempert et al., 2003).

Agent-based models are not only diverse in application domains, but also in purpose (Edmonds et al., 2019) – e.g., prediction, theoretical exposition, and illustration. As a consequence of this, modelling studies are also diverse in methodological details, such as the theoretical basis (Hesselink & Chappin, 2019), data sources and calibration techniques, and in approaches for validation (Qudrat-Ullah, 2005).
So far, there is limited theoretical underpinning of modelling choices (Jager, 2017), modelling practices are often ad hoc and model reuse and using models for theory development is nascent.

Significant advantages have been achieved through, for example, rich empirical data on preferences with agent-based models, using real-world preferences for consumers (Wolbertus et al., 2021) or investors (Melliger & Chappin, 2022) and specifying behaviour for different consumer groups in different countries (Chappin et al. in review).

⚠ Choice models can provide empirical underpinning of preferences of consumer groups.

The policy-modelling interface

It is important to use scientific approaches and insights to improve decision-making in the energy transition, along the approach mentioned above. There is a strong tension between the process in which models are developed and in which model findings are used to feed decision-making processes (such as those supporting policy/intervention decisions): the policy-model interface is complicated (Squazzoni et al., 2020). Bringing them closer together may at the same time 'politicize the science' as well as 'scientify the politics'. Both processes are quite different in nature, in timeline, in language, in what stakeholders are involved, and in what topics are discussed.

Specifically, the modelling arena typically is about the system-level developments/society, it is rather quantitative, assumption based, and analytical. Depending on the modelling approach, certain elements are easier to include in the analysis than others. The process with stakeholders is more about perspectives, about shared values, and about practical consequences for specific actions.

⚠ A strong tension exists between modelling processes and decision-making processes. For instance, the limitations with respect to modelling findings and the resulting policy advice should be clearly communicated, and the relation between these findings and the democratic process is not a simple one.

⚠ The modelling process is mostly disconnected from the political, decision-support process.

This means, these differences need to be acknowledged to give a prominent place to modelling in public decision-making. With co-design, for example, the modelling becomes part of the larger decision-making process. Any form of participatory modelling supports the process with the systematic approach of modelling. This can for instance include participation of key stakeholders in the model design and conceptualization. When time allows, this may contribute to an evidence based democratic policy process. It can also make use of multi-modelling techniques, where different perspectives are adequately represented (Nikolic et al., 2019) and through which uncertainty stemming from the method is explicitly explored (see e.g., Stedin's Openingsbod[5], which uses three models for the heat transition and determines the robustness of their findings on the similarity of the outcomes between those three models.).

⚠ Participatory modelling can support evidence-based policy support.
⚠ Multi-modelling may allow for modular processes in which different world views are adequately represented in various models.
⚠ Robustness of the model-based advice can be improved by using the similarity of findings of multiple models.

Models may be focused on addressing issues related to social complexity, on the value conflicts that may be the root for societal problems arising from the heat transition in specific local contexts (de Wildt et al., 2021). Key to this challenge are all kinds of uncertainties: which values play a role, who values can/should be conceptualized, what values are dominant in relation to the heat transition and what external factors are uncertain. By using advanced analysis techniques to deal with vast uncertainties, (e.g., exploratory modelling and analysis (Kwakkel, 2017)), the conditions for value conflicts emerging over time may be better understood and, possibly, avoided.

⚠ Modelling may take refined/new roles in policy/decision support.
⚠ Advancements in analysis techniques as well as and a focus on good modelling practices is crucial in bringing together modelling and decision support processes.

An example of an innovative approach is Stedin's Openingsbod[5], which acknowledges the decision making-process and frames the techno-economic analysis as a 'conversation starter' for the process of a municipality in which they are developing heating transition plans, and *not* as the blueprint for the households involved.

3.5. Intervening to shape the energy transition

Energy policy

To bring the energy transition to implementation, energy policies are a key ingredient. In the Netherlands alone, far over 100 energy policies affect investment and operational decisions with respect to energy technologies (see (Van Zijl, 2017) for an overview and an illustration). When considering types of energy policy (see type of instrument in Table 2), most intend to shape decisions of stakeholders in the energy transition, whether it is electricity producers, network operators, industry, SME, households. Policy instruments can improve the financial performance of some of the technology options, incentivize stakeholders to consider certain alternatives, or simply to create windows of opportunity. All of these, directly, or indirectly, aim to affect the social complexity and make stakeholder consider or reconsider technology options and how they use and operate technologies.

Table 2. An overview of energy policy variables, the main options, and the EU ETS as an example (Adapted from (E.J.L. Chappin et al., 2022)*.*

Policy variable	**High-level options**	**EU ETS implementation**
Regional scope	Regional, national, European, global	EU
Sector and actor	Production, consumption. Business, households. Variety of sectors involved. Supply, transport, demand.	Energy intensive industrial sectors

[5] https://www.stedin.net/zakelijk/branches/overheden/het-openingsbod/

Type of instrument	Regulation, e.g., limiting certain activities and products or requiring certain performance. Financial instruments, e.g., taxes, trading, feed-in tariffs, subsidy schemes, tax benefits Procedural instruments, e.g., audits. Information instruments, e.g., energy labels. Voluntary instruments, e.g., covenants.	Cap and trade market
Technology specificity	Only affecting specific technologies, supporting particular technologies more than others, technology-neutral	Not specific to technologies (the 'market' decides where to reduce at lowest cost)
Instrument-specific parameters	Varies widely between instruments, targets, baselines, levels.	Adjusting the emissions cap
Policy linkages	Regulating links with clauses, making policies mutually exclusive, compensation.	CDM and JI exchange credits, supporting renewables influences emissions locally
Policy changes	A new policy or changes to existing policies, can affect any of the other design variables	Banking, backloading, market stability reserve

Policies do not only differ in type of instrument; they also interact (see Figure 4). Indirectly, for example, the EU ETS operates on European level to provide a carbon price, which penalizes carbon intensive power generation technologies and therefore make renewables more competitive. The carbon price affects the need for national subsidies to renewables. (Melliger & Chappin, 2022). Such interactions lead to complex dynamics, which are heard to anticipate for policy makers as well as for who is targeted – the investor in renewables. These interactions span across national borders and are hard to get work in tender (Richstein et al., 2015).

⚠ Energy policies interact; this leads to complex dynamics affecting the intended policy effects.

Although energy policies aim to improve the energy transition process, the plurality of interacting policies, and the focus on financial policies, on procedures, and information may also not do justice to social complexity. There is no general understanding what, in general, is needed to cost-effectively bring about the desired emergent changes. Intervening too strongly may be costly (and heavily criticised or even unacceptable for this reason), intervening too weakly may lead to long delays, which, at the end of the day may be detrimental for society (and costly).

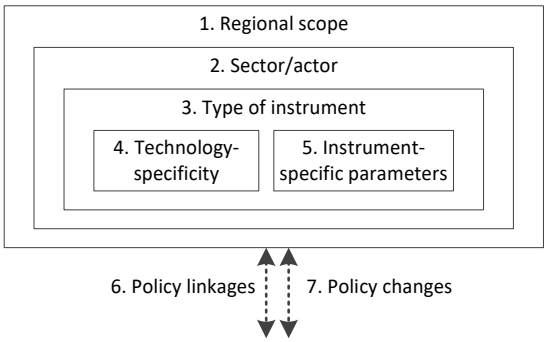

Figure 4. Design aspects for energy transition policies. From (E.J.L. Chappin et al., 2022).

⚠ It is unknown, when, how, and how strong to intervene in complex systems to cost-effectively achieve the energy transition, given the plurality of existing energy policies.

