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A Vision of a Decentralised Energy Market for Germany in 2030

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1. Introduction: Context and Methodology

Today, on 30 November 2023, the German Energy Agency — dena published a study "The Decentralised Energy System in 2030; A Systemic Bottom-Up Approach to Market Integration of Decentralised Consumption and Generation Assets" (*Das dezentralisierte Energiesystem im Jahr 2030 — Ein systemischer Bottom-up-Ansatz zur Marktintegration dezentraler Verbrauchs- und Erzeugungseinheiten*), supported by the German Federal Ministry for Economic Affairs and Climate Action (BMWK). The study was jointly conducted by the Fraunhofer Institute of Applied Information Technology FIT, one of the leading digital energy research centres in Europe, and Grid Singularity, awarded technology startup developing software tools to simulate and operate energy marketplaces. This article presents its methodology and the main fundings.

Philipp Richard, Director for digital technologies and start-up ecosystem at the German energy agency dena elaborated:

> *"Our motivation for initiating this study was to evaluate the benefits of a bottom-up market design in optimising the local use of renewable energy and alleviating grid congestion. The study shows significant impact on end customer electricity prices, as well as a reduction of CO2 emissions. It encourages us to consider further policy reform, especially with regards to energy community trading."*

1.1. Agent-based model of the German Energy Market in 2030: Asset Configuration

The Grid Singularity Exchange open-source software tool for simulating and operating local, regional or national energy markets was deployed to simulate a bottom-up, agent-based model of the German energy market, with 967 agents representing distributed energy assets (photovoltaics — PV, electric vehicles, heat pumps, battery storages, consumption load profiles, wind power plants) and their owners' trading preferences in a possible German electricity system in 2030. The number and the regional distribution of the respective agents were based on the German Market Master Data Register

([MaStR](#)) and the German government's [forecasts for distributed energy resources (DER) expansion for 2030](#) (Bundesministerium für Wirtschaft und Klimaschutz, 2022 and 2023, Bundesnetzagentur, 2022).

To configure the model of Germany's bottom-up, peer-to-peer (P2P) energy market in 2030, all DER agents except wind are grouped into local energy communities (LECs). For the second market level, Germany's energy market was divided into six regions, each comprising four representative LECs, reflecting the consumption and generation capacity and diversity of each region. Each region also includes additional agents representing industry (specifically aggregated industry consumption load) and wind power generation based on available forecasts.

