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Key points of a legislative initiative for reliable and adequate renewable energy supply

Sector Coupling and Innovation Act for Renewable Energy (SCIA)

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SCIA – Sector Coupling and Innovation Act for Renewable Energy

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Summary

The Energy Watch Group presents a legislative proposal for the introduction of a so-called combined-power-plant tariff. The aim of this instrument is to enable investments for full demand-coverage of 100% renewable energy, and stimulate the currently stagnating investment dynamics in the expansion of renewable energy in Germany and worldwide.

There are widespread discussions about the idea that balancing the fluctuations of solar and wind energy causes particularly high integration efforts and costs for grid operators. Concern is also raised in regard to a reliable and adequate 100% supply of renewable energies not being possible due to the lack of a base load. Yet, the technologies already available today – electricity generation from renewable energies, energy storage, digital control and accounting tools, and sector coupling with heat and transport – are already able to create a cost-efficient system with 100% renewable energies, which is reliable and adequate for the grids. Reliable and adequate renewable energy supply (RA-RES) is to be understood as an energy supply that is achieving 1) short-term reliability including services such as frequency maintenance, voltage maintenance, and black start capability, and 2) adequacy of capacity for energy security in the long term. In addition to cost efficiency, other advantages for the wider energy system include independence from imports and the related uncertainty with regard to price and availability, as well as climate, health and environmental protection benefits.

However, there are still hardly any legally binding incentives for such RA-RES investments.[1] This is due to the fact that existing renewable energy support schemes only promote individual investments in single technologies such as solar, wind or bioenergy. These schemes do not trigger the combined investments that are crucial to building a cross-sectoral integrated energy system that uses renewable energy to source electricity as well as power the heat and transport sectors. To the contrary, there are often considerable obstacles in most legal frameworks where electricity taxes, grid fees and renewable energy costs are levied on storage technologies. This results in a lack of market dynamics.

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[1] Exceptions might be given by examples of regulations for island grids and off-grid renewable energy systems that are not investigated here. Nevertheless, this proposal is particularly well suited for the implementation of RA-RES in island systems.

Intending to close precisely this gap, the Energy Watch Group proposes a Sector Coupling and Innovation Act for Renewable Energies, with a guaranteed tariff for investors as its central building block. This guarantee tariff offers a high incentive for innovation because only one condition is imposed on the investor: The supported generation mix of 100% renewable energies must be able to feed in electricity throughout the year, in line with demand and system requirements, i.e. RA-RES.

This gives rise to a variety of solutions that are the result of individual optimisations, taking into account individually available technologies, their current costs and in addition the specific needs of the project, e.g. a medium-sized production company, a hospital, a school or a residential area. Thus, a large number of investors will realise their individually optimised solutions, which in turn leads to a high degree of innovation.

On the basis of the rapid cost development, it can be shown that a tariff of 8 cent per kWh is sufficient for the case of Germany as suggested by our study on 100% full supply from renewable energies for the county of Bad Kissingen (Traber et al. 2020). Moreover, since the studied region does not have particularly rich renewable energy resources, it is expected that this level is indicative for cost-covering tariffs in many regions worldwide. However, in order to avoid unjustified profits, the specific tariff can be adjusted to national resource abundancy, financing conditions and technological advances over time.

The Sector Coupling and Innovation Act for Renewable Energies is to be introduced as an independent new law. Regarding policy implementation, the law is conceptualised to be anchored in national law and for EU member states specifically, the law is shown to comply with EU legal provisions. These are aiming particularly at the objectives of cost efficiency and the orientation towards a market-based approach, which are policy goals of most legislations worldwide. Particularly, the EU framework allows a guaranteed tariff which is differentiated into: 1) Small plants which qualify to receive a fixed feed-in tariff, and 2) Larger plants which must be oriented to the existing market by a sliding market premium.

Sector Coupling and Innovation Act (SCIA) at a glance:

- Legal basis and legal certainty for calculable, cost-effective and demand-oriented investments.
- Reliable and adequate renewable energy supply (RA-RES) with positive effects for the entire energy supply system by creating decentral cores that are not only balance-sheet independent but are also physically independent by design.
- Innovation and competitive advantages: Promotion of all components of sector coupling and storage-based, electricity-focused and highly efficient energy supply systems.
- Investors can try out new concepts due to reduced price risk while accepting a certain risk in terms of generation costs instead of solely relying on proven but narrow, less innovative concepts, as commonly supported with state tenders.
- Boosted by favorable cost developments already today, learning effects and mass production will facilitate continuous reduction of the level of guarantee remuneration and energy related costs in the future
- Climate protection and efficiency gains through the expansion of emission-free renewable energies and the electrification of the coupled transport and heat sectors
- Environmental and health protection, especially by reduced air and water pollution.

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List of Abbreviations

B	battery
BI	battery interface
CCH	combined cycle gas turbine for hydrogen
CHP	combined heat and power plant
FC	fuel cell
GTH	gas turbine for hydrogen
HP	heat pump
HS	heat storage tank
H2Comp	hydrogen compressor
H2Elsy	hydrogen electrolyzer
H2S	hydrogen storage
PV	rooftop photovoltaic
SCU	small cogeneration unit
PVU	utility scale photovoltaics
Wind	wind energy plant

CPP	combined power plant
CPPT	combined power plant tariff
DSO	distribution system operator
RA-RES	reliable and adequate renewable energy supply
SCIA	sector coupling and innovation act

1 Introduction

Achieving the Paris climate targets and limiting global warming to 1.5°C requires a rapid transformation of the world's energy systems towards 100% renewable energies. Although wind and solar power are currently the most cost-effective forms of energy generation, their expansion in most regions, countries and sectors is not sufficiently fast to reach targets compatible with the agreed climate target. In several major greenhouse emitting countries including Germany, India, UK and France, the growth of renewable energy, for instance of wind energy, is decreasing. In many other countries, the development of renewable energy is still in its infancy. Current deployment rates are in any case not sufficient for the overall fulfilment of the targets enshrined in the Paris agreement.

A main reason for this development is that the integration of renewable energies into the grid often relies unilaterally on the expansion of transmission lines. But the development of grid infrastructures is an expensive and lengthy process that often faces resistance from the affected population. A solution that not only makes sense from an economic perspective, but is also necessary from a climate policy perspective is to complement the expansion of transmission lines with decentralised and sector-overlapping investments in renewable energies and storage technologies at the level of distribution grids and medium voltage level.