Uncertainty and behaviour

Intervention by means of energy policies often aims to overcome financial and behavioural barriers, which partly originate from the multi-actor setting in which decisions are made (E J L Chappin et al., 2020). In part this is to take away uncertainty: uncertainty with respect to the viability of a business case, for example. At the same time, it does

not help to explain why individuals would or would not decide to consider certain behaviour. Similar incentives for PV panels through SDE+ subsidies, for example, persuade some households to invest. But other households (some with very similar properties) do not decide to invest. A general understanding is lacking; given the complexity of the systems being affected: it is fundamentally very difficult to anticipate – robustly – what level of subsidy would lead to who is investing how much in what technology at which locations, and in what timeframe. It is typically unknown when and how social tipping points are reached.

⚠ Uncertainty is a key barrier; energy policies may address or resolve various uncertainties. Behavioural barriers can be addressed through policies, but anticipating what uptake emerges, is unreliable. As a consequence, a strategy that embraces this uncertainty and acknowledges the unreliability should:

- start from a perspective to better be safe than sorry, and the leadership coming from this
- consider the local conditions, attitudes, opinions of individuals and key stakeholders
- aim to engage who is affected by these policies
- follow relevant best practices, e.g., from pilots
- enable ways to adapt to ongoing changes (external and internal)

Individual decisions and aggregate plans

An important distinction is that to policies affecting individual decisions (whether by individual households or companies) to more aggregate level plans (see Figure 5) and this distinction is important for all kinds of instruments. Individual investment decisions by households to install PV panels are affected by subsidy rules. Households learn about the energy performance of their own homes, or the home they intend to purchase through energy labels. A more aggregate nature has the concept of regional energy strategies (RES) in which cooperation is sought to make a concrete plan on a neighbourhood's basis. This is similar for participating in a local wind energy project (for instance through information meetings); although the policy instrument is quite different.

Emergent behaviour plays an important role for both types of foci: for individual decisions, it is hard to anticipate social tipping points (when larger groups will follow adopting technologies or practices/habits). For more aggregate activities the emergent phenomenon is in whether all required individuals get on board, provide the required commitment for success.

⚠ Emergent behaviour resulting from individual uptake decisions as well as from participation/commitment to aggregate initiatives is highly uncertain but crucial for success in the energy transition.

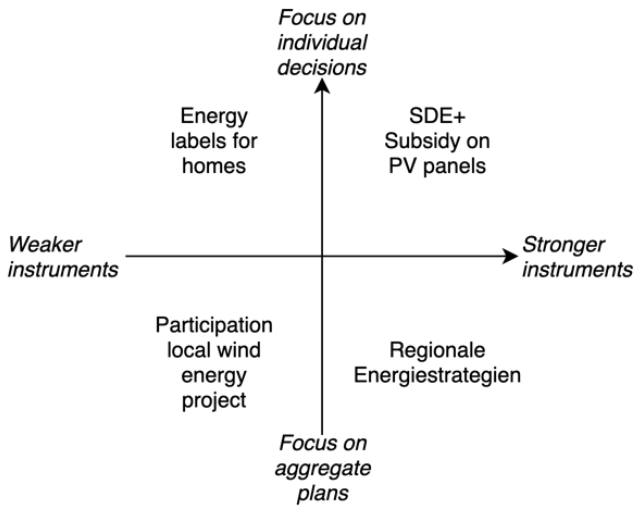

Figure 5. Typology for energy policies/interventions.

4. Research agenda and action plan

On the basis of the literature review and interview results of chapter 3 (and Appendix A), we identified the research themes outlined below in the different subsections. For each of them, we outline the research challenge and an anticipated action plan.

They all fit in Figure 6, which shows to provide an overall perspective of how emergent phenomena play a role in the energy transition. In the end, energy scenarios show the techno-economic optimum for a specific case study, on the basis available energy infrastructures and technological developments. Achieving that scenario is the end goal, and that is why the arrow points to it. It assumes, however, that a plurality of choices by individuals, households, companies, and other stakeholders make this a reality, and that the required policy interventions are implemented to make this a reality. But that, in turn, is an emergent system level phenomenon, which requires anticipation of what individuals perceive, how they consider their local context, and how they interact.

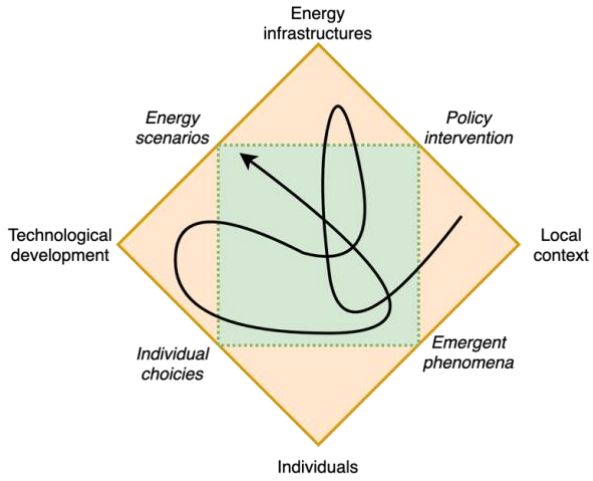

Figure 6. Research challenges context.

We outline 4 research challenges (see Figure 7). The first challenge innovates how behavioural theory is used in modelling of the energy transition. The second aims to improve the understanding of and individual decisions in the context of the energy transition and develop approaches to steer those decisions. The third aims to improve how emergent character of the energy transition can be empirically researched with a focus on the development of transition narratives. The fourth challenge explores the roles of key change agents including policymakers.

In the remainder of this chapter, we discuss the six research challenges. We define the research challenge, an action plan, and the potential impact of those actions. For each action plan item, we indicate in brackets how close this is to the market, and we rank them from high to low. Please note that high means it can be adopted relatively quickly and may help transition progress rapidly, but it is also limited in scope. Low means this is a research challenge with a more fundamental nature that may lead to a significantly better understanding of structural change processes in socio-technical systems like the energy transition. Therefore, this label *does not* equate to priority: in the longer term, all items are important.

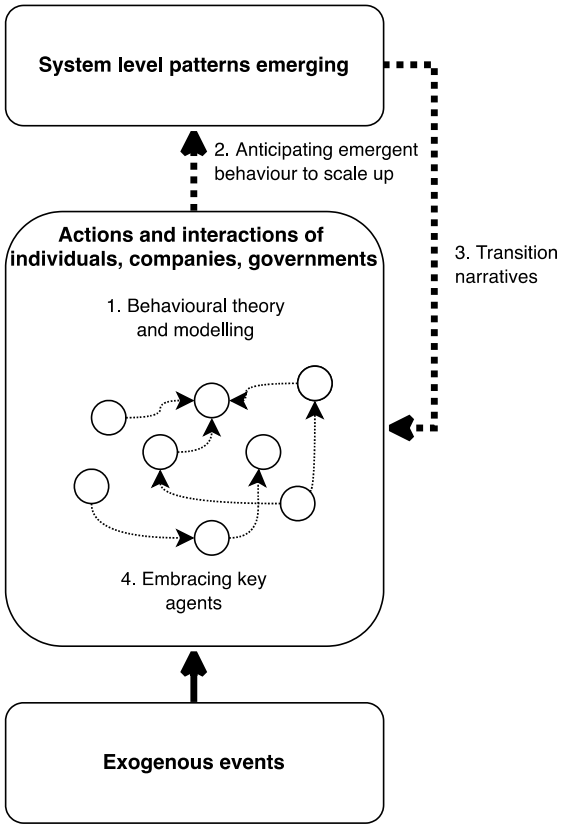

Figure 7. Positioning of the research challenges.

4.1. Behavioural theory and modelling of the energy transition

Research challenge

Behavioural theory is available to explain and anticipate behaviour of multiple stakeholders during the energy transition. For now, many of those potential insights go unnoticed. There is a challenge in connecting elements from behavioural theory into frameworks for the energy transition that can be used to focus in gathering empirical data as well as developing simulation models, with which insights in emergent behaviour is to be improved. The energy transition requires decision support that embraces the complexity of transition processes; at the same time, models do not do justice to all societal dynamics relevant to the decision process. The role of (semi-)quantitative models and simulation for public policy support is in flux. The challenge is to innovate modelling methods and policy design in such a way that this tension is better balanced, and decision support becomes more effective.