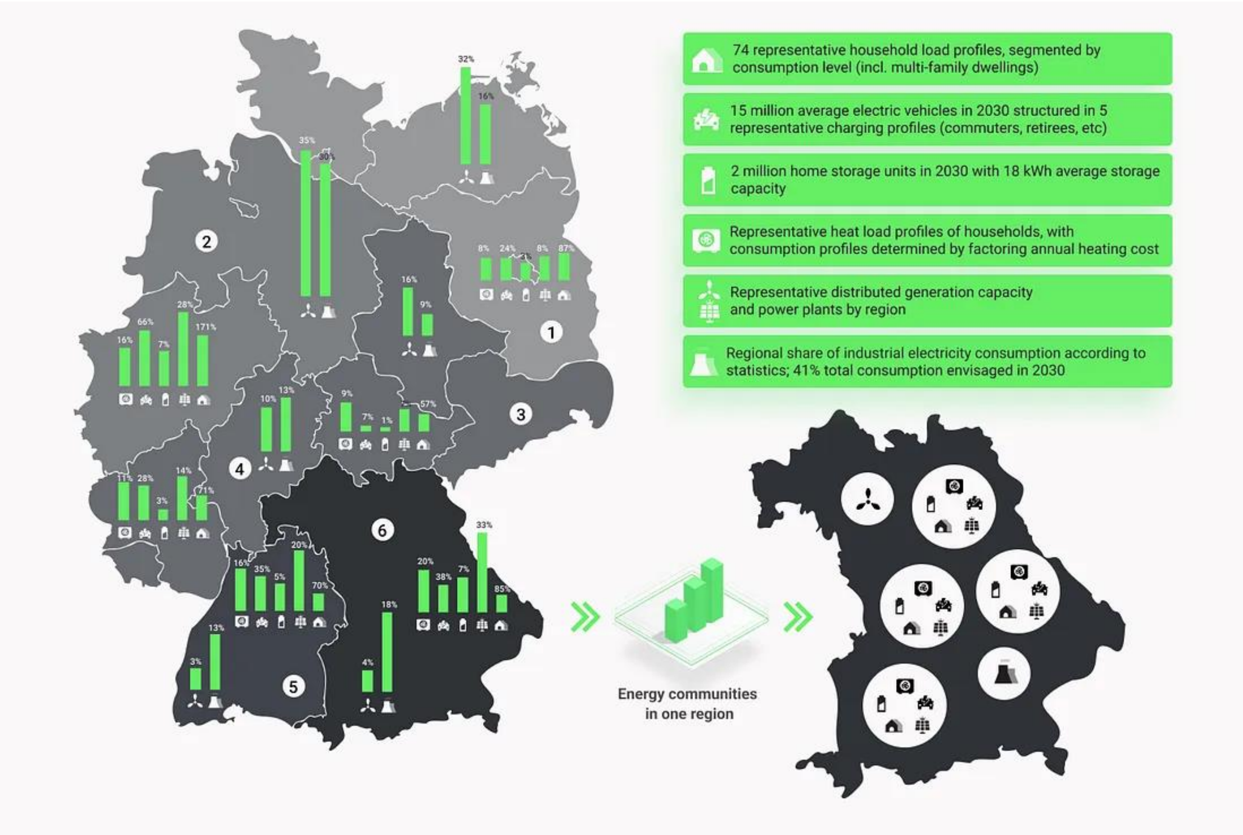

Figure 1. Grid Singularity Simulation Configuration of Germany 2030 Energy Market (map showing energy asset type, share and distribution based on German government forecasts and FIT calculations)

1.2. Agent-based model of the German Energy Market in 2030: Market Design

The study envisages the German electricity market in 2030 as one that is composed of connected local electricity markets in the form of local energy communities (LECs) fully engaging in peer-to-peer trading. The applied simulation model has three market levels and the trading is bottom-up P2P i.e. asset-based, moving up the market hierarchy, as follows: i) trading within LEC, ii) trading within and among LECs in one region, and iii) trading within and among LECs across the entire country. The market design follows the pay-as-bid spot market type, where bids and offers are matched hourly in a P2P exchange. Prices for matched trades are determined upon market conditions, considering feed-in tariff rates and utility rates, accounting for grid costs and ensuring that any matching gap is supplemented by the utility.