To date, however, there are hardly any legal instruments available to promote the reliable and adequate renewable energy supply (RA-RES) which is regionally achieving 1) short-term reliability including services such as frequency maintenance, voltage maintenance, and black start capability, and 2) adequacy of capacity for energy security in the long term. The possibilities of integrating RA-RES solutions at the distribution grid and medium-voltage level have so far usually not received systematic state support. On the contrary, sector coupling is frequently hindered by considerable barriers. The fair treatment of final electricity consumption with systemically useful electricity storage in terms of taxation, grid tariffs and surcharge obligations, which still exists in some cases, does not create stable incentives for investors.

In addition, the legal uncertainties in this area are also an obstacle. For electricity storage, hydrogen-based storage systems, heat storage units, heat pumps and, in general, for integrated energy system solutions at regional level, there are no legal instruments for market introduction. The proposal for the introduction of a Sector Coupling and Innovation Act based on a combined power plant tariff (CPPT) outlined below is intended to close these gaps.

At the same time, a number of start-ups and established companies with innovative ideas and business models are already available today to realise investments in round-the-clock secured capacity from 100% renewable energy and storage. Digitization, new storage innovations and generation from renewable energies have developed to such an extent that an investment dynamic serving the needs of climate protection could be initiated by a legal promotion practice specifically designed for this purpose.

The proposed support instrument limits the problem of market and regulatory risk and supplements the orientation towards electricity wholesale prices by aligning it with current regional electricity demand. To this end, the promotion of electricity generation through guaranteed tariffs has to be complemented by mandatory feed-in profiles based on demand profiles at the respective grid level.

With the proposed guaranteed tariff, transparency will be possible at a competitive price level. This creates the much needed and potentially game-changing basis for triggering rapidly falling costs in accordance with the learning curves and promoting the necessary development of the integration of renewable energies. The combined power plant tariff system will not only create RA-RES investments in rural areas. In densely populated urban regions, too, many objects including production plants, hospitals, schools and housing areas can be equipped with such integrated systems.

The central component of the proposal is a guaranteed tariff for combined power plants (CPPT). The CPPT is described and illustrated in detail in section 2 and the required level of legal tariff is estimated on the basis of our own calculations. Section 3 explains the compatibility of the CPPT proposal with national regulatory frameworks and EU legal requirements, followed by an outline of the legal implementation in Section 4.

2 Goal, concept and functioning of the combined power plant tariff

The objective of the Combined Power Plant Tariff (CPPT) is to strengthen the worldwide expansion and use of renewable energies, that is indispensable for climate protection, and at the same time necessary to promote reliable and adequate supply. In this way, renewable energies are incentivised to assume the much-requested responsibility for system security of the grid.

This proposal is expected to trigger a considerable promotion of competition through the guaranteed Combined Power Plant Tariff (CPPT). Whoever designs, technically implements and operates the combined power plant in the most efficient and cost-effective way, will increase his profit margin at the given tariff level. This holds in particular when private entrepreneurs organise a tendering competition for the best solution for the implementation and operation of a planned combined power plant. This stimulates competition at the technological level, leads to learning effects and thus to desirable efficiency gains overall. Investors can try out new concepts with lower risk and accept higher production costs instead of – as is predominantly promoted with state-tenders – relying on proven but not particularly innovative concepts. In turn, learning effects and mass production are expected to lead to a steady reduction of the level of the guaranteed tariff in the future.

This proposal intends to deliver towards all the three standard energy policy objectives including a secure, environmentally benign and cost-effective supply. Therefore, it creates legal certainty, enables economic planning and triggers innovation processes that are linked to the strong orientation towards regional requirements. RA-RES regions will provide predictable energy prices and isolation from fossil fuel price risks. At the same time, the stability of the energy supply at national and international level is increased by the creation of regional RA-RES cores that are not only balance-sheet independent but also physically independent. Black-out risks are reduced by decentral system redundancy that is created in addition to its central provision.

The concept lays out that RA-RES systems receive a fixed feed-in tariff or a floating market premium. For this purpose, the plants must be able to cover the empirical load profile at the local feed-in point with an entirely renewable generation mix, if necessary, in combination with storage facilities, throughout the year.

Central for the functioning of the CPPT is the guarantee tariff for electricity fed into the grid on the basis of renewable energies, in accordance with the empirical load profile determined in advance at the relevant feed-in level. The relevant level is the smallest grid area that can fully utilize the planned combined power supply. For the determination of the empirically based reference load profile, the normalised average load profile of the previous 36 months broken down into 12 calendar-monthly typical weeks appears suitable. The empirical load profiles thus defined are referred to in the following as feed-in profiles.

The CPPT is granted over a period of 20 years and is to be implemented primarily through a fixed tariff. This applies at EU level at least to small RA-RES systems. Only if market orientation is a specific policy objective and functioning electricity wholesale markets are established, the guaranteed tariff may be established by a floating market premium, which is foreseen at the EU level in the case of further specified large plants. Such market premiums can be paid annually as multiples of the hourly market price in such a way that the average achievable feed-in proceeds from market prices and market premiums match the level of the guarantee tariff. If, for example, the guarantee tariff is 8 eurocent per kWh and the annual average market price is 6 eurocent per kWh, 33.3% of the respective hourly market price would be paid as a premium for each kWh fed in. [2]

In the normal case envisaged, a one-year pioneer operation is carried out after commissioning, during which the CPP operator must produce the specified feed-in profiles. In this first phase, the feed-in profiles are verified by the grid operator in charge of system reliability at the lowest level, e.g. the distribution system operator (DSO). The guaranteed tariffs specified below are only granted if the feed-in profile is complied with. Once the pioneering operation has been successfully completed, the combined power plant can be freed from the obligatory feed-in profiles and completely released into market-oriented operation.

[2] This includes negative remuneration, i.e. feed-in penalties in the event of negative prices. During these hours, electricity is effectively stored and converted into heat through sector coupling.

2.1 Approved Technology Mix

In both variants of the tariff, the technology mix is left up to the plant investor and can include in particular storage technologies and any elements of sector coupling. In addition to new plants and existing plants, plants currently supported by conventional instruments can also be integrated into the combined power plant if they waive any further support previously granted, e.g. if they waive existing support by conventional feed-in tariffs.