Action plan

1. *Establishing a national energy transition modelling unit with a focus on representing behaviour and systems, good modelling practices and the policy-modelling interface*. A sounding board/support unit for all key energy transition modelling with their view on good modelling practices and an eye for the tension between good modelling and adequate policy support, including an adequate representation of behaviour as well as energy systems should be established. This should contain members with expertise both in energy systems analysis and modelling as well as behavioural experts. (high)
2. *Formalizing crucial portions of established, promising behavioural theories, connecting this to complex systems and energy transition and implementing them in existing and new simulation modelling frameworks.* This is a key approach to advance the representation of behaviour in energy transition modelling. It should be done in dedicated interdisciplinary research teams. Research that provides decision support for the energy transition considers various approaches to what emergent behaviour plays a role and can explore the modelled consequences. (medium)
3. *Develop inclusive/holistic system theory that describes change processes from both technological, behavioural, and social perspectives.* Such theory would provide a more holistic understanding of the energy transition and change processes alike. It would help explain barriers that come about due to complex interactions and provide an actionable resolution (if any) to speed up the energy transition. (low)
4. *Innovating simulations of social complexity emerging out of value conflicts.* Simulations may be developed for capturing values and value conflicts underneath polarized opinions with respect to the energy transition. This includes exploration in the specific local context, conceptualizing relevant local values and exploring what value conflicts may emerge. But also in a global context, values embedded in and value conflicts between Western societies and the Global South can be innovatively explored. Conceptually, crucial levers are to be found where to intervene for accelerating the energy transition given the existing and to be anticipated social complexity. (low)
5. *Adopting better uncertainty and analysis techniques for energy transition modelling.* Modelling studies on the energy transition that aim to affect emergent system-level behaviour must equip in their modelling approach state of the art analysis techniques that explore deep uncertainty with which they test the effectiveness of the simulated interventions in a very large set of possible future scenarios. Furthermore, machine learning techniques may support redefining modelling approaches to better support the fundamental processes that are part of the energy transition. By developing reusable model building blocks and approaches for inverse generative simulations we may develop a better understanding of fundamental simulation dynamics. (low)

Potential impact

This research challenge may have a significant impact on better understanding the complex interactions that could lead to undesired emergent behaviour and avoiding locking in into such patterns. It may provide an overhaul of how the balance is found between policy development processes and quantitative simulation modelling. This has substantial potential to improved, evidence-driven decision-making. It also has significant potential to provide better use for modelling work. And there is potential for fundamental understanding of what drives emergent value conflicts, which may inspire value conflicts theory.

4.2. Anticipating emergent behaviour to scale up the energy transition

Research challenge

Acceleration is a main challenge for the energy transition; vast acceleration is needed to meet our pledged contribution to mitigating climate change. This requires scaling up beyond the use of pilots and getting into a new phase in the energy transition. This new phase requires systemic changes emerging from large groups of individuals and companies. The challenge is to adequately anticipate emergent behaviour in the energy transition: to embrace complexity and not ignore it, to acknowledge prediction is often unreliable and nevertheless be constructive towards more effective and efficient interventions. For the energy transition at large, this means planning and implementing substantial investment in new and intensified infrastructure and energy systems integration. Specifically for the heating transition, which is affecting the public directly, this means a broader set of stakeholders need to become engaged.

Action plan

1. *Developing empirically grounded choice models for specific energy transition decisions.* This can be done by collecting on large scale preferences for technologies to replace natural gas heating with, and including technology preferences, the rich local context, the techno-economic possibilities and the policy context and timeframe. These choice models can then be directly used to improve (existing) heating transition models, to show emergent patterns under these preferences. Models that capture emergent behaviour then are improved in their realism and comprehension by, on a very large scale, grounding them in empirical data on the observed behaviour of individuals and key stakeholders. This possibly includes a wide range of behaviour types and can lead to developing decision-specific consumer segmentations. This may inspire no-regret options and locations, may provide useful starting points for the participatory processes needed to bring about the desired pathways and may inspire to an understanding of where social tipping points may exist, and how they may be reached. (medium)
2. *Improving regional participatory approaches and communication strategies, taking stock of best practices from earlier pilots in RES regions, and integrating moral aspects of the energy transition.* This can be done by mapping local preferences and by involvement of local stakeholders in the decision-making process. Local aspects of the energy transition will affect all households and their awareness, the sense of urgency, the knowledge on pros and cons of specific actions. Regional approaches should consider energy justice, energy poverty in their social context as well as global geopolitical developments that become key exogenous drivers of change (affecting energy prices, availability of resources and technologies). Innovations in existing approaches such as participatory value evaluation, serious games, participatory simulation modelling, innovative combinations, and state-of-the-art communication strategies may enable more effective participatory processes that accelerate decision-making (e.g., on the needed energy policies) while gaining awareness, understanding, and support by larger groups of citizens and other stakeholders. This may democratize the process in which policy decisions are made. Communication strategies should be developed accordingly. (medium)
3. *Developing proactive energy infrastructure investment strategies in view of energy systems integration.* This is needed to avoid infrastructure bottlenecks during the scaling-up phase of the energy transition. No regret investments should be allowed and implemented rapidly, and approaches to systemically determine and motivate such no-regret investments should be developed given the known uncertainties, advancing machine learning techniques. These should do justice to existing systems (infrastructures, equipment, services) that need to be dismantled, the respective stakeholder's roles for which this has implications, their past developments, and the local conditions that apply. This should be done when developing, regional or national transition pathways. Fairness and transparency should be key. (medium)

Potential impact

These actions may lead to much more appropriate instrumentation, taking stock of what complexity means for studying system-level phenomena that emerge out of local actions and interactions. This enables us to better anticipate which energy transition processes may result in specifically desired or undesired emergent system-level behaviour. Potentially, this avoids lock-in, bottlenecks and escalation of local problems that may emerge from local energy transition projects when trying to scale up and accelerate the energy transition.

4.3. Developing transition narratives

Research challenge

Connecting the perspectives of emergence and complexity has consequences for policy development and the current policies. Policies are traditionally aimed at altering the routines and the habits of individual parties in society. The perspectives of emergence and complexity contribute to this viewpoint by emphasizing the importance of the relations and interactions of the concerned parties. Transition unfolds in interactions between agents in which new narratives evolve and, consequently, new (adaptive) behaviours will emerge. This has the consequence that policies should not be aimed at the individual as such but at the interconnections between agents including organizations, cliques of individuals and individuals themselves. Policies should aim at strengthening social networks by the introduction of new narratives which are derived from the aggregated policies. This way of thinking about change has significant implications for the energy transition. Little research has been conducted which narratives should be developed in relation to speeding up the energy transition. Which narratives should be developed is related to the specific themes of the different communities, organizations and cliques of individuals in society. Narrative development should be aligned with the existing themes which organize behaviour within these parts of society. In the action plan, first knowledge should be developed of the themes of these communities which foster self-organization and emergence. Second, information and messages should be developed which tap into these themes in developing new narratives in relation to the energy transition. Third, research is necessary to the specific conditions which enhance or impede desired narratives which stimulate transitional behaviours within these communities.

Action plan

1. *Identification of potential target groups in society for pilot projects*. These pilot groups can be used to experiment with the development of narratives in favour of the energy transition. (high)
2. *Diagnosis of the important themes within these potential target groups.* Themes should be analysed as these draw the attention and self-organization of the agents. Messages and information should be aligned with these themes to start op new narratives. (low)
3. *Development of information which can be brought in these target groups*. As messages and information should be aligned with the existing narrative themes, experiments have to be conducted to explore which information and by which channel have most of influence on desired behaviours. (low)
4. *Observation of behaviour*. Behaviours and the way how self-organization takes place should be observed, analysed and interpreted. The target groups should be modelled with the use of emergence and the theory on complex systems to develop models which can be of use to predict self-organization and transitional behaviour for other target groups. (low)

Potential impact

Potential impact

These actions will lead to more comprehension how narratives which stimulate transitional behaviours can be fuelled and stimulated. This comprehension can lead to the alteration of existing policies and the development of new additional policies which might be more effective to bring about the energy transition.