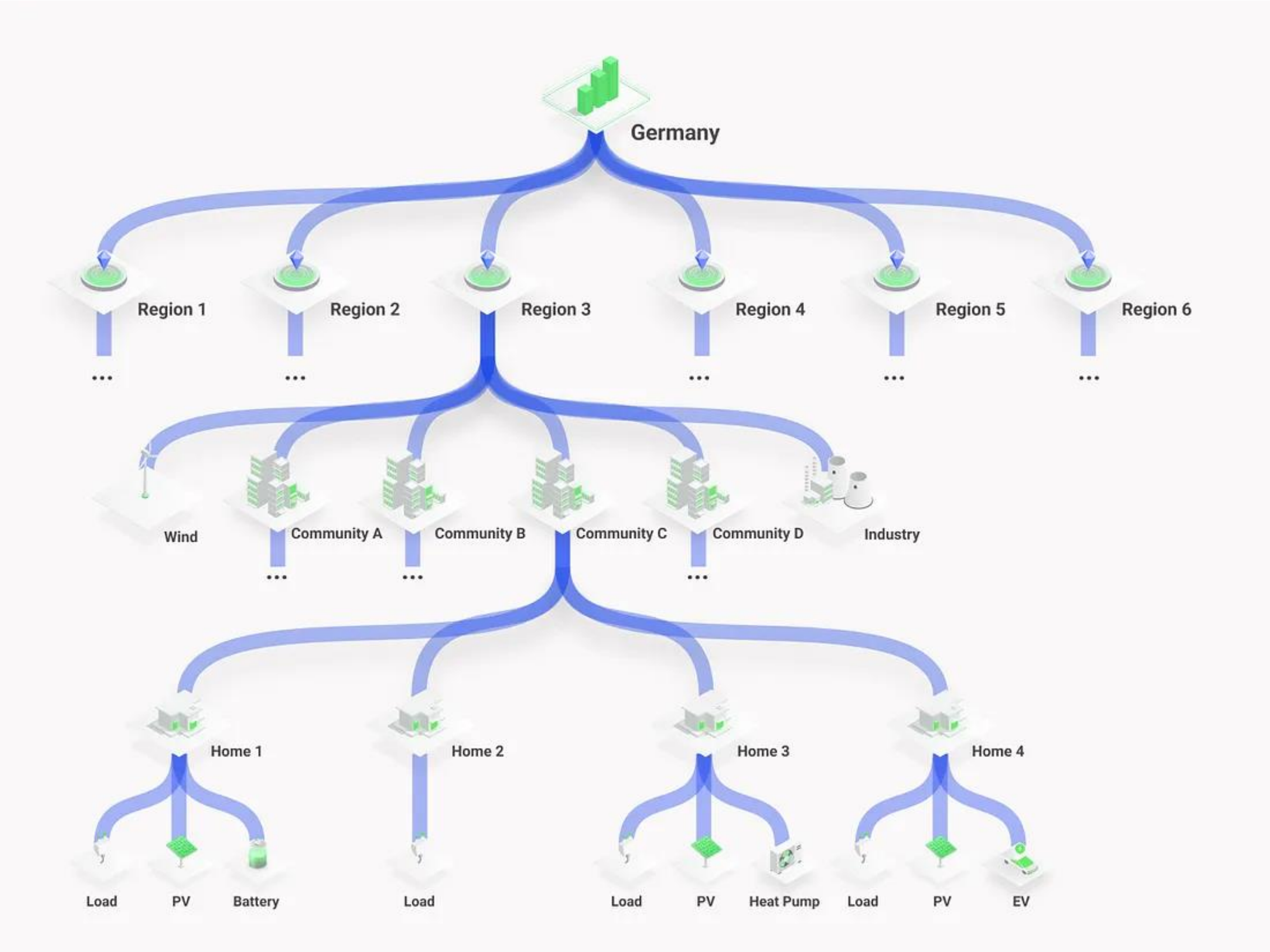

Figure 2. Market Trading Levels Illustration (national, regional and community, with the community composed of multiple homes with varied energy assets, and wind and industry assets placed at regional level) in the Grid Singularity Simulation of Germany 2030 Energy Market

A synthetic hourly day-ahead exchange price for externally supplied electricity (the utility rate) for the simulated year (2030) was generated by using the open source price forecasting tool Prophet (Taylor and Letham, 2017) and training the model with historical generation and electricity price time series, while taking into account the expected renewable generation profiles. The generated average day ahead electricity price was EUR 73.14/MWh, which represents an increase of 43 percent compared to prices of the previous years (2016 to 2020). The increasing volatility is reflected in the increase in the standard deviation of 37 per cent. After adding all levies and taxes, with the exception of the EEG levy, this results in a household electricity price of 21.05 ct/kWh exclusive of applicable grid fees. To determine the levies and tax charges included in the total utility price calculation, the average values of years 2018 to 2021 were used.

The feed-in-tariff rate value, serving as the price for sale of electricity surplus to external markets, varied according to whether the energy producer was a PV or a wind power plant. The PV feed-in-tariff was set to 8.6 ct/kWh, while the Wind Power Plant feed-in-tariff was set to 5.2 ct/kWh.
This grid fee value was determined on the basis of the average grid fees of recent years and data from the German Federal Network Agency and the German Association of Energy and Water Industries — BDEW (Bundesnetzagentur, 2021a; Bundesverband der Energie- und Wasserwirtschaft e.V., 2022), resulting in set grid charges of 7.68 ct/kWh for households and 2.63 ct/kWh for the industry.

In one of the simulation scenarios, time-variable grid fees were applied instead of constant fees (as in other scenarios) or variable fees based on energy consumption or production, which could have been an alternative grid fee model to investigate. First, the average daily grid utilisation at regional level per hour of the simulated base scenario was calculated and assessed to identify the hours of day when grid utilisation deviated by 10 percent above or below the average. Then, these findings were used to set grid fees to be 80 percent higher or lower compared to the base scenario to compensate for the grid utilisation deviation at these times. The time-variable grid fees for one day are shown in the figure below.