Figure 1 below shows a schematic diagram of a conceivable plant with electricity storage, photovoltaic and wind power, electric car and combined heat and power plant with hydrogen electrolysis and bioenergy as a further fuel. The capital invested in the plant is refinanced on the one hand by avoiding the previous energy purchases (electricity, heating fuels, combustibles) for own use and on the other hand by the remunerated feed-in. This means that every euro guaranteed by the state through the CPPT can trigger a multiple of the investment.

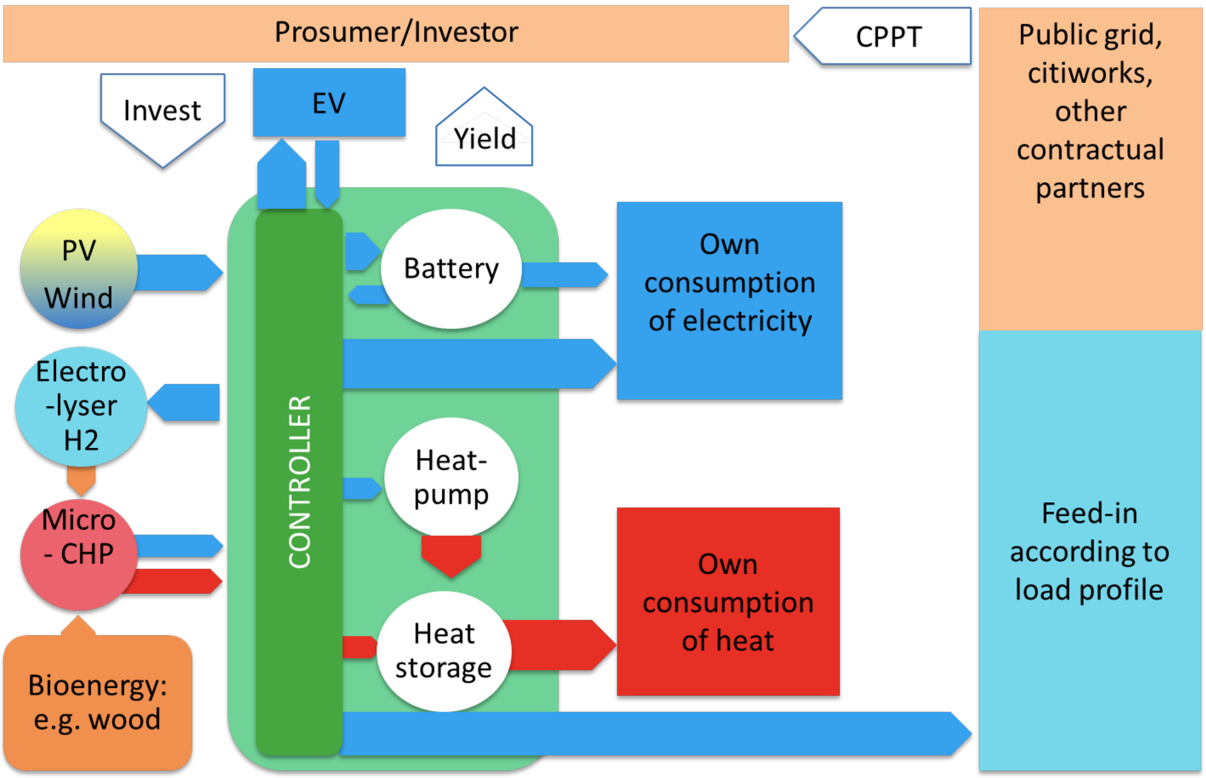

Figure 1: Energy flows electricity (blue) and heat (red) in the combined power plant and financial flows (white).

2.2 Feed-in profile and marketing

A 100% renewable energy generation and the hourly coverage of the empirical load profile, which was fixed as a binding feed-in profile in the relevant grid area, is obligatory for the entitlement to the tariff. This is shown in green with the remunerated and agreed feed-in profile in Figure 2 below. Deviations from this feed-in profile are only possible by mutual agreement between the producer and the grid responsible party.

For the electricity quantities supported by the CPPT according to the defined feed-in profile, further marketing as green electricity by the combined power plant operator is not permitted. Marketing as regional electricity is possible for the combined power plant operator or its marketer.

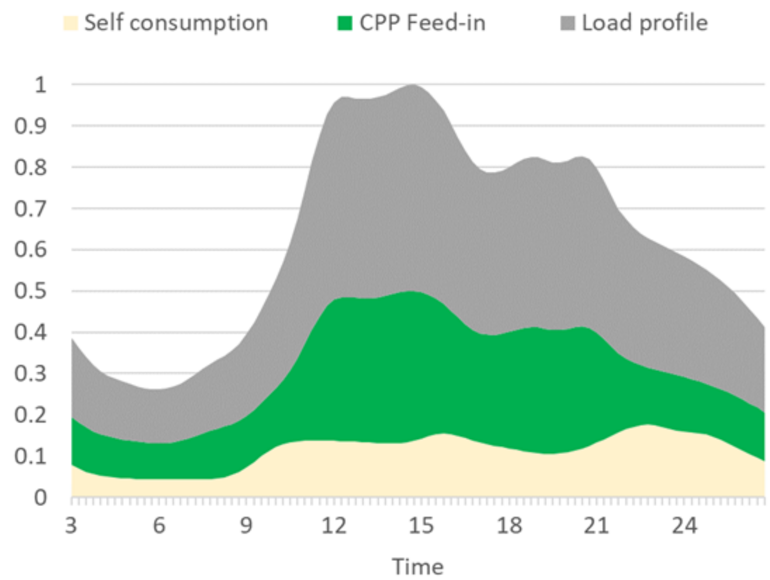

Figure 2: Exemplary feed-in profile (net supply, green), own consumption (beige) and residual load (grey).

2.3 Level of tariff and financing

The proposed tariff is 8 eurocent per kWh [3]. This value is supported by techno-economic cost estimates presented below on the basis of an energy model developed for this purpose. Any

[3] Clearly, this level of remuneration does not consider counter-productive administrative costs and costs of delays due to licensing barriers.

differential costs, i.e. the difference between the sum of tariff and the sum of market values, are supposedly financed from a surcharge on consumption.

A justified level of tariff derives on the one hand from the full costs of the mostly conventional energy supply, which is replaced by a climate-friendly supply. These include the costs of covering the defined feed-in profile from conventional sources, including the costs of system services, networks and non-internalised external damages. This would justify a tariff level of more than 10 eurocent per kWh (Jacobson et al. 2019).

