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The Future Swiss Electricity Market: Evolution or Revolution?

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The authors bear the entire responsibility for the content of this report and for the conclusions drawn therefrom.

Zusammenfassung

Damit das zukünftige Schweizer Stromsystem nicht nur eine CO2-neutrale Energiebereitstellung ermöglicht, sondern dies auch möglichst kosteneffizient erfolgt und einem hohen Grad an Versorgungssicherheit gewährleistet, ist eine Koordinierung aller involvierten Akteure notwendig. Ein effizientes Marktdesign scheint dabei die vielversprechendste Möglichkeit zu sein, eine solche Koordinierung zu erreichen. Das vorliegende Projekt zielt darauf ab, eine Bewertungsmethodik für diese Herausforderungen zu entwickeln und mögliche effiziente Designoptionen zu identifizieren. Dabei werden zwei grundsätzliche Stoßrichtungen analysiert: einerseits ein evolutionärer Ansatz, welcher Anpassungen am aktuellen Strommarktdesign vorsieht (z.B. die Kombination eines energiebasierten Grosshandelsmarktes mit Kapazitätsmechanismen); und ein revolutionärer Ansatz, welcher eine signifikante Umgestaltung des Strommarktes erfordert.

Aufbauend auf einer Problemstrukturierung wird ein schematisches Schweizer Strommodell entwickelt, um die evolutionären und revolutionären Entwurfsoptionen hinsichtlich ihrer Effizienz und Umsetzbarkeit zu vergleichen. Dieser Vergleich erlaubt Schlussfolgerungen ob und inwieweit eine Abfolge kleiner Anpassungen oder eine umfassende Überarbeitung des Strommarktdesigns notwendig sind, um eine sichere, kostengünstige, und nachhaltige Energieversorgung in einer klimaneutralen Schweiz zu gewährleisten.

Im ersten Projektjahr wurde mittels Literaturrecherche die Problemstrukturierung durchgeführt, welche die Grundlage für die Modellentwicklung im kommenden Jahr bildet. Ausgehend von den drei Haupttrends (Dekarbonisierung, Sektorkopplung und Digitalisierung), welche das zukünftige Stromsystem prägen werden, zeigt die Recherche, dass eine relativ grosse Bandbreite bezüglich der resultierenden Herausforderungen und Auswirkungen in der Literatur besteht. Allgemein werden v.a. Investitionsanreize und eine stärkere Rolle der Nachfrageseite als wichtige Aspekte identifiziert, welche auch in der folgenden Modellierung zu berücksichtigen sind. Dabei stellen die durch wetterabhängige erneuerbare Erzeugung geprägten Preisdynamiken, die steigende Relevanz von Speichern, und die zunehmende Dezentralisierung wichtige Herausforderungen dar.

Summary

The future Swiss electricity system needs to support the development to carbon-neutrality while providing secure and affordable electricity. The required coordination could be best achieved by a well-designed market. This project aims to address this challenge by developing a structure for market design evaluations and apply it to two distinguished pathways: an evolutionary one, i.e. adjustments of the existing electricity market framework (based on energy only wholesale markets and capacity mechanisms), and a revolutionary one, based on a significant reconfiguration of the current design.

Building upon a problem mapping and structuring, a schematic Swiss electricity-system model will be developed to compare the evolutionary and revolutionary design options with regard to their efficiency and viability to cope with the expected challenges for the Swiss electricity system. We will provide insights how and to what extent a sequence of small adjustments or a major overhaul of the electricity market design could be used to derive the future Swiss electricity system.

In the first project year, the problem mapping and structuring was carried out by means of literature research, which forms the basis for the model development in the coming year. Based on the three main trends (decarbonization, sector coupling and digitalization) that will shape the future electricity system, the review shows that there is a relatively wide range in the literature regarding the resulting challenges and impacts. In general, investment incentives and a stronger role of the demand side are identified as important aspects. In this context, the altered price dynamics defined by intermittent renewable generation, the increasing relevance of storage, and the increasing decentralization of the electricity system form the main challenges that need to be tackled in the model.

Contents

1 Introduction

1.1 Background information and current situation

The electricity system will be the central pillar of our future energy provision. However, it will be challenged by several developments (e.g., a high share of intermittent and decentralized generation, low marginal costs structures, coupling with heat and mobility) and accompanied by new opportunities (e.g., demand flexibility, digitalization). The extent of such transitions calls for better coordination of the involved actors and a potential rethinking of market designs for a mostly zero variable cost world. From a Swiss perspective, two more aspects play a crucial role: First, its relatively small size in comparison to its neighbors limits the influence of Swiss decisions on key developments. Second, imports and exports are relatively more important in Switzerland than in larger economies.

These points lead to a central question: How can future electricity market designs help to ensure a secure, sustainable and economical energy provision for Swiss citizens and industries? Is it possible to adjust the current market design to cope with the above challenges, or would a substantially differing design be more suitable to this end?

1.2 Purpose of the project

To address the above sketched research question, this project aims to develop a model tool for the comparison of different electricity market designs and assess a set of design options for the Swiss market. In particular, we will model and compare the performance of an evolution of the current electricity system design – centered on (spot) energy markets with potential capacity mechanisms – as well as a revolution of the design – focused on pricing the quality (reliability) as well as quantity (kWh) – under different future development conditions that reflect the above challenges.