4.4. Embracing key/change agents and emergent leadership

Research challenge

The first implication we would like to address is the importance of the linguistic domain in emergent change. Agents are involved in relationships through symbols that are gestures and responses intertwined with feelings and emotions. These symbols generate themes, which organize human experience and actions. As discussed in the section about complex responsive systems, themes are an important part of emergent change. Hence, policy makers should know how agents interpret and make sense of the symbolism of their behaviour and interactions.

The previous sections show an importance of so-called key-agents. Key-agents are able to reduce the equivocality of fellow-agents, and together with them they can (co-)create a world by acting from a common base. This thinking is

supported by different research studies. Hogg (2001), for example, argues that social identity is acquired by becoming a member of a societal system and by developing a social identity in the social systems by means of interactive processes. Being accepted by others and becoming established in a societal system is an important motivator of behaviour. In this sense people want to become members of a societal system so that they can construct a social identity by acting and interacting in concert. Key-agents can set the right conditions for other agents to interact by providing them with the assurance that they are a part of the in-group, that they are confronted with the same issues and in working through these issues they are developing a collective social identity which is in favour of the energy transition.

We argue that policy makers have also a very important function in this enabling role, namely the reduction of ambiguity in participation. If policy makers are successful in this, other agents will be more inclined to take up key-agent roles. This could refer to the principles of empowerment, but this implication goes one step further. Empowerment entails delegating responsibilities and mandates, but there is always the preconception that overall control lies with government and policy makers. In practice, this has an important consequence for effective policy makers. Policy makers should have a good understanding of their own attitudes and potential responses in relation to transition processes. Furthermore, policy makers should have the capacity to comprehend the attitudes and potential responses of other agents and how this might affect the transition. This refers to the conception of primal leadership which describes two important aspects of leadership: personal competence (self-awareness and self-management) and social competence (social awareness and relationship management).

More research should be conducted in strengthening the theoretical and empirical implications when tying the theories on emergence and complexity to transition processes and in particular the energy transition. Second, as an extension of the first point, little research has been conducted to the role of policy makers, policy development and effectiveness in relation to societal systems using the theories on emergence and complexity sciences. Third, complexity theory is a theory which is surpassing the unique characteristics of the individual agents. The responsive nature of agents and individual persons in particular, urges an elaboration of behavioural and psychological theories on behaviour and psychological barriers and enablers, which provide more comprehension of acceptance processes of the energy transition within individuals. Potential avenues are for example the inactivity theory (cf. Gifford, 2011), proactivity theory (Bindl, & Parker, 2016) and social identity theory (Janssen, Beers, & van Mierlo, 2022)

Little is known about the role of key-agents including policymakers in the energy transition. As discussed in the implications, key-agents might be an interesting concept to use for a more in depth understanding of emergent leadership and interactional patterns.

Using the lens of emergence and complexity, research should be conducted to the current state of affairs in current energy transition. In this research study the role of key-agents and policy makers in societal system should be investigated. Also in this research, it is important to comprehend how key-agents' behaviour impact emergence and self-organization within the societal systems they belong to.

Action plan

1. *Identification of potential target groups in society for pilot projects*. These pilot groups can be used to experiment with the development of narratives in favour of the energy transition. (High)
2. *Identification of the key-agents within these potential target groups.* Not only themes should be analysed but also the characteristics of key-agents who support these themes and related narratives. Key-agents can be considered as the hubs in the social network who align external messages and information the existing themes to start op new narratives. (medium)
3. *Identifying key-characteristics of key-agents.* What are important characteristics of key-agents which make them key-agents. From leadership literature we know that traits and personality are an important component of building up authority and being entitled to influence the narratives in a community. (low)
4. *Development of information which can be provided to key-agents in these target groups*. As messages and information should be aligned with the existing narrative themes, experiments have to be conducted to explore how key-agents diffuse information and messages through the social network and how this affect transitional behaviour. (low)

5. *Observation of key-agents' behaviour.* Behaviours and the way how self-organization takes place by key-agents' behaviours should be observed, analysed, and interpreted. The target groups including the position of key-agents should be modelled with the use of the theory on emergence and complex systems to develop models which can be of use to predict the influence of key-agents on self-organization and transitional behaviour within target groups. (low)

Potential impact

Key-agents are these agents which are a part of cliques of individuals, communities and organizations which shape up society. Identification of key-agents and stimulating these key-agents to bring about narratives which are in favour of the energy transition, will stimulate a community of which they are part of, to conduct behaviours which are in line of the energy transition. Second, key-agents are often a liaison between different communities and may connect these in aligning energy transition positive narratives. Finally, key-agents are often an important source of in-depth knowledge of community related narrative themes, which helps policy makers in developing diversified information and messages specifically for target communities.

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Appendix A: Interviews

This appendix contains the interview reports which are used as input to the main text.

A.1. Interview Caspar Chorus (Full Professor Choice Modelling)

Interviewer: Emile Chappin
Date: 11-01-2022

On emergent phenomena

Important to define the phenomenon 'emergent behaviour' clearly: Trends or patterns observed on the aggregated/system level that are not a simple sum of the individual actions.

On prediction vs shaping

This is what makes emergent behaviour 'unpredictable': it cannot be simply extrapolated. Nevertheless, it does not necessarily imply there is a full lack of control of such emergent phenomena. You can try to steer the individuals and interactions to make the probability that a particular pattern emerges more likely or to evaluate what/where investment in infrastructure is useful. The challenge is not to perfectly predict, but to find promising ways to shape the emergent phenomenon under study.

What to research

How does emergence come about/what are the ingredients that need to be researched?

- The interaction of agents (one's decision is influenced by (the perception) of those of others, observation, discussion, copying behaviour, etc.).
- Local/spatial/infrastructural characteristics provide reason for interaction (what you see/what infrastructure exists affects local decisions).

Important to differentiate two strands of research (with examples)

- The development of effective policies. E.g., how to financially promote adoption or how nudges/information could lead to emergent knowledge through social media. How to financially support early adopters in adopting EVs. Or now to use influencers to spread positive information about Covid vaccination.
- Supporting good infrastructure decisions. Examples: Where to place/how to support charging poles for electric vehicles. Developing renewable heating in neighbourhoods. Infrastructures often need critical mass in order to thrive (as an emergent phenomenon). This relates to tipping points and the Morhing effect[6]

Differentiating types of behaviour

Emergent phenomena are particularly relevant for behaviour that involves explicit observable decisions:

- *Adoption behaviour.* What policy is needed to effectively improve adoption (subsidy, information, etc). In particular for devices with very low adoption rates (EVs some time ago). What aspects actually lead to emergent phenomena may be different in different regions of Roger's innovation adoption curve. Early adopters/innovators may try anything new, copy from whom they find important. Late adopters/laggards may be affected by other things (competitive prices). A calibrated model/policy analysis may be overfit to specific

[6] See https://en.wikipedia.org/wiki/Mohring_effect

categories of adopters. This could be detrimental for green policies (e.g., e-bikes), because the policy is fit to the innovators, not the rest of the population.

- *Use behaviour.* What if capacity is underused or overused, how to stay within reasonable bounds so that systems remain effectively operational. For the use of cars on a highway, too many cars make the system break down. This calls for billing use 'rekeningrijden'. For public transport, too few users may make infrastructure operators lower the capacity, effectively making it even less attractive to use public transport. This calls for supporting use. This highway vs public transport can be used as an analogy.
- *Opinions (and related latent concepts).* These are not necessarily 'real', observable decisions, and therefore not as easily capturable. This means that most policy studies of this kind only result in process advice (involve and inform citizens). There are opinion dynamics models, but their predictability/validity is debated. Nevertheless, this may provide an opportunity for a breakthrough. If better models are developed capturing opinions, perceptions, preferences, sentiments, polarization. All ingredients for acceptance of technologies.