Figure 3. Graph of Time of Day Grid Fee Model, Grid Singularity Simulation of Germany 2030 Energy Market

The study investigated six simulation scenarios in addition to simulating the base case scenario, researching the implementation of P2P trading at different market levels, with additional analysis of the impact of the time-variable grid fee and time-variable electricity price models, as shown in the table below:

Current Energy Market Model	Time-Variable Utility Prices	National P2P Trading	Local And Regional P2P Trading	Local P2P Trading	Dynamic Grid Fees (Time-Of-Use)	Time Variable Grid Tariffs And National P2P Trading
Base Case	Use Case 1	Use Case 2	Use Case 3	Use Case 4	Use Case 5	Use Case 6
Utility Price: **Constant**	Utility Price: **Time Variable**	Utility Price: **Constant**	Utility Price: **Constant**	Utility Price: **Constant**	Utility Price: **Constant**	Utility Price: **Constant**
Peer-To-Peer Trading (P2P): **Not Allowed**	P2P Trading: **Not Allowed**	P2P Trading: **Country-Level**	P2P Trading: **Community + Region**	P2P Trading: **Community Only**	P2P Trading: **Not Allowed**	P2P Trading: **Country-Level**
Grid Fees: **Constant**	Grid Fees: **Constant**	Grid Fees: **Constant**	Grid Fees: **Constant**	Grid Fees: **Constant**	Grid Fees: **Time-Of-Use**	Grid Fees: **Time-Of-Use**
Feed-In Tariff: **Applied**	Feed-In Tariff: **Applied**	Feed-In Tariff: **None**	Feed-In Tariff: **None**	Feed-In Tariff: **None**	Feed-In Tariff: **Applied**	Feed-In Tariff: **None**

Table 1. Scenario Overview, Grid Singularity Simulation of Germany 2030 Energy Market

The P2P electricity trading among market participants applied in the study is a more advanced application of EU directives on energy communities than the trading mechanisms currently applied in Austria and Spain, which while progressive compared to other EU members, only allow indirect intra-community trading with a single, predefined energy price. While regulators term these peer-to-peer, they are more correctly described as peer-to-market energy trading mechanisms. Many energy communities today are even more restrictive, allowing a community member to purchase surplus electricity only from a specific DER, usually a solar panel, which they own or lease. The latter is also known as a collective self-consumption scheme, where the energy generation in the community is aggregated and then allocated to each member, using a predetermined allocation coefficient, usually based on the share of generation that is owned or leased by the individual community member. More advanced communities share storage capacities but generally none apply actual, market-based P2P trading. Furthermore, the currently applied energy community regulation in the EU member states impedes trading between communities, further restricting the scope of the relevant EU directives in practice. Consequently, the results of this study represent important findings for policymakers in Germany and across the European Union.

2. Findings and Recommendations

The conducted analysis shows that the implementation of P2P electricity trading markets leads to **an important reduction in electricity cost for the participating households and the industry**. For households, the electricity bills would be reduced by 4 percent in the case of local, intra-community

P2P implementation without inter-community trading and **up to 20 percent if P2P trading is enabled across all communities and regions in Germany**. Participants in P2P electricity trading were able to purchase electricity from their peers at a lower price than from the utility, resulting in improved matching of electricity generation and consumption at the local, regional, and national levels. Electricity cost savings progressively increased with the expansion of P2P electricity trading scope, from community alone to between communities in a region, finally resulting in a fully fledged bottom-up energy market for the entire country.