1.3 Objectives

The project is expected to provide three main insights that will allow Swiss decision makers to evaluate the ongoing system transformation and identify potential policy, market, and regulatory solutions:

- First, the project will provide a problem mapping and structuring. Based on a comprehensive literature and scenario review, we will identify the main drivers of potential changes in typical electricity systems, assess their scope and importance for the overall system, and map design modification options. Then, we focus on the Swiss case to single out drivers that can be shaped by Swiss decisions.
- Second, a schematic electricity-system model will be developed based on the mapping. This parsimonious model will provide a representation of the basic system structure covering its main actors and their relations. The model will be calibrated for Switzerland applied to evaluate two design pathways: On the one hand, an 'evolutionary' market setting that supplements the current electricity system with complementary capacity mechanisms. On the other hand, a new ('revolutionary') market design requiring substantial framework changes, which allows retailers, consumers, and generators to contract reliability ex-ante.
- Third, based on the two assessments, we will compare the evolutionary and revolutionary approaches with regard to their efficiency and viability. The comparison will help to identify which setting provides a more robust solution and requires less ongoing interventions to achieve the desired safe, sustainable, and economical energy provision. Given the high uncertainty regarding some of the main development options – especially concerning sector coupling trajectories – the model will also indicate drivers and objectives central for the design choices.

2 Procedures and methodology

Following the objectives of the project, we conduct a three-step approach:

1) Review the policy literature and model approaches,

2) Model development and calibration

3) Assessment and comparison of different market design approaches.

The three steps are conducted subsequently throughout the project runtime. In addition to the direct project steps, the basic conceptual framework for the revolutionary market design approach is based on research conducted by the environmental economics research group. Following we will shortly present the basic approaches underlying each project step. The respective results and insights derived in the project so far as presented in the following section.

2.1 Problem mapping and structuring

The first project step will be a comprehensive mapping of the relevant drivers and resulting challenges and opportunities for future electricity systems. Building upon the extensive literature on electricity markets and policy design and our own expertise, we will derive a detailed description and mapping of the problems and relevant solution approaches discussed in the scientific literature and stakeholder debates. By clustering and structuring those into few main aspects, we aim to break down the multitude of debated proposals into a consistent framework of influencing drivers and resulting market design impacts.

Given the large body of literature addressing electricity market aspects, we derived a guiding framework for the literature review by transferring the complexity of electricity systems into a simplified three-layer structure as shown in Figure 1.

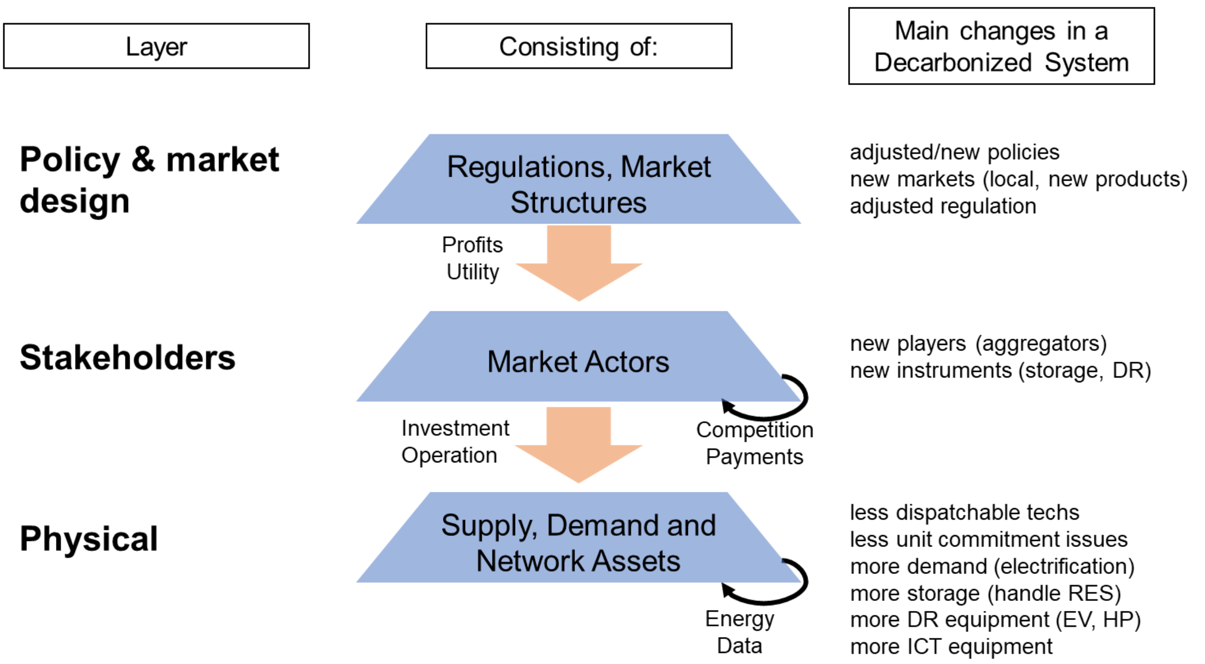

Figure 1 Three-layer representation of the electricity sector

The physical layer includes the technical aspects of electricity systems on the supply, transport and demand side; the stakeholder layer captures the role and relation of the different actors in the system; and finally, the policy and market layer captures the wide range of regulatory, policy and market design concepts and adjustments prevalent in electricity systems. Naturally, the three layers are highly interlinked with policies and markets shaping actor behavior and thereby investment and usage patterns of the underlying technology of the system.