On the other hand, the tariff should not be higher than the full costs of the supported combined power plants in order to avoid excessive profits. We propose a tariff derived from a current cost calculation for the German county of Bad Kissingen and its more than one-hundred thousand inhabitants with an energy system optimised entirely on the basis of 100% renewable energies. It shows that the necessary level of cost-covering tariff is only around 8 eurocent per kWh (Traber et al. 2020). These techno-economic calculations can be regarded as conservative for many locations in Europe, as the availability of wind and solar energy in the county of Bad Kissingen is not better than in most regions typical for Europe (Ram et al. 2019; Child et al. 2019; Jacobson et al. 2019; Hansen, Breyer and Lund 2019). Moreover, the vast majority of costs are independent of location. However, many regions in the world have even better conditions for RA-RES provision. Optimal tariffs should therefore be adjusted to regional costs if local resources or financing conditions deviate considerably.

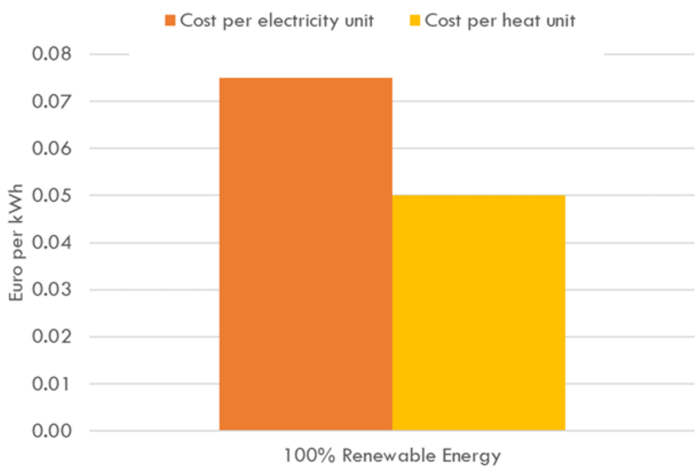

Figure 3: Costs per kWh electricity and heat for 100% renewable energy supply. Source: EWG 100% Mod.

The competitive costs are made possible by a comprehensive generation mix that fully covers demand for electricity, heat and mobility. Figure 4 below exemplifies the necessary investments in various technologies required for a transformation to a 100% reliable and adequate renewable energy system over ten years. This shows the great importance of heat pumps, batteries, Cogeneration plants (SCP; CHP) and hydrogen processes for the efficient integration of wind and solar energy.

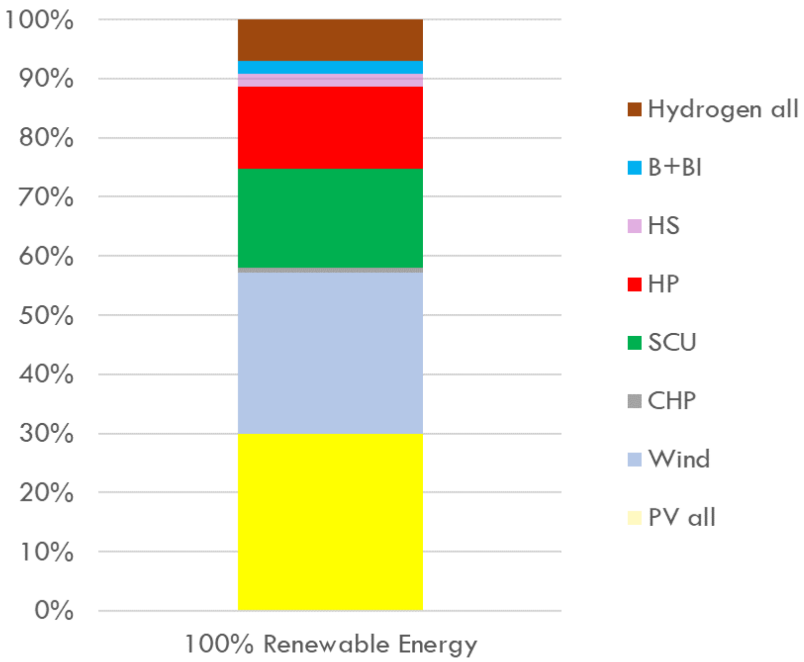

Figure 4: Investment shares of technologies for a 100% full supply from renewable energies. Source: EWG 100% Mod.

3 Compatibility with regulatory requirements exemplified by the EU framework

Electricity market regulations worldwide can be divided into two categories: wholesale market-based approaches and planning-oriented approaches. In the absence of markets, planning plays a more central role – and has been the obvious standard approach in the first century of electrification. While gaining importance over the last decades, wholesale markets are currently hardly established on regional or project-based scale [4].

[4] Digitization facilitates more decentralized market organisation as is increasingly realised in peer-to-peer networks of prosumers (Sousa et al. 2019). These markets are clearly distinct from the wholesale market perspective referred to in our context.

Consequently, national regulations for renewable energies in all regions of the world have to differentiate between centralized, wholesale-oriented investments and decentral projects. This is in particular expressed in the EU regulatory framework. The EU framework can thus serve as an example for national regulations, in which market-oriented support is suggested for larger units while a fixed remuneration is allowed for smaller, decentral investments. For jurisdiction particularly outside the EU and without established electricity markets, the introduction of a fixed tariff is proposed.

As we will elaborate in this section, legal compatibility of the proposed legislation on combined power plant remuneration with EU law is, in our opinion, given. This applies practically unrestrictedly to small plants, even though this term is not clearly defined in various parts of EU law, in particular by the Renewable Energy Directive and the Guidelines on State aid for environmental protection and energy 2014-2020 (EEAG). In the case of large-scale plants, for which support is proposed in the form of a sliding market premium, further criteria for compatibility with European law must be met.

For clarification of compatibility with EU regulations a legal examination was carried out by the law firm von Bredow Valentin Herz Rechtsanwälte based in Berlin, hereinafter BVH. The complete statement is freely available on the EWG website (BVH 2020). The main findings of this statement are summarized below.