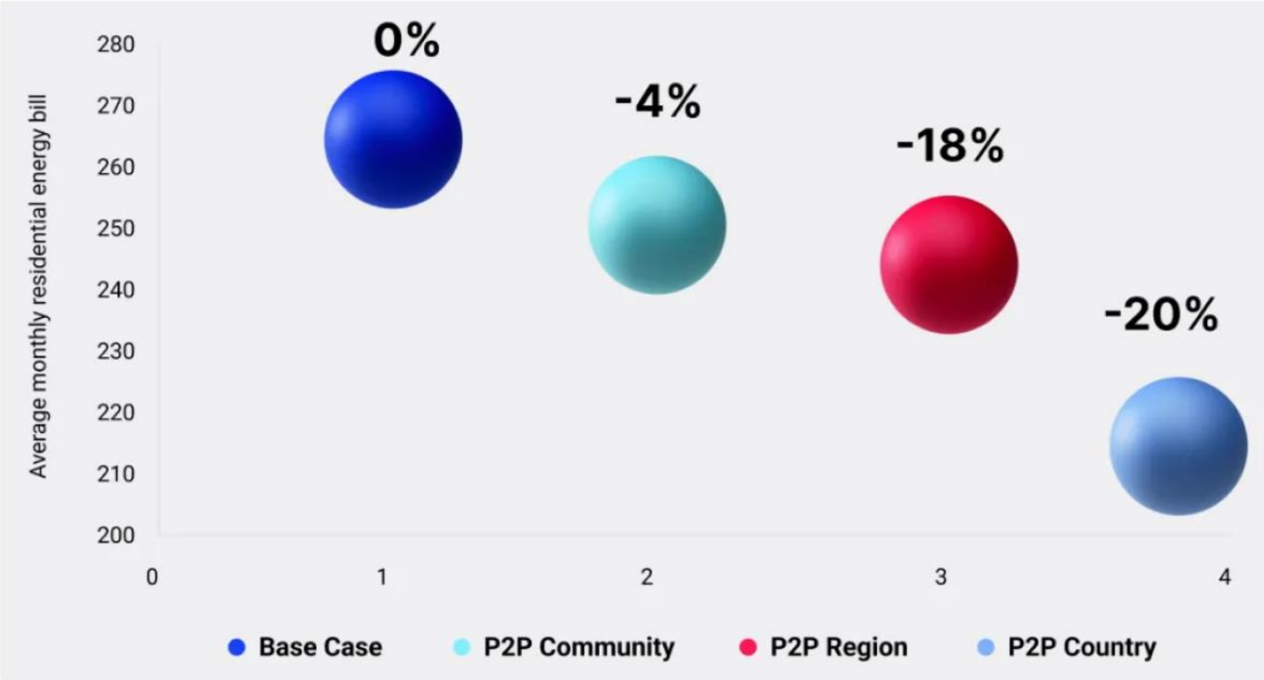

Figure 4. P2P Energy Trade Scale Impact on Energy Cost Reduction for Residents, Grid Singularity Simulation of Germany 2030 Energy Market

Furthermore, the P2P trading scope expansion also brings about a momentous increase in the degree of autonomy, also termed self-sufficiency, which reflects the ratio of total demand satisfied by generation at the analysed market level (or differently put, the share of self-consumption in the total consumption). The average **self-sufficiency rate for the community rises from 6 percent in the base case scenario where self-consumption is limited to owners of renewable assets, to 31 percent with the activation of local P2P trading when these assets are effectively shared with other local energy community participants. When P2P trading is scaled** to inter-community trading at a regional level and then at national level, the average self-sufficiency rate for the region increases to **a very high 70 percent and 73 percent,** respectively, effectively including wind generation and industry consumption in P2P market trading. In conclusion, the study indicates that **over two-thirds of the electricity demand of households and industry in Germany can be met with the country's PV and wind generation by implementing a bottom-up P2P market design**. This outcome implies a significant relief of the transmission grid use, but can also lead to a higher utilisation of the lower grid levels, and the implications for grid network planning and operation can be a subject of further research.

At the same time, the results show no significant impact on electricity costs, emissions or self-sufficiency when time-variable electricity prices and grid charges are introduced, which may be due to limitations of the modelled asset configuration and/or selected time of use grid fee model. Notably, in the simulated model of the German energy market in 2030, battery storage is the only modelled energy asset that offers flexibility and responds to the corresponding price signals, providing benefits exclusively to owners of these assets and increasing electricity costs for inflexible consumers when time-variable electricity prices are introduced. In order to take advantage of dynamic grid fee models, the flexibility in the system must be increased, rewarding those that invest in renewable and especially flexible resources while providing a reasonable level of protection for inflexible consumers.