The purpose of this structure is twofold. On the on hand, it captures the intricate set of interactions within an electricity system and allows to identify how those are expected to change while moving towards a decarbonized future. On the other hand, the structure will shape the review process. By clustering the existing research insights along the layers, we will be able to identity where common insights have already been derived, where diverging viewpoints are prevailing, and where research gaps are still existing.

Physical Electricity System Layer

Physical and engineering aspects play a crucial role in electricity markets as maintaining a balance between supply and demand requires a specific set of physical assets, which are usually categorized into supply side, demand side, and network assets:

- The ***supply side*** consists of a diverse set of power plant technologies which have a significant influence on the systems overall affordability, system adequacy and stability. The plants' characteristics differ greatly across technologies while the transition will have important implications for the way system stability is managed. The altered mix on the supply side will also have significant impacts on the other physical dimensions of the system.
- The ***demand side*** consist of a diverse set of consumers that gain utility from using electricity and pay a price in exchange. With the expected emergence of new electricity demand due to a transfer of mobility and heating demand into the electricity sector, the demand side is assumed to become more flexible and take a more active role within the electricity system.
- Related to this flexibility development on the demand side are ***storage assets***. They represent an emerging technology placed in-between supply and demand. They are similar to flexible shiftable loads in their system effect. However, storage technologies differ from flexible demand (and each other) in their short- and long-term efficiency.
- Finally, ***electricity networks*** in the form of transmission and distribution networks allow transfer of energy from the supply to the demand side. Consequently, they will be impacted by changes on the supply and demand side respectively. In addition, the emerging digitalization (i.e., smart meters and smart grids) could also impact the planning and operation of network assets.

Stakeholder Layer

Stakeholders invest and operate the assets of the physical layer based on their respective individual incentive structures. Stakeholders try to achieve a goal (e.g., maximizing profits or utility) given a set of available instruments (e.g., the supply and flexibility technologies). Thereby they shape the composition of the physical layer while the policy and market layer shapes their incentives space and the interactions between the different actors in the system. Generally speaking, interactions of stakeholders owning the same type of assets (supply, demand or networking) is usually of a more competitive nature while interactions with other types of assets can be competitive as well as of complementary nature.
In the electricity system of the last century the main actors have been energy utilities, regulators, and consumers. With the restructuring and liberalization of electricity market new actors emerged,

especially on the supply and retail side and with the transition towards a decarbonized system new actors are likely to enter the system.
The resulting interaction of those new stakeholder mix will have significant implications for the overall system. The same physical assets can be operated differently if owned by different stakeholders. Similarly, different operational incentives and profits leads to different investment incentives for different stakeholders and will impact the ownership distribution of assets. Consequently, not only the understanding of the individual role of the respective system actors will be crucial for assessing future electricity systems but also their interaction and the bi-directional relation with the physical layer.

Policy and Market Layer

Policymakers can alter regulations and existing policies as well as introduce new policies to obtain specific political goals and steer (or at least influence) the behavior of stakeholders. In addition, the restructuring introduced a market dynamic that can in theory evolve itself through stakeholder activities (e.g., many wholesale markets in Europe have emerged as private trading platforms). However, policymakers still set the general regulations and standards for market activities and define the conditions for the trade of energy and services.
Similar to the other two layers, there is a high level of interaction between the different elements within the policy and market layer. Given the multitude of political objectives beside a decarbonization, it is likely that electricity system will remain subject to a diverging set of (potentially even conflicting) policies and regulations. As the policy layer defines the maneuverable space for stakeholders which as described above defines the composition of the physical layer, the interaction between all three spheres is important to properly assess the overall future system aspects.

2.2 Model design and calibration

The second project step will be the development, tailoring, and application of a schematic electricity-system model. We aim to develop a parsimonious model that captures fundamental system dimensions and relevant actors identified by the structure problem mapping stage. This model will have a conceptual structure, that is, a microeconomic model describing the incentives of the main actors and their inter-actions, and will be used to derive the behavior of these actors (investment and deployment/demand decisions) to assess the market outcome. To gain some insights on which aspects are likely to be most relevant, the model will be parameterized to capture the main characteristics of the Swiss electricity system (existing generation capacities, potentials, cost structures, demand, and potential demand flexibility). However, it will not aim at a detailed quantitative assessment.

The actual model development will be carried out in 2022. Based on the problem mapping of the first step investment aspects (capacity mechanisms, refinancing, and incentives for different market actors) are seen as central. On the supply and storage side classical profit maximizing behavior of companies will be modeled, while the demand side will need to account for incentives based on different tariff structures. Network aspects will be included in a highly simplified manner.

Figure 2 shows a concept of such a model design for a rural-urban system structure. The model will need to capture the different actor categories (e.g., homeowners vs. renters) and characteristics of the actors in the system (share across urban and rural regions) as well as supply potentials (e.g., hydro and new renewables). The actor incentive structures and interactions are the main elements of the model design and their mathematical formulation will need to be formulated in way that enables the representation of different market/policy design for a common set of actor and system characteristics.