Generalising results

It is hard to generalize results from (how one type of appliance is used) to another, because of the function/status it has in a household. This challenge holds for results on all levels (models, good strategies, effective policies)

Going to the core of the concept, some level of generalization is possible. In this case it implies representing the relevant aspects that shape the interaction between agents or the spatial components. For a case, the right psychological mechanisms then need to be specified.

Resources

- Cheetah results paper, hard-linking choice models with agent-based models for smart thermostats (Emile J.L. Chappin et al., 2022)
- On empirical agent-based models: (Bruch & Atwell, 2015; Chersoni et al., 2022)
- On preferences related to charging poles: (Wolbertus et al., 2021)
- Classical models, e.g., Schelling's segregation model.

A.2. Interview Gerdien de Vries (Associate Professor Climate Behaviour)

Interviewer: Emile Chappin
Date: 18-01-2022

On emergent phenomena

These are relevant phenomena on the group/system level that may come about over time. Emergent phenomena can be undesired (protest against CCS in Barendrecht) or desired (sustainability becoming 'cool'). Many of these phenomena can/could have been influenced.

On prediction vs shaping

For different parts of energy systems (different types of appliances/energy functions), existing research has already identified many relevant parameters/aspects, but this does not necessarily imply that it is known how to shape them and the systems they are part of so that we achieve the emergent phenomena we desire.

Very different kinds of aspects play a role; there needs to be a correspondence between all these aspects and the policy goal before the chance increases that desired emergent phenomena actually occur. Because some of these are harder to measure than others, this is extremely complicated. Nevertheless, there are opportunities, to, more generically, know what the possible hampering factors are and how to influence them.

There are promising developments that desired phenomena may emerge and that influencing these is possible. In the context of the energy transition, developments of social norms against flying, eating meat, and driving large inefficient old cars are examples. These activities are not the default anymore, and people discuss these openly. This is less the case, so far, for solar panels and heat pumps. Nevertheless, developments with similar properties can be found

elsewhere (e.g., wearing a seatbelt, smoking). Arguably all are, in the end, triggered by government intervention: governments communicating, promoting, banning specific actions.

What to research

What the necessary ingredients are, in terms of how group norms can emerge in favor of specifically societally desired technologies, can be researched. These can be seen as the necessities before a 'social tipping point' could be reasonably expected. There are three areas/perspectives for such research:

- Multi-disciplinary research, capturing all relevant aspects, and interdisciplinary research to actually integrate these aspects.
- Model and theory developments, capturing the developments in all relevant aspects, eliciting what are the factors that are hampering large uptake of 'a behaviour' at the moment.
- Focus on system-level analysis, capturing the interactions between different energy functions, how technological options compete/connect/cooperate, how different stakeholders with their roles and governance play a role.

Differentiating types of behaviour

Important to differentiate between

- *Observable* and *non-observable* behaviour. The first can be better measured and taken into account, and implicitly, also more clearly influenced. Non-observable behaviour is harder to influence, may require different theory and methods, are less systematically understood.
- *Decisions/behaviour with a self-focus and an others-focus.* To study decisions or behaviour that are focused on their own home, appliances, habits are rather prominent. This is less so, for behaviour that is targeted to local, regional, or the wider environment. They are harder to capture, and also other, soft, intangible aspects tend to play a role.

All combinations exist: in the internal sphere, purchase and use decisions are observable, but
in the external sphere, there are opinions or attitudes about technologies that are hard to measure. But there are also protests, which are measurable when they happen. These may form a quadrant.

Aspects that play a role

Implicitly, already many aspects that play a role were mentioned. There are different areas for such factors, and it is important to consider how they are specific to the different types of behaviour, and to the different types of technologies/energy functions.

Examples:

- System-specific: necessary infrastructural developments
- Technological: is it reliable
- Financial aspects: is it affordable
- Behavioural: windows of opportunity for deciding; hassles that impede deciding.
- Cultural: what a device/appliance means to people in terms of status.

Generalizing results

Generalizing is typically very difficult because which aspects are relevant is very context-specific. And because some are hard to systematically consider/account for, generalization opportunities are limited. Nevertheless, because of all the possible interactions, this is also vital for a better understanding of emergent behaviour in the energy transition. Constructively, the relevant aspects can be framed as (possibly interacting) boundary conditions. There are different means for these aspects to be influenced and findings on those levels (and on higher system level) may be at a more generic level:

- *Routes/assemblages* how aspects may come at play. Combinations (or sequences) of communication, financial stimulation/taxing, use of innovators. The order/prioritization in which barriers need to be tackled (e.g., a building block framework or simulation model, with thresholds for different aspects before progress happens).

- *Use of role models:* e.g., movie stars driving a Toyota Prius, or nowadays using influencers in a policy campaign. This spreads knowledge about new technologies, through new authorities (whereas authorities used to be the doctors/scientists that would be trusted). At the opposite end is the possible polarisation effect if the role models differ too widely for different segments of the public and the differences between different norms grow (e.g., anti-vaxxers).
- *On the level of a grand theme*, e.g., sustainability vs individual appliances/type of behaviour: sustainability is becoming cool/normal, which is a larger development, through which many sustainable behaviours may become more relevant to reach social tipping points.
- *Theory:* making use of relevant theory, such as the Theory of Planned Behaviour, Rogers adoption-diffusion.
- *Marketing* studies very effectively, on the basis of market segmentation how to persuade/influence people to purchase specific products. This makes use of role models (cool people using their products) and emotions (e.g., Unox rookworst). But they do not necessarily look at how a group norm may emerge.

Resources

- On social tipping points: (Moser & Dilling, 2007; Otto et al., 2020; Stadelmann-Steffen et al., 2021)
- On hassle/barriers: (E J L Chappin et al., 2020; G. de Vries et al., 2020; Hesselink & Chappin, 2019)
- On renovation behaviour (characteristics of individuals, households, and homes, technologies and systems all play a role: (Ebrahimigharehbaghi et al., 2021; Friege & Chappin, 2014; Rede, n.d.)
    - De klimaatspagaat: over de psychologische uitdagingen van duurzaam gedrag (Reint Jan Renes)
- WRR reports on knowedge, behaviour and policy: (*Met Kennis van Gedrag Beleid Maken | Rapport | WRR*, n.d.; *Weten Is Nog Geen Doen. Een Realistisch Perspectief Op Redzaamheid | Rapport | WRR*, n.d.)
    - 'Met kennis van gedrag beleid maken': https://www.wrr.nl/publicaties/rapporten/2014/09/10/met-kennis-van-gedrag-beleid-maken
    - 'Weten is nog geen doen': https://www.wrr.nl/publicaties/rapporten/2017/04/24/weten-is-nog-geen-doen
- Cialdini's 6 Principles of Persuasion are reciprocity, scarcity, authority, commitment and consistency, liking and consensus. By understanding these rules, you can use them to persuade and influence others. Of course, doing so isn't always an ethical thing to do:

A.3. Interview Igor Nikolic (Associate Professor Participatory Multi-Modelling)

Interviewer: Emile Chappin
Date: 18-01-2022

On emergent phenomena

Emergence is the process in which patterns and structures come about in systems, that you cannot simply trace back to its elements. Patterns come about over time due to dynamic aspects and interactions between system elements, become 'stable', and are a property of the system.

On prediction vs shaping

Decisions and interactions are iterative, that is why systems are chaotic. This implies that small changes may have big effects (moving you to another system attractor) but also that systems are rigid (it may be very hard to get away from one system attractor to another).

On a fundamental level, every action, including all intervention, is context and time-dependent, and therefore there is no guarantee for success (on achieving the 'desired change'). Nevertheless, doing nothing is also no option. Research on what can be influenced (without assuming that systems can be adequately steered) is needed.