3.1 Overview of EU legal requirements for support schemes

Energy law in EU member states including Germany is characterised by regulations at the EU level. The field of renewable energy is mainly regulated by the revised Renewable Energy Directive (RED II), which came into force in December 2018 as part of the EU’s "Clean Energy Package". Together with the Electricity Directive, the RED II gives considerable stimulus to decentralised energy generation, inter alia regulations on self-supply (including community self-supply), renewable energy communities and the avoidance of double-charging for storage facilities by active customers. Article 3 of the RED II sets a concrete target of at least 32% of the EU's gross final energy consumption to be accounted for by renewable energies by

2030. Article 4 of the RED II contains provisions on how Member States may design support schemes for renewable energy in the future.

3.2 Distinction between small plants and larger plants

For the assessment of compatibility with the EU regulatory framework, a distinction must be made between small installations and larger installations, as mentioned above. The term "small installation" is not defined in RED II, however, different thresholds can be derived from the Electricity Market Regulation and state aid law. Since the recitals of RED II contain a reference to state aid law, the thresholds of 500 kW and, in the case of wind turbines 3 MW or 3 generating units (as referred to in paragraph 125 of the Guidelines on State Aid for Environmental Protection and Energy 2014-2020 – "EEAG"), can be applied according to the results of the examination.

According to the findings of the expert opinion, 'the preferable arguments are that support for combined power plants via a combined power plant tariff is permissible if the individual plants that make up the combined power plant are small plants. Whether the total output of the combined power plant exceeds the limit values is irrelevant according to this interpretation.' In specific terms, it is therefore conceivable to combine a 3 MW wind turbine with, for example, two 500 kW photovoltaic systems and a 500 kW bio-heating power plant to form a combined power plant.

3.3 Promotion of larger plants

In case of the promotion of larger plants, further requirements have to be met according to the legal assessment (BVH 2020), which are ensured by the proposed design:

> *"When designing the market premium for larger plants [...] the requirements of Article 4 (2) to (4) of the Renewable Energy Directive must be observed. Thus, support schemes must a) provide "incentives for market-based and market-oriented integration" of green electricity into the electricity market, b) avoid "unnecessary distortions of competition", c) take into account system integration costs and d) grid stability."*

With regard to points a) to c), the experts come to the following conclusions in their individual opinions:

a) Incentives for market-based and market-oriented integration:

> *"In our opinion, the planned model shows sufficient market orientation. In the intended design, the plant operator has the possibility and incentives to increase or reduce electricity generation in line with current market prices. To this end, the plant operator can deviate from the previously defined feed-in profile in times of high or low market prices."*

The fact that direct marketing or marketing via municipal utilities can make sense in many conceivable market and grid load situations is explained in Appendix 1 on economic impact.

b) Avoidance of unnecessary distortions of competition:

> *"Flexible electricity generation capacity is currently provided primarily by conventional power plants based on fossil fuels. These do not always receive a comparable premium for this. However, operators of fossil power plants can only produce electricity cheaply and flexibly because they do not (fully) bear the overall negative consequences of fossil power generation. Furthermore, large fossil power plants in particular can participate in the markets for balancing and control energy under comparatively simple conditions, whereas flexible RE plants have so far been largely barred from accessing these markets. Promoting flexible feed-in capacity on the basis of renewable energies is therefore more likely to eliminate or mitigate an already existing distortion of competition to the detriment of renewable combined power plants than to create new distortions".*

Accordingly, this point does not appear to be an obstacle to the legislation presented.

c) system integration costs and d) grid stability:

In this respect, the report clarifies that according to RED II, the market integration of renewable energies is not the only objective of the support schemes, but also grid stability (Article 4 (2)), as well as the minimization of system costs (see also recital (19)). The opinion states that

> *"A market premium for combined power plants [...] would be based on both points: locally and regionally, it would help to stabilise the networks by ensuring that feed-in was in line with demand. Nationwide, it relieves the transmission networks and thus reduces their expansion costs. However, these positive effects for the overall system have not yet been fully reflected in the electricity price that can be obtained on the*

stock exchange. This is because system integration cannot be guaranteed by the signals of the electricity markets alone, because the existing electricity markets can balance out demand and generation volume in relation to the overall market (Germany), but they do not take into account the local requirements of the distribution networks, which can deviate significantly from market developments. Without subsidies, a macro-economically favourable combined power plant is therefore regularly financially unattractive for investors. The EEAG explicitly identifies such "positive externalities" as a form of market failure that may justify promotion."

4 Legal implementation of the proposal

The key points presented in this paper for a Sector Coupling and Innovation Act for Renewable Energies with a tariff for combined power plants and reliable and adequate renewable energy supply requires further refinement and optimisation. A concrete draft law is to be prepared in discussion with the scientific community and the responsible ministries. The tariff for combined power plants should be laid down in a separate law on the market integration of guaranteed feed-in from renewable energies and not be anchored in other renewable energy support legislations.

A corresponding Sector Coupling and Innovation Act does not replace existing support for individual renewable energy plants. Nonetheless, existing support often needs to be amended in order to meet climate protection targets. For example, amendments of existing feed-in tariffs and similar support policies should take place in parallel with the objectives of reducing bureaucracy, providing well defined renewable expansion pathways and implementing regulations for the promotion of investments by citizens. In particular, electricity withdrawals for the conversion of electricity by means of storage facilities, for the production of secondary energy sources from renewable energies such as green hydrogen, and for more flexible own consumption are to be exempted from levies. Furthermore, the EU requirements for citizen energy could serve as a blueprint for the amendment of renewable energy support policies and should be considered for the design of policies globally.

It has to be stressed that the more and more popular promotion practice via nationwide or state-wide tenders is not recommended. State-tendering leads to unnecessary increased costs of investments due to price risks that are often influenced by government decisions.

Implementation with the help of state tenders is also not suitable for sector integration, since the necessary diversity of combination options and needs with green electricity generation technologies, storage, sector coupling, and digital control can hardly be reflected in a state tender design.

The proposal elaborated here in key points is not limited in its applicability to the national level in the European Union. In principle, all nations around the world can implement a combined power plant tariff and anchor it in their legislation to support reliable and adequate renewable energy supply, just as many nations have successfully implemented the basic principles of the German feed-in tariff for renewable energy in the past. Rather, conformity with EU law also means that a transparent, justiciable and economically conclusive proposal for supporting decentralised 100% renewable energy systems for international implementation can be tabled. In addition to the integration of renewable energies through the electricity transmission system, the simultaneous creation of decentralised full supply cores with 100% renewable energies will accelerate their expansion. This could even substantially contribute to the implementation of the agreed global 1.5 degree climate target of Paris.