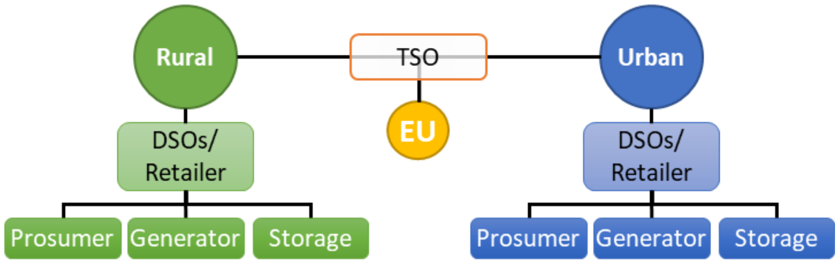

Figure 2: Example of the schematic system model: actors and network structure for spatial aspects

2.3 Marker and policy design assessment

The third step and final part of the project is the assessment and comparison of two different transition pathways. We will address the question to what extent persistent market interventions are likely to be required in the different market designs to ensure a secure, sustainable, and economical electricity provision for Switzerland. This comparative assessment will also link the model results with the ongoing debate on prospective pathways to a net-zero economy. As the two potential design options will be evaluated for a set of different external drivers and developments, we will be able to identify which adjustments will be needed under specific future developments.

3 Activities and results

Within the first project year the review of the policy literature and model approaches has been conducted to obtain a first problem mapping and structuring. The review has been discussed with the SFOE project coordinators to identify a suitable setting for the 'evolutionary' pathway which in turn defines the minimum requirements the model tool will need to address. In addition to the project work the environment economies research team at the University Basel has developed a first draft for a 'revolutionary' market design. Following we will shortly highlight the main findings of those two tasks.

3.1 Problem Mapping

As indicated in Section 2.1 the review was focusing on the physical, stakeholder and policy dimension of electricity systems to obtain a comparability across different literature streams.

Physical Electricity System Layer

The guiding questions for this part of the review were: What technology mix exists in the future system? What technologies are assumed to enter and leave the system? How is the demand structured? For the relevant literature we mostly focus on (large scale) numerical model scenario studies with a focus on the European region. Those studies are mostly following a cost minimization logic, without markets, without explicitly modeling policies, and without explaining how to achieve this optimal system.

The investigated studies differ substantially on both modelled technologies and their shares (Figure 3). However, as one common exterminator all decarbonized scenarios rely on a mix of *PV and wind* on their supply side. Across the investigated studies those two technologies cover on average a share of

70% or more. Nevertheless, the distribution of generation between PV and wind sources can differ drastically from one scenario to the other. Beside PV and wind the scenarios also differ in the remaining technologies of the system, albeit they all agree that some further technologies will be needed.

Regarding the demand side, the studies also greatly vary in their underlying development assumptions. While there is a general agreement that electrification will play a crucial role, the actual extend for the resulting demand increases vary from 3’000 TWh up to 10’000 TWh (Figure 4), with the majority being in the 4’000 to 6’000 TWh range. In comparison, total net electricity generation/demand in the EU was around 2’800 TWh in 2018.