Differentiate *discovery* from *emergence*: although a traffic jam is an emergent phenomenon of a transport system, it can be easily predicted (it happens every morning).

What to research

From what emergence is, these are ingredients for researching how to increase the probability of achieving a desired trajectory:

- Consider which behavioural rules (of the system elements) should be implemented that with minimal effort the maximal output is obtained. Avoid unnecessary hassles.
- Consider behavioural interventions (small, e.g., nudging and large, e.g., financial/regulatory).
- Consider carefully how to take away existing system elements that are in the way of changes to a new system attractor. (Do not ignore what currently is there but consider that explicitly). How do we deal with those that evidently will lose?
- Consider what principles, behavioural structures, institutions exist or could be developed that send the system in the direction of the desired attractor.
- Consider auto-catalytic processes: how can you come up with self-reinforcing processes, through which desired emergence becomes more likely.

Inspirational examples:

- For the *energy transition*, one example for which a number of these are relevant is how Elon Musk got rich with Tesla (making EV perform better than any other, making it interesting and cool, having an innovative image.
- Another inspiration can be *open source*: opening up the process through which our (soft) IT infrastructure is developed, sharing the effort, becoming more vulnerable as a programmer but also more robust as a system. Embracing community spirit. It is a different paradigm. What paradigm shifts can be envisioned for the energy transition?
- A third example is *2nd hand furniture*: it should become normal not to purchase everything new, but to appreciate the aesthetics of the old and consider a wider set of criteria (including the wider implications of consumption behaviour).

How to research

- *In silico vs in in vivo.* Computation is important. We have only one reality to intervene in and experiment with, irreversibly, so we have to do that carefully. With computation, we can evaluate a myriad of possible interventions and study emergent phenomena. Nevertheless, empirical research, learning in the real world is vital for the understanding of how to achieve the energy transition as well, so this is a recurring tension. This tension suggests that we have to shift to a paradigm where (partial) failure is allowed so we can learn (similar to open source).
- *Agent-based modelling* embraces the generative nature of emergence.
- *Multi-modelling* compensates for the focus/perspective that comes with a particular model or modelling method (e.g., behavioural nuance lacking in disease spread models, physical/energy/material constraints lacking in many simulation models).
- *Marketing.* Why sustainability is not properly addressed from a marketing perspective and with their methods. With as a fundamental question: how can you apply marketing to collective action (instead of products and services)?

Aspects that play a role

Specific to the energy transition, the pure *scale and embeddedness* provide unique challenges: energy is vital for all societal functions, it requires vast infrastructures. They are also interdependent and connect a wide variety of stakeholders. Changing systems at this scale cannot be done at only one end (e.g., the consumer).

It can also not come about only by a small group of strongly motivated people (e.g., in an energy community). *Norms and values* need to change/need to match with the change we desire to occur.

A paradigm shift in how to consider and deal with *uncertainties* (of various kinds). More explorative approaches to design, less focus on optimization, but more on robustness. Accept that systems evolve and that we must *adapt* along the way. Sustainability can be considered as the ability to keep adapting the system as a whole.

A.4. Interview Henry Robben (Full professor Marketing)

Interviewer: Rob Blomme
Date: 13-01-2022

On emergent phenomena

Emergent behaviour is what is related to behaviour within consumer markets and business markets. These markets are often scarcely interconnected. Marketing efforts and interventions (so called marketing mix) are not really influencing individuals in these markets but influences the way how individuals talk and behave towards each other within a rather closed market system. The marketing literature on complex systems and emerge is underdeveloped but there is a need for new paradigms to understand market behaviour in transitions.

On prediction vs shaping

The effects of marketing interventions are always unpredictable. A specific attention to a product of service can grow into hypes while other products/services are not getting some attention. Marketing efforts can influence the themes which are discussed in these markets which can lead to exponential attention for a specific product or service. Sustainable marketing tries to put forward the importance of the energy transition but it is unpredictable to what extent attention is given to this transition

What to research

- The interaction of consumers or business representants due to marketing inducements in relation to the existing narrative themes.
- The nature of the dyadic ties which the agents in a market have with agents in other markets determine the distribution of new narratives and information, which in turn are important for transitions.
- The role of social media in the interaction between markets and the distribution of narratives across markets.

Important to differentiate two strands of research (with examples)

- Early adopters play an important role in the development of narratives and attention to the necessity of the energy transition. The identification of these groups and fostering these groups to spread out narratives to other groups/markets.
- Distribution of the physical conditions for energy transition might demonstrate that target groups are relieved of impediments for further adoption.

Aspects that play a role

- Important to know is the nature of the themes amongst the different markets. Markets should be narrowly defined not only because of class background but also the location (city block level etc.)
- Important to identify are the early adopters and the way how these influence other parties and potential adopters. Bringing these parties together, will have the effect that narratives are diffusing and distributed.

Literature

- Literature in the field of green and sustainable marketing
- Literature in the field of complexity sciences in relation to

A.5. Interview Danielle Zandee (Full professor Sustainable Organizational Development)

Interviewer: Rob Blomme
Date: 13-01-2022

On emergent phenomena

Change and transformation processes are always emergent. Change is brought about from within the system, never from outside the system. Events from outside the system has influence on the way how the behaviour of the

participants organizes itself. Henceforth, change agents should be included in the system and this self-organizing behaviour.

On prediction vs shaping

Events and participants in these events outside the system may affect self-organizing behaviour within the system but the outcomes of this behaviour are unpredictable. Co-creation and participating in emergent processes are a condition to have influence on these outcomes. An important way how to invoke positivism and innovation is the use of appreciation and dialogue in relation to initiatives in the energy transition. The five process steps as described in the appreciative inquiry approach are an effective way to start up dialogue and to develop new narratives which lead transitional actions and secure new routines of behaviour. The five steps can be defined as:

- The Definition. The choice for an affirmative topic: An introduction energy transition as an affirmative attractor.
- The Discovery: What are the best practices which can be used as a leverage
- The Dream: What is the future we want?
- The Design: what is the next step which we want to deploy?
- The Destiny: action! Each action is an input for new reflection and the development of new narratives and actions.

Another avenue in this co-creation process which can be used is the concept of action research. The stages of planning, acting, developing and reflecting should be followed in this process of learning and transition.

What to research

Interesting avenues for research how these concepts of appreciative inquiry and action research play out in large transition processes. As such, further research should be conducted in the application of these concepts.

References

(Bradbury et al., 2019; Heffner et al., 2003; Zandee & Cooperrider, 2014)

A.6. Interview Joost Spithoven (Policy advisor Municipal City Alphen aan de Rijn)

Interviewer: Rob Blomme
Date: 26-01-2022

On emergent phenomena

Fuelling emergence can be organized by co-creation and co-direction between the important partners in society including governmental and municipal bodies, firms and citizens. The society is driven by a diversity of autonomous forces including the effects of COVID, globalization, demographic changes, other transitions, and in particular people's search for creativity and happiness. Henceforth, is direct top-down intervention by the Dutch government pointless; if these interventions are not aligned with these movements within society, people will not follow these and will resist against it. Human beings have a tendency to look for alternative routes dependent of the worries and concerns they have at the same moment. Worries and concerns which may impact the personal condition will drive people to look for answers and other avenues to escape from these feelings. As such, transition is a process which has to take place from as well a top-down as from a bottom up perspective. Co-creation and co-direction by all related bodies are a condition for a successful transition.