For this purpose, the European legal framework should also be reviewed and adapted to the requirements of a 100% renewable energy electricity system of the future. This is a task that will be necessary anyway in the implementation of the European Green Deal of the EU Commission.

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Appendix

Annex 1: Economic impact

To illustrate the economic impact of the combined power plant tariff, the main elements of the CPPT are shown in the figure below with an exemplary mandatory feed-in profile. The guarantee remuneration can be achieved through a fixed remuneration or also through market premiums.

The functioning of the KKV can be separated into two steps.

1. Determination of the a) relevant load profile with the b) mandatory feed-in quantity to be fulfilled and compensated according to the load profile. This results in the entitlement to remuneration and the obligatory feed-in profile of the combined power plant operator. These specifications are made before the investment in the plant's elements. This step is the basis for the guaranteed feed-in tariff and investment security.

2. Market orientation: The respective direct marketer is free to conclude agreements on deviations from the feed-in profiles defined in step 1 in consent with the combined power plant operator obligated to feed in. This ensures market orientation. Ideally, the combined power plant operator is released from the obligation to comply with the defined feed-in profile after a test phase.

The guarantee tariff represents the price that can be earned for each unit of electricity fed into the grid and, in the exemplary Figure 5 below, is consistently higher than the marginal costs, i.e. the variable costs of an additionally generated unit of electricity. This means that per unit an operating profit can be generated corresponding to the difference between price and marginal costs, which in the figure corresponds to the area between the guaranteed tariff and the marginal costs assumed to be constant here. The short-term profit can be used to cover fixed costs - in particular the costs of the investment.

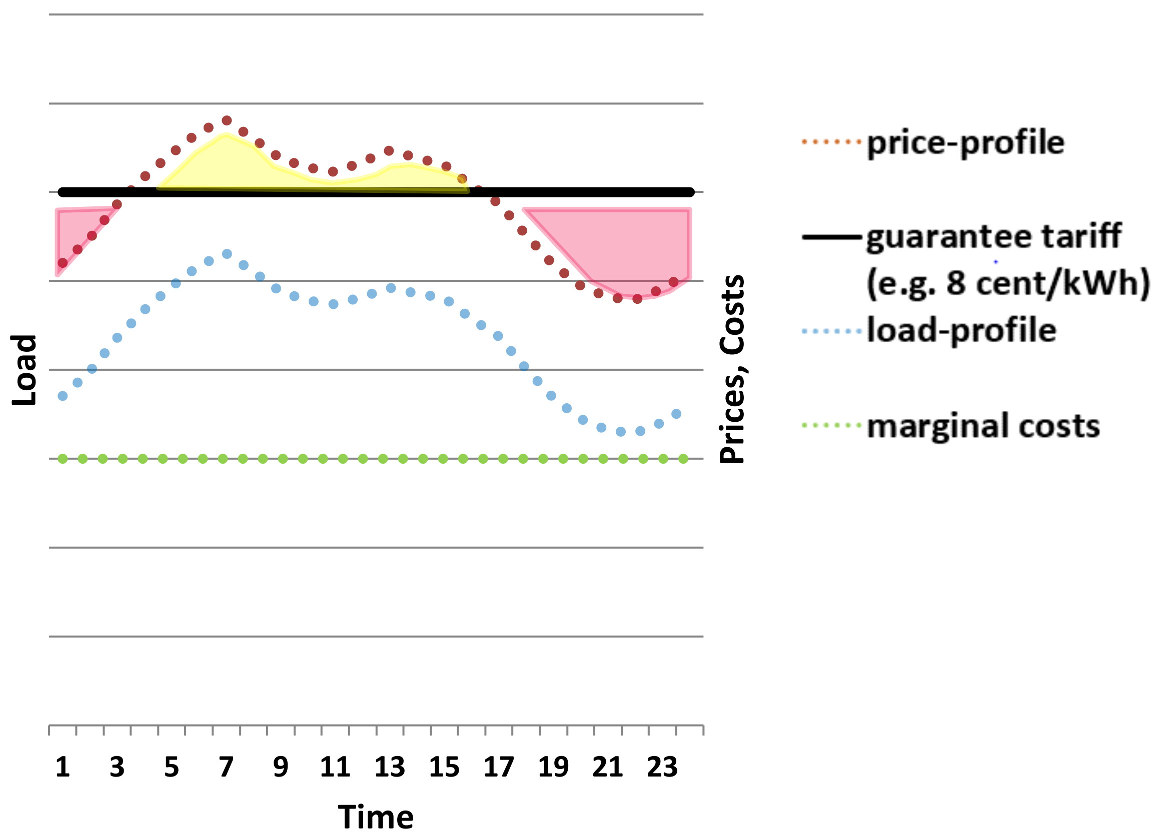

Figure 5: A stable, investment-ready value prior to capital investment is achieved by means of a guarantee tariff (right-hand scale). Market premiums are negative in times of high market prices (yellow areas) and otherwise positive (red areas). At the same time a feed-in profile is defined (load profile 0, left scale).

The efficient, market and cost-oriented operation is to be illustrated by the following examples of typical unexpected developments, which include a drop in electricity prices on the one hand and an increase in the operating costs of renewable energy generation on the other.

Figure 6 below illustrates a situation in which there is a significant drop in market prices compared to the prices expected in advance according to price profile 0 in the midday hours between 11 a.m. and 2 p.m. (price profile 1). In this situation, the initial marginal costs 0 are not covered by the market prices in the midday hours, so that overall operating losses would be incurred in the amount of the shaded red area.

This would be the case, for example, if the fuel costs for electricity generation in a bioenergy power plant could not be covered by market prices.