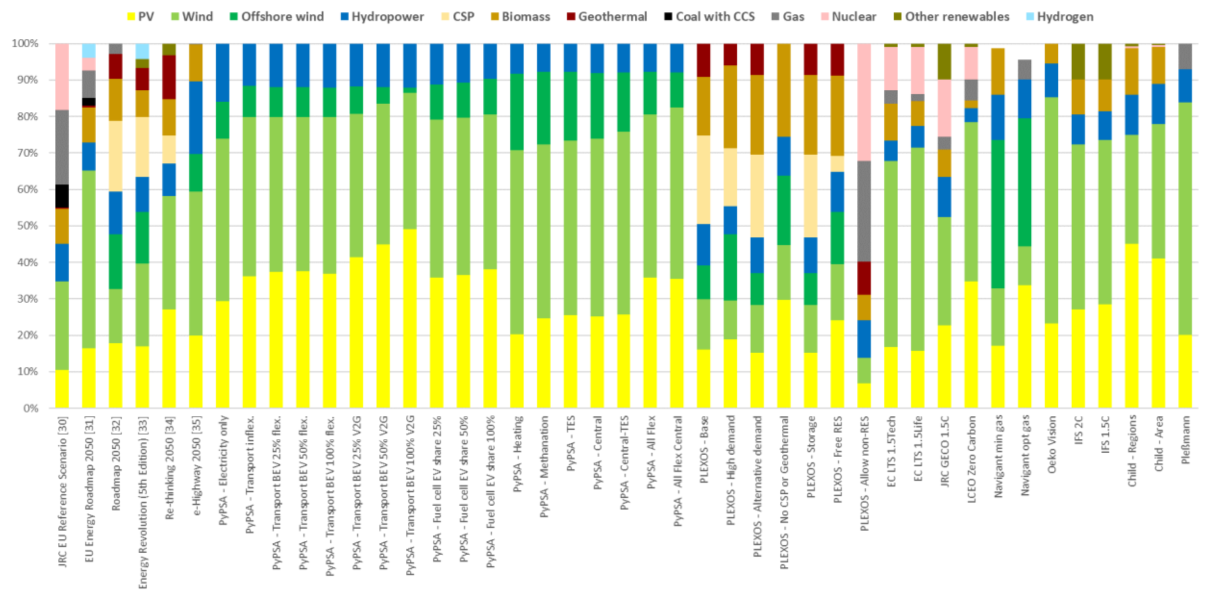

Figure 3: Technology generation shares of the European decarbonization studies

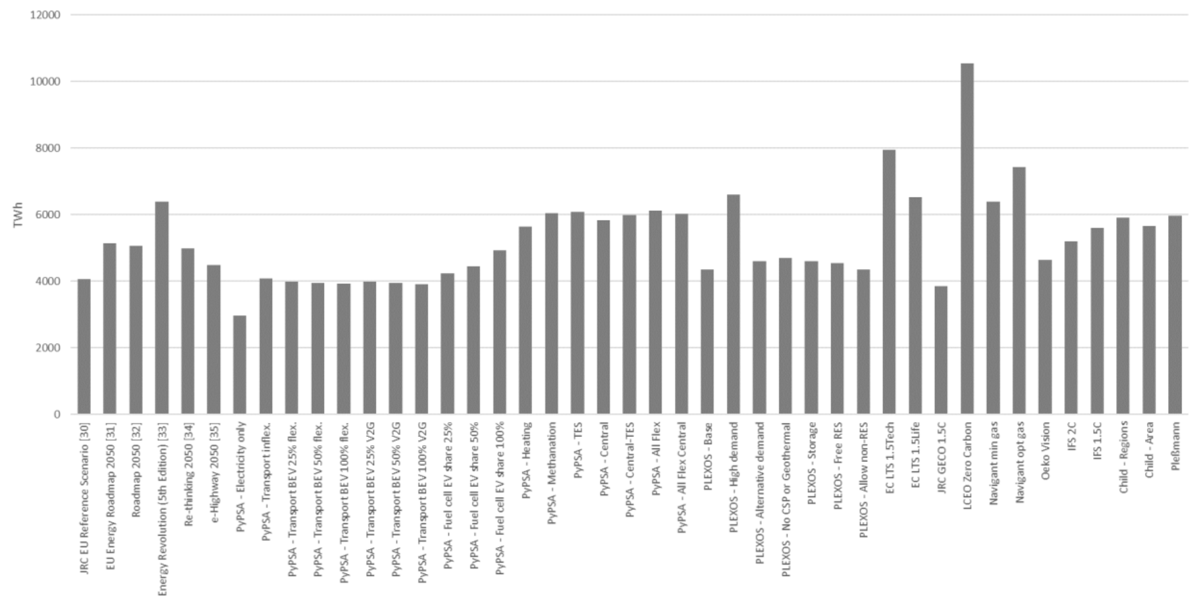

Figure 4: Total generation/demand of the European decarbonization studies

Regarding storage developments most studies assume that the existence of short term storage is a given while the future of seasonal storage and power-to-X technologies is less clear. Studies focusing on a 100% RES system rely on either significant storage capacities or a mix of CSP, biomass, and geothermal technologies to provide back-up.

As most of the large scale scenario models neglect network aspects – and in particular distribution network constraints – no common agreement exists on the role of network developments within the literature. However, those studies that at least include (cross-border) exchange capacity find that those capacities support future systems by linking different demand and generation regions.

Overall, most of the differences between the investigates studies are due to assumptions on costs developments for the different technologies and externally defined constraints (i.e. allowed/non-allowed technologies like nuclear).

Stakeholder Layer

The guiding questions for this part of the review were: What actors are investigated? What role do those actors have in the system? How are the actors modeled/defined? For the relevant literature we found a mix of conceptual and small scale model studies that usually investigate only one (or very) few actors. Studies investigating the interaction among different actors are scare.

The literature on the supply side is mostly focused on company behavior; in particular profit maximizing investment assessments (i.e. net present value analyses) as well as handling of risk and uncertainty (i.e. mean-variance approaches). As with the scenario models the underlying technology assumptions are one of the main drivers for the resulting findings. Most investigations focus on a perfect competitive setting and apply optimization, equilibrium and simulation approaches when numerical quantifications are conducted. Studies investigating storage actors follow a similar structure but are relatively scare so far.

On the demand side the development is assumed to be more fluid. Consumers in a decarbonized system are assumed to have a higher degree of freedom in choosing their respective objective, ranging from economic to environmental interests and social concerns. Consequently, also the representation of electricity consumers has become a growing field for researchers. Roughly speaking, future consumers in a decarbonized electricity system can take one of the following roles: i) inflexible consumers (like traditional consumers), ii) flexible consumers, iii) prosumers (owing own generation), or iv) prosumagers (owning generation and storage). In particular, the potential of the demand side to contribute flexibility is widely discussed in the literature and the potential for demand-side flexibility is thought to be significant.

The more active role of consumers calls for a similar perspective as supply oriented assessment, namely investigating investment and usage decisions. Moreover, instead of maximizing their utility (or minimizing their energy costs), consumers may also seek several objectives when becoming a prosumer or prosumager (e.g. environmental concerns, self-sufficiency etc.). In addition to the individual consumer perspective, also their potential cooperation has become the focus of research and practical implementation. The behavior of both individual and collective actors has been extensively studied in the literature; e.g. based on experiments and model-based assessments and simulations. A particular focus for consumer incentives is the role of tariffs (see also the following part on the policy and market layer).

On the network side, research is focusing on incentive regulation aspects with limited investigations beyond this focus. Finally, aggregators are seen as a potential important actor in some studies. However, their actual relevance is still rather unclear. Investigations on aggregators usually follow a classical profit orientation approach.

Policy and Market Layer

The guiding questions for this part of the review were: What policy and market design options are investigated? Is there a common system design? Are there 'out of the box' approaches? The relevant literature is similar (and often linked) to literature investigated for the stakeholder part. In addition, there is a body of empirical studies focusing on existing policy and market approaches. Naturally, electricity policies and market design questions are strongly related to the realm of climate policies. However, as a future decarbonized electricity system will by design require a strong climate policy (i.e. a high carbon price) we exclude climate focused studies from the review.