The following table summarises the key results of the study:

Key Performance Indicators		Base Case Scenario	Dynamic Utility Prices	Dynamic Grid Fees (Time-Of-Use)	P2P Community	P2P Community and Region	P2P at all levels	Dynamic Grid Fees + P2P
Aggregate Energy Bill		211137	245272	211256	205815	173577	169625	148834
			16%	0%	-3%	-18%	-20%	-30%
Aggregate Residential Energy Bill		141658	168319	141777	136336	115757	113857	122069
			19%	0%	-4%	-18%	-18%	-14%
Aggregate Industrial Energy Bill		69479	76952	69479	69479	57819	55768	63640
			11%	0%	0%	-17%	-20%	-8%
Self Sufficiency	Community	6%	5%	6%	31%	31%	30%	22%
	Region	6%	5%	6%	31%	70%	40%	41%
	Germany	6%	5%	6%	31%	70%	73%	68%
Energy Trade Volume	Household	56222	45455	56891	53297	55782	54370	36461
	Community	0	0	0	146265	141744	136988	123081
	Region	0	0	0	0	427293	169684	224008
	Germany	0	0	0	0	0	318647	276015
	Conventional Energy Market	859915	849754	860296	722698	300931	242945	285168

Table 2. Key Performance Indicators, Grid Singularity Simulation of Germany 2030 Energy Market (energy bill, self-sufficiency rate, energy trade volume per market level: community, region, national, and group: households, industry, in absolute terms and percentage relative change for each simulated scenario compared to the base case scenario)

Dr Ana Trbovich, cofounder of Grid Singularity, emphasised the importance of inter-community trading, which is the innovation focus of the company's current, EU-supported FEDECOM project, and which requires leveraging novel decentralised blockchain technology:

> *"The study unequivocally demonstrates the strong economic and environmental impact of peer-to-peer electricity trading, especially at scale, urging regulators to consider easing the setup of energy communities and facilitating trading among these communities."*

The study derived the following recommendations for German policy makers:

- The EU directive on the regulation of energy communities should be advanced and implemented nationally, strongly considering enabling inter-community trading in addition to intra-community trading to unleash more benefits for the citizens and the grid.
- In line with the EU Digital Energy Action Plan, a framework for testing P2P electricity trading in demonstration projects should be created to demonstrate the benefits of energy communities and define clear criteria for implementation in Germany.
- Market platform models should be researched and developed to ensure holistic operation of P2P electricity markets, enabling the operational and regulatory framework to control, protect and settle financial transactions (effectively enlarging the current, more limited scope of community coefficient-based exchange).
- The roll-out of smart metering systems, enabling remote access to high resolution (at least 15-min) submeter data for energy asset generation and consumption, is a prerequisite for P2P electricity trading as well as other flexibility and wider energy optimisation services, which should be implemented quickly and worldwide.
- To connect and integrate a broader level of market participants, additional digital technologies such as digital identities and corresponding, decentralised registers for machine identities of energy assets — ideally linked at EU level — are recommended. With the help of digital identities and data exchange concepts such as data spaces, and granular, time-based proof of electricity origin and distribution can be leveraged to issue and trade fully verifiable guarantees of origin, and to enable a rapid transition of market roles (e.g., from self-consumption to ancillary services to trading markets and back to self-consumption). End-to-end digitalisation is an accelerator for implementing and enabling an efficient and secure operation of energy communities.
- The penetration of flexibly deployable home energy storage systems envisaged for the future is not sufficient for time-variable tariffs to induce a global cost-reducing influence on the electricity price. To effectively reduce electricity prices, flexible operation of heat pumps and EVs is necessary across the board. Further studies could investigate which market share of flexible consumption units, such as heat pumps, should be achieved or how high the degree of

flexibility of loads should be for variable electricity tariffs to contribute to a global reduction in electricity costs.

Prof. Dr. Jens Strüker of Fraunhofer FIT and University of Bayreuth concluded:

“Our study represents a crucial initial step in the economic and ecological evaluation of P2P electricity trading. We have demonstrated that the incorporation of flexibility into P2P markets can significantly reduce costs and CO2 emissions. Despite existing regulatory challenges, there is an urgent need to further develop public end-to-end digital infrastructure to seamlessly integrate millions of PV installations, electric vehicles, heat pumps, and battery storage systems as flexible market actors. Information Technology is not merely a nice-to-have tool; it is an absolute necessity for advancing the energy transition.”

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