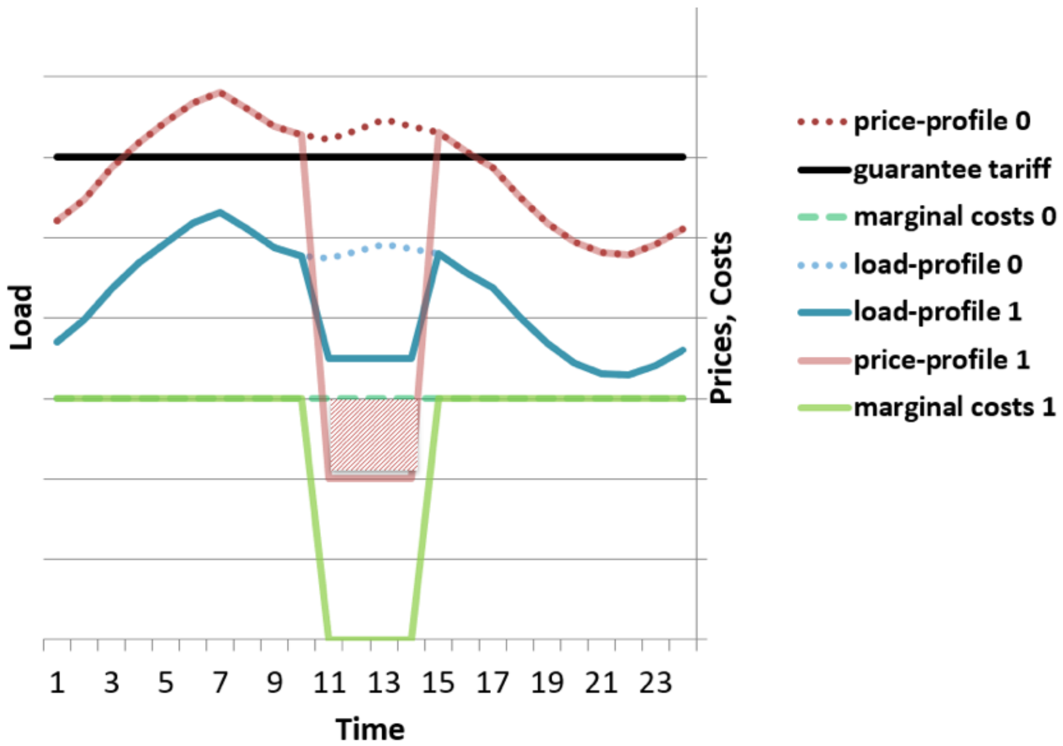

Figure 6: Price decline in operational business in step 2.

Both direct marketers and CPP operators can improve their situation by deviating from the obligations laid down in step 1 by agreeing on an alternative compensation for non-delivery that is on the one hand lower than the guarantee compensation and on the other hand higher than the operating profit of the combined power plant operator if the agreed generation profile corresponding to load profile 0 is met.

In the situation of a cost shock shown in Figure 7 below, the supply obligated party makes an operational loss in the hours between 11 a.m. and 3 p.m. By means of agreed renegotiation, an efficiency gain can be generated by deviating from the mandatory feed-in profile 0 to feed-in profile 1. It should be emphasised that the network operator (e.g. municipal utility) can refuse such renegotiation, particularly for reasons of investment security, and that the load profile and the remuneration obligation defined in step 1 are maintained. In particular, this case can occur if the electricity price is not decisive for the grid operator due to grid bottlenecks.

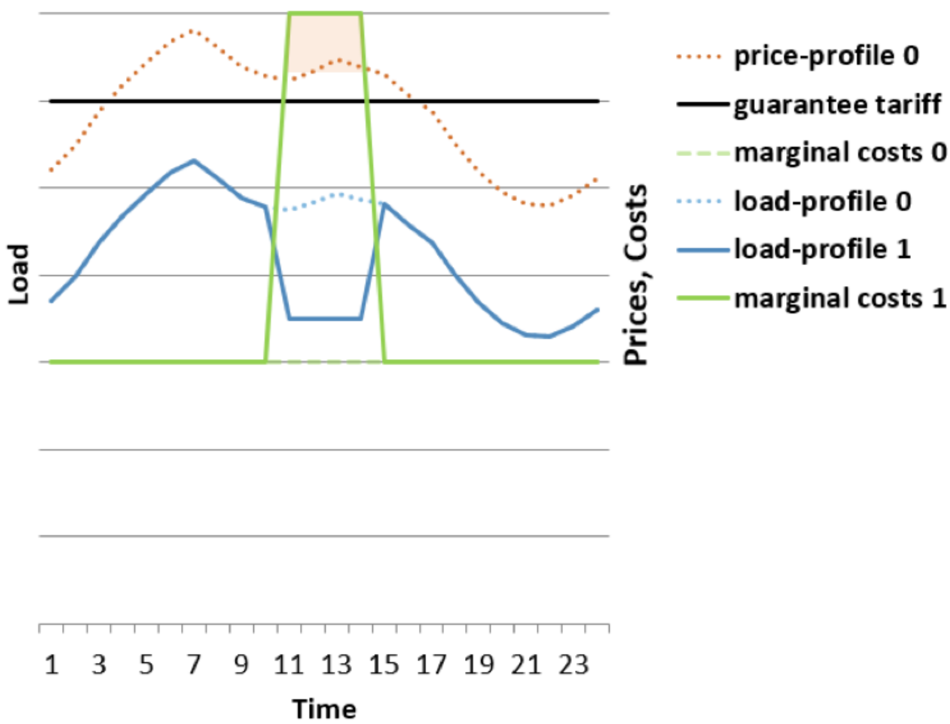

Figure 7: Cost shock in operational business in step 2

Similar cases are also conceivable with opposite deviations in market prices and costs as in the examples described above, i.e. high prices on the electricity market and low variable costs of the combined power plant, as well as the case of a regional bottleneck situation. In Germany, for example, measures of feed-in management could be saved and the redispatch of fossil power plants could be avoided. In any case, such deviations can reduce any possible financing via the levy and at best even reduce previous levies.

Annex 2: Cost assumptions and used profile data

For the optimization of the coverage of the energy demand in the example of the district Bad Kissingen, consumption profiles for heat and electricity as well as wind power and solar availability data in hourly resolution were used (Traber et al. 2020). For this purpose, wind, solar and electricity consumption profiles of the reference year 2017 were taken from publicly available data sources. The heat consumption profiles were calculated using the method developed by Hellwig and refined by the Ökoinstitut (Hellwig 2003; Koch et al. 2017). The calculation took into account the building condition in the district and weather data from 2017. The linear cost minimization model set up by the EWG for the optimization is formally presented in Appendix 3 and can be solved in the programming language GAMS.

The model results are based on assumptions regarding the technology costs, broken down into investment, maintenance and operating costs, as well as the losses due to the different stages of charging, storage and discharging the energy storage processes. Due to rapid technological development with learning and scaling effects, the investment costs are subject to a large dynamic which cannot be fully predicted. To capture this uncertainty, the range of investment costs can be represented by one scenario each with high, medium and low costs.