On the supply side most studies either focus on long term dimensions (i.e. investment aspects and supply security) or on short term aspects like spatial and temporal resolutions (i.e. real-time/intraday relations and zonal and nodal market structure). Albeit, assessment of renewable support policies form a large part of the electricity market literature – with both a conceptual and an empirical focus – they are only partially relevant for future market design choices as specific renewable technology support should not be a long-term feature of electricity systems. However, they will likely form an important element of the transition process, with auction based mechanisms taking a more prominent role in recent years.

A central theme regarding investment incentives is the role of capacity mechanisms. Investigated capacity remuneration mechanisms differ on the parameter fixed by the procurer (volume vs. price), the nature of the volume being procured (market-wide vs. targeted technologies), and the procurer (centralized procurement vs. bilateral arrangements with load-serving entities). However, there is no common agreement that capacity mechanisms are needed to maintain a stable electricity system nor on their design.

Albeit storage technologies are expected to play an important role in future systems there is no such common agreement with regard to storage policies. There is limited research on how an actual storage support policy could be designed (which is often linked to a more general demand side policy assessment) and whether such policies are needed.

Demand side oriented policies and regulations can roughly be structured along three lines: i) energy efficiency policies aiming at reducing the overall energy demand, ii) tariff design and the respective incentive structures for consumers as well as the linkage to DSOs and utilities, and iii) flexibility market related polices. The latter also links to the broader relation of the demand side with system and network aspects. The emerging field of consumer cooperation adds to those three fields, but remains limited in its extend so far (and mostly focused on the regulatory settings for cooperation).

While energy efficient policies have a strong focus on building renovations and heating (and thereby to sector coupling), tariff design and flexibility policies are directly electricity related and strongly interrelate with the consumer stakeholder literature, especially the role of prosumers in future electricity systems. One common aspect of this literature are the need for a higher time resolution of price signals (either via tariffs or flexibility markets/mechanism) at the consumer level to account for system conditions. However, it is unclear how much is actually needed to induce sufficient incentives. Similar there is an extensive investigation on the role of capacity components in tariffs and the interplay between investment incentives and cost allocation; especially with respect to network tariffs. Finally, the social dimension (often in form of acceptance) and distributional aspects of new market structures is become an increasing area for research.

As identified in the stakeholder part, most of the literature on network related policy choices are embedded in the regulatory economics literature and investigate different incentive regulation approaches or are strongly linked to the above-described tariff design questions and flexibility markets. One particular market aspect of electricity networks is the role of interconnections between different countries/zones and the related import/export aspects.

3.2 Revolutionary market design

Parallel to the project, the environmental economics research team at the University Basel has conducted research on potential electricity market designs. The objective is to identify an alternative solution to address the challenges of a mostly renewable electricity system that does not follow an energy-and/or-capacity market approach. The approach is envisioned for the 'revolutionary' pathway assessment and will be compared to an evolution of today's system with a focus on energy markets and capacity mechanisms.

The revolutionary approach should provide the following characteristics:

- It can support a high share of RES without promotion policies in the long run
- It creates demand-side flexibility
- It is beneficial to all involved parties and no actor is 'forced' to participate
- It should have as little regulation as is possible

The subsequent developed approach has two main pillars: 1) electricity is traded with different qualities based on the reliability of supply and 2) consumers can mix different qualities. The design is an extension of the basic idea of priority service (e.g., Chao & Wilson, 1987) and builds upon the idea of paying for capacity but defines the desired capacity level via endogenous mechanisms.

The basic market design is centered around consumer choice and contract design. Consumers chose a supply contract that entails a secure load level and on top a load level which can have a lower supply reliability. Retailers offer consumers supply contracts that fulfill those reliability contracts by buying from generators a mix of different supply options. Wholesale markets allow retailers to trade excess supply and a regulator is required to ensure that the supply portfolio of retailers fulfills the contractual reliability obligations.

A first conceptual model with those properties has been developed and first results indicate a higher welfare than a pure 100% reliability approach ensured via capacity mechanisms. The refinancing via long term contracts furthermore allows intermittent generators to obtain capacity payments instead of relying on short term wholesale market refinancing. This reduces the problem energy based payment systems face when high shares of renewable generation lead to price reductions and thereby reduced investment incentives for renewables. In addition, the contractual setting allows a decentralized solution, thus enabling consumers to define their desired level of reliability instead of depending on an external definition of system reliability.

In a next step the properties of the developed market design approach need to be verified for varying assumption sets. A crucial element is the challenge that the contracts are including a reliability element that basically represents a probability. While the true reliability can only be verified ex-post, an ex-ante approach needs to be accompanying the market design if it is supposed to work in reality. A full assessment of the basic market design properties is scheduled for 2022.

4 Evaluation of results to date

The objective of the review was to identify common trends and conclusions already provided by the existing literature and identify needed elements the modeling tool needs to capture, in particular with respect to stakeholders and their interaction. Following we will give a short overview of the main conclusions drawn from the review. The actual translation into model elements is scheduled for the next project year (see next Section).

Figure 5 provides a summary of the main commonalities identified in the literature. The three main trends shaping the future electricity system are effects related to the decarbonization of supply, the electrification of heating and transport demand, and the implications a further digitalization will have.