On prediction vs shaping

Following direction is one of the key terms which are addressed in the interview. Transition is an emergent process, but governmental bodies can not only play an important role in the provision of information concerning the transition, but also to start up bottom-up initiatives in a co-creational process with stakeholders. An estimation for places with chances for success are the potential areas where initiatives can be deployed. In the further guidance of these initiatives the shift can be made from co-creation to co-production. Public and private capital investors should be

mobilized to organize and realize a multi-annual investment program for these specific stakeholders. Henceforth, first new initiatives should be deployed in co-creation with as a result a need for further exploitation, second these needs and initiatives should be fostered by filling in the conditions including investments and related budgets. This last step of co-production is an important step to secure the co-creational initiatives. Strengthening the relationships between the different parties (sometimes at a city block level) is an important aspect of this approach in fostering emergence; successful stories will be diffused by these relationships which in turn will have a positive effect on the willingness of other parties and stakeholders to start up new co-creational processes in the energy transition. As this ink spot kind of process is not really predictable, parties have to co-direct these processes of co-creation and co-production.

What to research

Important aspects for further research to substantiate these efforts which are deployed within society, are how these co-creation, co-production and co-direction processes can be fostered and developed. A critical reflection on potential enablers and impediments of this trinity can help parties out to make these emergent processes and henceforth, the energy transition more successful.

A.7. Interview Tessa Hillen (Stedin)

Interviewer: Emile Chappin
Date: 18-02-2022

On the role of the DSO

Stedin, as a DSO, has a very specific role in the energy transition. The role of a network operator (for natural gas and electricity) is specified by law. The DSO provides the infrastructure needed locally to connect the transmission grids to end consumers. They have to connect everyone that requests a connection. Investments in infrastructure have to be functional/supported by a clear need and approved by the ACM. Part of the energy bills is fed back to provide input to the DSO.

Stedin's active role

Stedin takes an active role in the energy transition; they enable many of the change processes, supplying the infrastructure needed now, and during the transition. With their infrastructure, they enable the ability for heating options to be connected, and for solar PV panels to feed electricity back to the grid when there is a local oversupply. They are also part of projects in which municipalities work towards natural gas free homes. They provide information on what the consequences are of particular choices (what is technically possible and how plans should technically be implemented) and they organize and execute their part of the implementation. Additional to their traditional tasks, they advise on what technologies would be best in what locations, primarily on the basis of techno-economic analyses. Stedin's advice does not come from the pure grid operator perspective; Stedin acknowledges their societal function (in addition to the focused duties of a grid operator). Society benefits from executing an energy transition in accordance with lowest societal costs, while conforming the objectives in the climate agreement. Stedin aims to contribute to municipalities' decision making with their knowledge.

Key challenges for the energy transition with an emergent character

The techno-economic possibilities are not the main challenge anymore: it also includes social aspects, to bring and keep all relevant stakeholders on board, which primarily is the task of others. But the DSO sees a key challenge in being able to accommodate the wishes and demands of all changes in connections in reasonable pace, especially given the end targets of the energy transition and the vast expansion of infrastructure that this implies. Stedin does not want to be or become a bottleneck, but the pace in which investments can be implemented is limited, but they are only being allowed to do investments that are certainly effective.

Accommodating individual switches – hard to anticipate

Any change requested in connections needs to be accepted and accommodated (by law). And only formal requests can be executed. It is not explicitly monitored what is the reason why a connection to a home needs to be upgraded in capacity. For instance, when an electricity connection is upgraded, this could be to connect a hybrid heat pump, but

this is not necessarily recorded. For some technologies, e.g. going all-electric, can be noted because a removal of the gas connection and upgrade in electric capacity. But for other technologies, there is no way to monitor the individual choice, e.g. of going for a hybrid heat pump. This means there is a lack of overview what is the current status of the energy transition.

Furthermore, it is hard to anticipate, if not impossible, where such requests will be made in the (near) future. This has the consequence that investing proactively in expanding the local infrastructure is also not feasible; it is also not legal because only formal requests can be the basis of investment. A few expansions may still fit within the currently installed capacity, so some investments may be delayed. But to adequately plan when to invest where and also how much would require better information on when other households would consider switching to other heating systems and what systems they would be. This would be required for the DSO to underpin their investment plans, and then still needs coordination with and approval of financial regulators (ACM), as required by law.

Stedin considers developing models on the basis of a wide range of factors to determine locations where it is likely that many expansions are necessary and build a case for pro-active investments there. Developing adequate simulations/modelling is an active area for research. A crucial requirement for developing such a method is having compliance from policymakers and financial regulators (ACM).

Switching to hydrogen heating – a case where everyone should be on board

In a project where existing gas infrastructure is to be converted to hydrogen, this technically only functions if a full switch is made. This means that all houses connected have to switch away from natural gas and either connect to hydrogen or become full-electric. This has to be accepted and coordinated. In order to convince everyone, early on in the heat transition, the advantages for the households should be clear: financially competitive, technically executed well, provide comfort and so on. But this is not necessarily enough for full acceptance and support. And for a good review after the process by the participating households.

Key elements in this challenge:

- Financial compensation of households is possible in the context of a first scaling up project with direct subsidies on infrastructure and heating systems in homes, but this may not be feasible in terms of funding when scaling up much further. Although that is needed for the heat transition end goals. The role of financial support by central government is crucial, but not clear at the moment.
- All households must switch – either to participate in the hydrogen system or to go all-electric. In case there is not enough support, projects like this would stall, which implies a significant delay in the heat transition. Rules need to be developed to deal with this (e.g., a minimum acceptance rate over which a full switch becomes possible by a municipality)
- Stedin needs to get a specially determined role for operating a hydrogen infrastructure (not the same as all laws that now exist for natural gas because that would have side effects).

What to research

- What can be required (by law or otherwise) how households can be forced of natural gas infrastructure in a switch to hydrogen?
- How to better anticipate in which streets/locations most likely expansion is necessary. Where is no-regret expansion possible, and can approval with the ACM be found?
- How to monitor the progress in the heat transition (which households already switched, when, and to what alternative energy source)?
- Who performs what roles for new infrastructures? (E.g., required legislation changes for enabling the anticipated role of the DSO in the hydrogen infrastructure.)

Resources

Openingsbod: https://www.stedin.net/zakelijk/branches/overheden/het-openingsbod
Stad aan 't Harvingvliet: https://www.stedin.net/over-stedin/pers-en-media/persberichten/gasnet-van-stad-aan-t-haringvliet-kan-over-op-groene-waterstof

A.8. Interview Martine Verweij (Director MVI-Energy, Green Bridges)

Interviewer: Emile Chappin
Date: 21-02-2022

On the role of processes and shared world views

In order to achieve desired emergent behaviour, attention to and guidance of the process is vital. Specifically, to use a process through which a whole sector together develops a shared world view, including a vision on the future related to the energy transition. It provides for a shared history for who participates and a coherent view on what action is needed for, in this case, a successful energy transition. Experience shows that individual participants' own perceptions and actions become more coherent with the shared vision/worldview. By that process, the emergent process is also more likely to fit with this coherent view.

In order to speed up the energy transition, this process is crucial: giving attention and taking the time to adequately feed such a process is important (which sees paradoxical at the first glance).

On prediction vs shaping – in view of resistance

The system-level behaviour emerging over time becomes more predictable for two separate reasons. First, it is clearer what the (shared) world view is, and within that, what stakeholders' positions are. This may make it easier to anticipate barriers for desired emergent changes. Second, the process itself strengthens relationships between stakeholders and increases mutual empathy, which is beneficial in case, later in time, new tensions emerge, due to new developments. De-escalation is easier when actors can be reminded of an earlier positive shared experience. This may make undesired emergent changes less likely.

When a new project is a started in a particular context, such as the installation of solar panels near a village, it is good to realize that the resistance that might emerge, is often connected to experiences and happenings in the past. Issues – such as the loss of facilities (school, swimming pool) over the years, in an ever less densely populated area – that were not actively acknowledged as being painful for a community, will come to mind when new projects are taken on, in the same community. When starting up a new project in a certain area it is important to expect that behaviour of resistance will emerge, related to all that happened in the past that still needs to be acknowledged. Good processes start not with a solution to be implemented on a particular location, but with listening to the people, giving thanks for what is right and allowing all those that feel involved to face the pain of the past. So that from there, all involved can open their mind and heart for new developments[7]. This relates to the concept of *collective trauma*.