The scenario for high costs, "Conservative", is based on own assumptions in order to represent as realistic costs as possible, which can arise for smaller projects with conservative consideration. The "Neutral" scenario represents costs that are currently to be interpreted as average realisable costs, which have already been published in specialist studies (Ram et al. 2019) and have been used for the results of this work presented above. The "Optimistic" scenario can ultimately still represent a scenario for currently low costs, but which appear realistic for the near future.

	PVU	PV	Wind	CHP	SCU	B*	BI
Conservative	730	1014	1240	577	3000	270	135
Neutral	620	907	1150	503	2500	185	118
Optimistic	510	800	1060	429	2000	100	100

	GTH	HP	HS*	H2S*	H2Comp	H2Elsy	CCH	FC
Conservative	625	810	50	19	256	990	1000	3500
Neutral	550	780	40	14	256	685	888	3000
Optimistic	475	750	30	9	256	380	775	2500

Table 1: Investment costs in Euro per kW (capex) for energy technologies in three scenarios; *storage technologies in Euro per kWh.

In connection with the low level of technological maturity, hydrogen electrolysis, hydrogen storage, battery storage and also photovoltaics show high dynamics in terms of costs and continue to offer the greatest cost reduction potential. Operating expenses (OPEX) are less uncertain and are therefore presented without scenario assumptions. For bioenergy, biogas is assumed to be the energy source at a procurement price of 7.5 eurocents per kWh.

	PVU	PV	Wind	CHP	SCU	GTH	CCH	FC
Opex fix €/kW*a	13.2	17.6	1.5	17.2	17.2	14.3	1.4	5.3
Opex var €/kWh	0	0	0	0	0	0	0	0
Lifetime a	30	30	25	30	30	35	35	35

	B	BI	HS	H2S	H2Comp	H2Elsy	HP
Opex fix €/kW*a	9	0	0.6	0	1	1.6	16
Opex var €/kWh	0.000	0.000	0.000	0.000	0.000	0.001	0.000
Lifetime a	20	20	35	30	15	30	25

Table 2: Variable and annually fixed operating costs (OPEX).

The efficiencies of conversion into the storage technologies batteries (BS), heat storage (WS) and H2-storage (H2S) are differentiated according to the charging and discharging process as well as long-term storage and are summarized in the figure below. An important influencing factor is the required return on capital. Here we assume capital costs (WACC) to be a nominal value of 7% for the case study "Bad Kissingen".

	B	HP	HS	H2S	H2Comp	H2Elsy
Charging	0.955	1	0.95	1	0.98	0.62
Discharging	0.955	3.6	0.95	1	1	1
Long-Term	0.5	1	0.5	1	1	1

Table 3: Efficiencies of the conversion processes differentiated according to charging (charging), withdrawal (discharging) and long-term storage (LZ). Withdrawal from the heat pump (HP) refers to the heat units that can be generated from one unit of electricity.

Annex 3: Mathematical Model

The modelled problem's objective is the minimisation of the total levelized cost of energy $TLCoE$ including electricity and heat supply minus the proceeds from the sale of potential excess electricity Q_{ex} with market price P^t. Denoting the capital recovery factor CRF and technology-wise cost C^n, we get

$$\min_{q,k} \; TLCoE = \sum_{n=1}^{N}(CRF^n F^n k^n + \sum_{t=1}^{T} C^n q^{n,t}) - \sum_{t=1}^{T} P^t Q_{ex}. \tag{1}$$

The load coverage of consumption of electricity by generation is implemented by the following balance

$$\sum_{l=1}^{L} E^{l,t} - BE^t - HE^t - HPE^t = EV^t + Ex^t. \tag{2}$$

After deduction of the charging current for batteries BE and hydrogen HE as well as the electricity for heat pumps HPE, the electricity generation $E^{l,t}$ of all electricity technologies L covers the electricity consumption EV^t including the delivery to the public grid Ex^t.

The load balance of the heat sector is represented by the following equation

$$\sum_{m=1}^{M} W^{m,t} + E^t_{CP} WK - HS^t = WV^t. \tag{3}$$

It states that heat production in heat technologies m and coupled heat production in cogeneration plants CP, i.e. WKE^t_{CP} with thermal parameter WK, after deducting the heat storage requirement HS^t covers the heat consumption covers WV^t. To cover the heat and electricity demand, the existing plants K_0 and new plants K - which together constitute installed capacity K_{all} - are usable. Thus, total capacity consists of existing capacities and new investments,

$$K^n_{all} \geq K^n_0 + K^n, \tag{4}$$

where the total capacity can be limited to an upper limit:

$$K^n_{max} \geq K^n_{all}. \tag{5}$$

The available generation capacity resulting from the installed capacity after deduction of the unavailability ($Noa^{n,t}$) limits the power generation $Q^{n,t}$. This is illustrated as follows:

$$K^n_{all}(1 - Noa^{n,t}) \geq Q^{n,t}. \tag{6}$$

In addition to heat pumps and coupled electricity and heat generation, storages are a further element of sector coupling. The storage processes take into account the energy storage capacities, the maximum charging rate and the losses from short-term and long term storage processes. The central relationship for the temporal development of the storage levels is modelled as follows:

$$Q^1_{Cha} = (Q^T_{Cha} + QS^T \eta_{Cha} - Q^T/\eta_{Dis})\eta_{LZ},$$

$$Q^{t>1}_{Cha} = Q^1_{Cha} + \sum_{tt<t}(QS^{tt}\eta_{Cha} - Q^{tt}/\eta_{Dis}) \tag{7}$$

The storage level Q^t_{Lad} corresponds in the first time step $t = 1$ to the storage level after the last time step T, adjusted by the long-term storage efficiency η_{LZ}. For the following time steps $t > 1$ the storage level of the first period is updated by the balances of the periodic energy storage (QS^{tt}) and discharge ($-Q^{tt}$) of the following time steps. Storage operations are adjusted by the charging efficiency η_{Cha}, while discharged storage energy is reflected in the storage balance by the discharge loss factor η_{Dis}.

$$Q^t_{Cha} \geq Q^t/\eta_{Dis} \tag{8}$$

ensures that the effective discharge Q^t/η_{Cha} is at no time greater than the storage level.

$$K^S \geq Q^t_{Cha}, \tag{9}$$

limits the storage of energy to the installed storage capacity K^S, and through

$$K^{SI} \geq QS^{S,t} \tag{10}$$

the load power is limited to the strength of the existing storage interface K^{SI}.