As shown especially in the physical layer the decarbonization will be addressed by increasing supply by PV and wind generation with an accompanying residual supply by other carbon free technologies and storage. However, there is no common agreement on the scope of those three aspects. Nevertheless, they clearly indicate the importance of investment incentives for identifying suitable electricity system designs.

The two other main trends lead to significant alterations on the demand side or at least open up those options. While again the scope of those aspects is not commonly agreed upon in the literature, the insights highlight the importance consumers will play in the future electricity system. Their importance is also shaped by the increase in PV as crucial supply option, as a significant share of this generation is expected to come from rooftop installations.

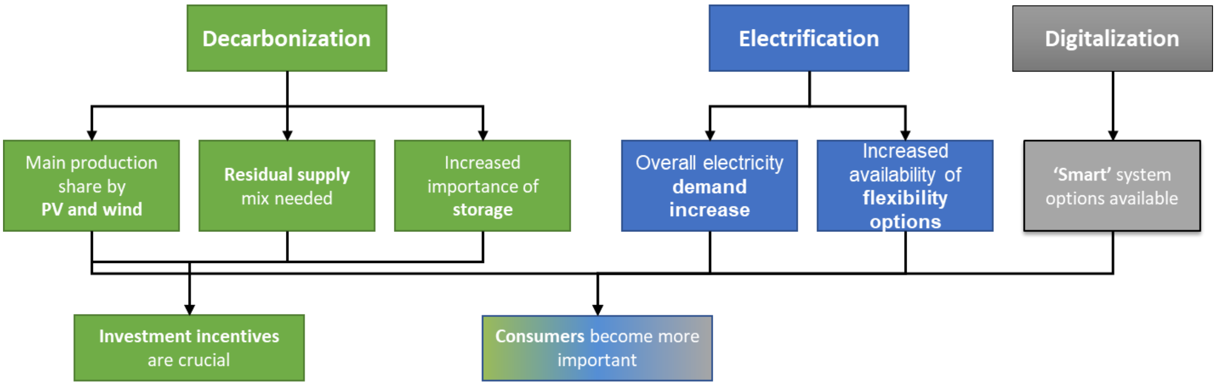

Figure 5: Common drivers, trends and consequences as identified in the literature review

While there is no real common conclusion on the scope the different developments will have, there is nevertheless a good understanding of the associated challenges for the future electricity system and the resulting policy and market design challenges. Figure 6 translates the above defined aspects of the future electricity system into respective challenges and resulting system alterations. On the market side the increased role of weather dependent intermittent renewables with high capital but negligible variable costs will have to lead to new price dynamics. Today's price structure is defined by the different variable cost levels of conventional generation and the load level. In the future the interplay between RES surplus and deficit times will shape will not only lead to a different time structure but also to a different price shape. In addition, the expected higher share of storage in the system will make opportunity costs more important for price setting. Those price dynamics will naturally lead to a different investment risk. Together this interplay forms one of the main aspects a market design needs to address and is thereby also a central aspect the model framework will need to capture.

A second important dimensions can be summarized as an increase in decentralization. The availability of local generation and storage options, coupled with an increased participation of consumers and an increased controllability of those new system components also leads to a different relation between local, regional and national markets. This also includes the relation between distribution and transmission system operators, which is often neglected in (techno-)economic electricity system assessments.