Collective trauma, according to Erikson, is 'a blow to the basic tissues of social life that damages the bonds attaching people together and impairs the prevailing sense of communality'; it 'works its way slowly and even insidiously into the awareness of those who suffer from it,' and while 'it does not have the quality of suddenness normally associated with trauma, but it is a form of shock all the same' (Erikson, 1976:154).

In other words; the *new* of the energy transition will most probably trigger *old* (individual and collective) trauma (and may lead to new individual and collective trauma), leading to emergent behaviour that is highly unpredictable and possibly even violent. If processes are designed in a trauma-informed way, chances are high that emergent behaviour will be more easily channelled and the process will be more forward-looking.

Club van Wageningen

The Club van Wageningen is a key example of a purpose-driven community that arose due to a very strong process. Over 150 people from different backgrounds (grid operators, energy companies, start-ups, prosumers, ICT-companies, national government, scientists, and municipalities) got together in a Future Search process to ensure that an ever more digital energy system remains fair, inclusive, and democratic (https://clubvanwageningen.nl/). This process led to the emergence of collective leadership, including a vision and an action list in the area of a fair and inclusive digitalization of the energy system.

[7] More info: Spiral of activism, Joanna Macy

What to research

- On good processes: methods such as a Future Search or Theory U, need to be skillfully executed; facilitators need to cultivate on embodied presence and be highly self-aware – managing large group processes requires a very strong awareness of oneself and all that might trigger oneself to lose mental and emotional balance and presence (resulting into fight, flight or freeze behaviour as individuals in a group [verbally] 'attack' a facilitator).
- Decision-support tools are typically focused on individual challenges and lack needed interactions between systems and sectors (such as energy, nitrogen, nature, water and social challenges in the built environment).
- Decision-support tools largely neglect the process in which participants open up to listen to others, and gain trust to allow collective and individual decisions to be made. There is too little attention to the delicacy of the process required.

Resources

- Examples of 'more coherent behaviour' of a whole field of actors due to good processes:
  - Club van Wageningen - https://clubvanwageningen.nl/
  - North Sea Energy Lab - https://reospartners.com/projects/north-sea-energy-lab-towards-the-north-sea-as-a-sustainable-energy-source/
- Processes:
  - Awareness Based Collective Action/ Theory U (Scharmer) - https://en.wikipedia.org/wiki/Theory_U
  - Future Search (large scale intervention method) – https://futuresearch.net
  - Social Labs - https://www.greenbridges.nl/the-social-labs-revolution/
  - Spiral of Activism – The work that Reconnects - Joanna Macy.
- Research on trauma, collective trauma: (Perry, 2012; Short & Szolucha, 2019) and this infographic on trauma: https://www.cdc.gov/cpr/infographics/6_principles_trauma_info.htm

A.9. Interview Marco Sodderland (Motivaction)

Interviewer: Emile Chappin
Date: 21-02-2022

Segmentation of consumers

Motivaction researches about and advices on 'what drives people'. Specific to the heating transition, they connect to CE Delft that performs techno-economic analyses (what technology would fit well where) and APPM for process management.

Motivaction developed segmentation called 'Mentality' of consumer groups on the basis of shared values. From their original 8 groups, differentiating on status and basic values, they cluster 5 groups of people on sustainability topics (see Figure 8), which are labelled five shades of green ('Vijf tinten groener' in Dutch). These do *not* cluster against basic demographics (e.g., age, income), but they do cluster by sets of values.

How to use a segmentation like 'Vijf tinten groener'

This particular clustering is vital for understanding 1) what drives people and 2) how to approach people in relation to energy transition and sustainability concepts and 3) how to bring people on board on energy transition projects.
It can be used to anticipate where people are that are the innovators (in Roger's terminology) or followers. Each group can be approached in a way that fits its values; but also the way contribution and participation is requested can be adapted accordingly.

For example, a municipality may opt to invite the citizens to an information meeting about the local energy transition with a hardcopy letter, signed by the deputy mayor. This signifies (from the sender), importance/priority. Not all receiving such a letter actually feels invited or inclined to go. There are many other approaches for this purpose.

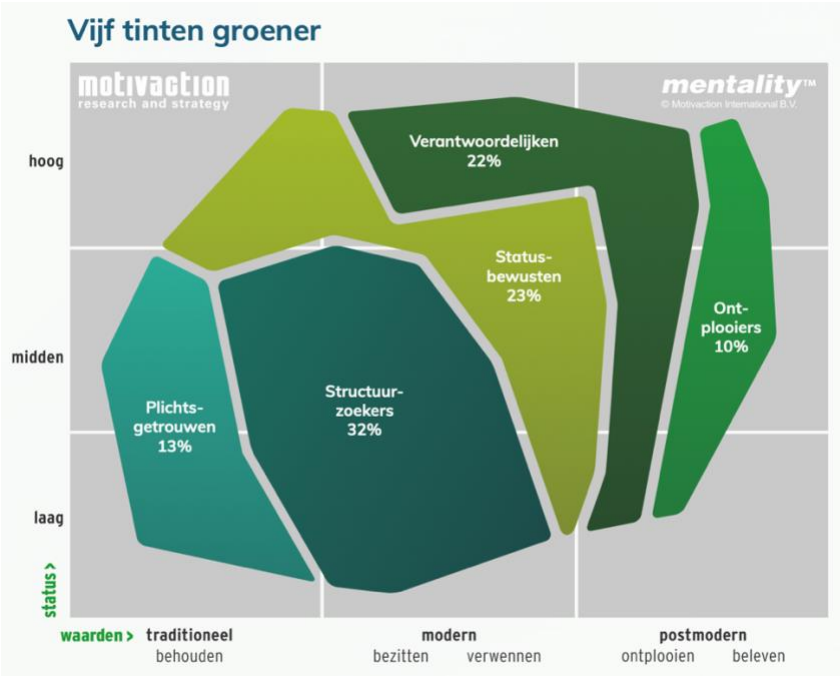

Figure 8. Motivaction's segmentation of sustainability.(in Dutch). From Motivaction's leaflet.

Strategically, one could choose what group to target first:

- Start with the large sceptical group, because if they participate successfully, it may trickly down through all of society). In general, the attitude towards sustainability needs to be considered. You then start in a neighbourhood where you can expect a large portion from this group. And you adapt the form of communication to match with this group. To inform them early on and to involve them enough so they have influence on the main choices (and not have the impression the choices were made before they became part of the process).
- Start with a very green group, because a success story may have benefit for the overall progress in the heat transition. And also here, adapt the communication to fit this group. Highlight the innovative character and the ability to act to the benefit of the environment, be a leader in it.

Important challenges

- The sense of urgency has not increased significantly over the last decade and this is important for how to address and communicate. Nature, environment and climate are, in general, the fifth topic on the citizens' priority list in the Netherlands.
- Day to day decisions are habitual, larger decisions to take action know various hassles, and perceived risks of lower comfort, of higher prices. Both are essentially disconnected from the objective (to mitigate climate change).
- Municipalities are not able to show the dedication, leadership needed to make plans very concrete, to create enough momentum. All of this requires specific expertise in the context of the heat transition.
- Responsibilities are shifted around (municipalities, central government, network operators, housing corporations). This hampers progress.

How to communicate about the required changes through the energy transition

The public needs to be informed on large scale, but it cannot be pushy, fatalistic, or unspecific. A large group is sensitive to their direct environment, so communication may benefit from having a local character, to be manageable/clear and concrete. It needs to connect more to citizens' perspectives and world views. It should, in contrast, not be about enormous and fatalistic, because this will not reach a large portion of the group. This should consider who lives where and in what segmentation (see above). And more awareness leads to a larger sense of urgency. It matters who communicates, and through what means. It matters to what people are invited and what it means to participate.