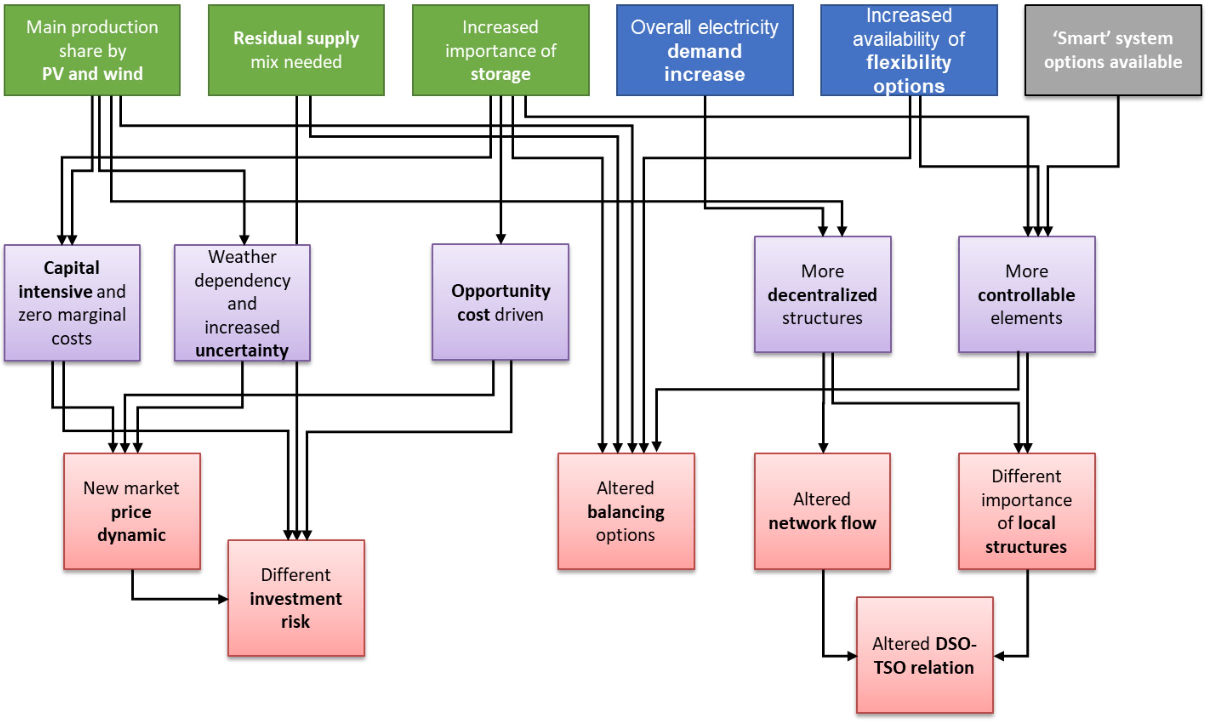

Figure 6: Resulting challenges and system alterations based on the literature review

Evolutionary Market Pathway

Given the insights derived from the review a first clarification of the evolutionary market design pathway can be derived to identify the subsequently needed elements of the model. The basic concept of the evolutionary approach is the adjustment of today's market design addressing the identified challenges. To this end, the basic framework of a wholesale based energy market and tariff based end-consumers will remain as main design elements.

On the wholesale layer, we envision a further coupling of international markets (up to nodal approaches) and a further increase in real time trading. However, the overall structure of the wholesale market will remain rather similar to today and provide the relevant short term operational signals for market participants. With respect to long term investment signals, capacity mechanisms are seen as the most likely adjustment. Several European markets already have such mechanisms in place, albeit there is not coordinated nor uniform approach so far. In the long run either national approaches (i.e. strategic reserves) or a more coordinated European approach (i.e. capacity market(s)) can be envisioned. On the end-consumer side a full transition to real-time tariffs with hourly or sub-hourly resolution seems unlikely. Nevertheless, the time resolution of tariffs is likely to increase and the share of fixed and variable components will be adjusted, in particular with respect to network charges.

While in the long run continued support for specific technologies (i.e. renewables or storage) should not be a fixed component of the market design, such policies could be part of the transition from today's system into the new design. To this end, the model approach will also need to account for such policy approaches. Furthermore, the whole system pathway needs to be subject to a strong decarbonization policy (i.e. a carbon price). Otherwise, additional policy interventions may be needed to compensate for an insufficient climate policy.

5 Next steps

With the finalization of the review, the next project step is the design of the basic model outlet and its subsequent calibration to the Swiss electricity system and the identified two future pathways (evolution and revolution). The basic structure of the evolutionary setting defined above and the corresponding framework for the revolutionary design will be refined in early 2022 and subsequently the specific design aspects (i.e. What type of capacity market? What tariff configurations?) and numerical specifications will be determined. The actual numerical simulation of the pathways is scheduled for the last project year (see Figure 7).

For the general model design, the identified challenges will be the guiding frame. In particular, the model design will have to account for the two major challenges and alterations; i.e. have a proper investment representation as well as sufficient representation of local impacts on the whole system. A full sketch of the evolutionary and revolutionary pathways will follow for the calibration stage, as investigated capacity mechanisms and tariff structures need to be clarified and quantified.

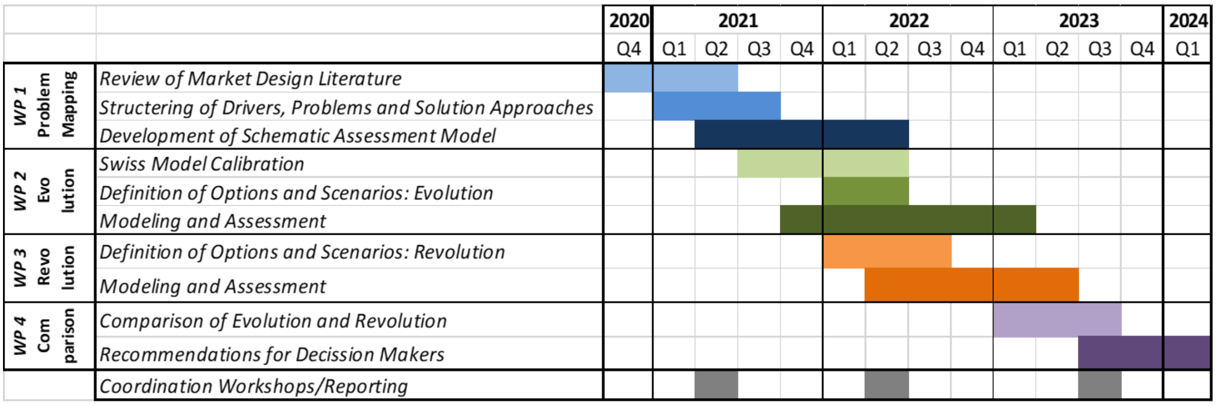

Figure 7: Project time plan

6 National and international cooperation

Given the Covid situation, participation at workshops and conferences has been limited during the first project year. A direct cooperation with other national or international research groups is not planned for the project. Once the model design has made significant progress, the proposal will be discussed with experts in the field.

7 References

The review paper is expected to be published as working paper by early 2022.

The conceptual description of the revolutionary approach is expected to be finalized in 2022 and subsequently published.

Chao, H. P., & Wilson, R. (1987). Priority service: Pricing, investment, and market organization. *The American Economic Review*, 899-916.