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The prospects of hybrid-electric regional air transport - an assessment of travel time benefits of domestic short-haul flights in Germany with 19-seater aircraft

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Abstract

Aviation policy in the EU aims at improving connectivity and reducing environmental impacts. New propulsion systems that are locally free of emissions, e.g. with battery or hydrogen powered designs may contribute to this objective. Initial research suggests that such innovations are best applied in commuter aircraft with up to 19 seats. However, the market for these aircraft has been steadily declining since the end of the 1990s. In this paper, the authors analyze the prospects of re-vitalizing this aircraft category by applying an innovative business model, using hybrid-electric commuter aircraft designed in a cooperative project between Bauhaus Luftfahrt and the German Aerospace Center (DLR) in order to contribute to both objectives. The aircraft, based on characteristics of the BAe Jetstream 31, features a full electric range of approximately 200 km at a payload of 16 passengers, increasing to 1250 km, when the jet fuel-based range extender is used. The potential use of such a hybrid-electrically powered regional aircraft for regional air transport services from smaller airfields is demonstrated from a demand perspective. Travel time benefits are quantified alongside initial demand potentials, based on forecasts for 2030 at the regional pair level as provided by the German Federal Transport Plan.

Keywords: Regional Air Transport; Flightpath 2050 4-hour-goal; Commuter Aircraft; Electric Propulsion

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1. Introduction

Among the aviation-related policy goals of the European Commission is the “Flightpath 2050 4-hour-goal” that 90% of intra-EU air travelers shall be able to reach their destination, door to door, within four hours (European Commission, 2011). Hence, it is on the one hand a major policy objective to improve the accessibility of European regions with the help of connectivity provided by the air transport system. On the other hand, it is a further objective to make aviation more climate-friendly and sustainable, as public pressure on aviation is continuously increasing. This has led to a boom in research projects aiming at the development of aircraft with propulsion systems that are locally free of emissions, e.g. with battery or hydrogen powered designs. In recent years, research has concentrated on aircraft with 4-9 seats, as for instance shown in the overview by Liu et al. (2017). Also commercial projects like Zunum Aero (2018), e.SAT (2019) or Alice (Eviation, 2020) suggest that such innovations are initially best applied in relatively small commuter aircraft. More recently, EU-funded research projects UNIFIER19 (Community Friendly Miniliner, Pipistrel, 2019) and ELICA (Electric Innovative Commuter Aircraft, European Commission, 2019) address the application of hybrid-electric propulsion for 19-seater commuter aircraft. In this category, aircraft have a long tradition of being used also in scheduled passenger transport, with a strong focus on commuter services in the US. However, the number of active aircraft has been steadily declining since the end of the 1990s and only very few aircraft types with this seat capacity are still in production.

In order to demonstrate the capabilities of technologies currently available, a hybrid electric commuter aircraft with 19 seats has been developed in a cooperative project between Bauhaus Luftfahrt and the German Aerospace Center (DLR), named “Cooperation on Commuter Research – CoCoRe”. The aircraft (see Fig. 1), based on characteristics of the BAe Jetstream 31, features a full electric range of approximately 200 km at a payload of 16 passengers, increasing to 1250 km, when the jet fuel-based range extender is used.

Besides the mere replacement of conventional aircraft, e.g. on existing short-haul commuter routes, new business models for the regional aviation market were investigated in the project. The analysis was conducted against the background of available technologies and their potential contribution to Flightpath 2050 objectives, such as the 4-hour-goal and a higher contribution to environmental sustainability.

In the paper, the potential use of the hybrid-electrically powered regional aircraft on regional air services from smaller airfields is demonstrated from a demand perspective. Travel time benefits are quantified alongside initial demand potentials, based on transport demand forecasts at the NUTS-3 region par level (administrative districts and independent cities) for 2030 as provided by the German Federal Transport Plan. While the technologies under consideration in the project are immediately available, the year 2030 for the impact analysis was chosen as design, certification and testing, as well as the introduction of the proposed regional air transport business model in combination with the required infrastructures may take a considerable lead time.

The paper is structured as follows: Section 2 provides a brief overview of the (potential) contribution of regional aviation to connectivity, together with a summary of the historical development of this aviation sector in Germany. Section 3 introduces a potential business model for 19-seater (hybrid-)electric aircraft on short-haul domestic routes. In a next step (Section 4), the authors present the methodological set-up and the data used for the estimation of resulting travel time benefits. After the presentation of results, the article concludes with a critical assessment of the findings.

Fig. 1. 3D-Rendering of the 19-seater hybrid electric commuter aircraft as explored by Bauhaus Luftfahrt and DLR.

2. Regional Air Transport in the Context of the Flightpath 2050 4-hour-goal and Technological Innovations

Even though research indicates that the Flightpath 2050 4-hour-goal will be very difficult to achieve (Grimme and Maertens, 2019), regional air transport can be regarded as a valuable contribution to regional accessibility. With regional air services remote areas can be connected both to other regions and to air transport hubs in a time-efficient manner, in case only poor ground transport connections exist. Moreover, from a total or lifecycle cost perspective, regional air transport can be cost-efficient if passenger demand levels do not justify costly infrastructure investments. However, regional air transport has faced a difficult time over the past two decades in Europe, as many services with small aircraft have been discontinued. A thorough analysis of the development of regional aviation in Germany and potential routes with enough demand for a revival of regional services can be found in Maertens (2017). On the one hand, services like the regional air services from smaller German airports like Kiel, Bayreuth or Erfurt vanished completely and passengers switched to ground transport modes, which operate at higher frequencies (long-distance railway) or on-demand (e.g. private car). Moreover, ground transport modes often feature lower transport user costs than regional aviation. On the other hand, intra-modal competition, often with low cost airlines, led to a displacement of regional air services on routes where the demand could be stimulated with the use of larger aircraft. Hence, intra- and intermodal competition in combination with the high cost base per available seat kilometer of small turboprop aircraft can be identified as key contributing factors for the demise of the regional aviation market in Europe and other world regions.

Besides this, from a technological perspective, regional aviation has been widely neglected by aircraft and engine manufacturers. In other segments of aviation, new aircraft types have been introduced over past decades, improving major characteristics such as fuel consumption, range and maintenance costs. The market segment for small commuter aircraft has not seen a comparable level of innovation. As shown by Paul et al. (2019), the market for 19-seater aircraft has been steadily declining, with only 18 recorded deliveries to civil operators in 2018.

These developments indicate a vicious circle for regional air transport:

- The small market size can be seen as a key factor to the lack of innovation, as manufacturers and investors apparently do not see a business case for major investments in a sector where only a small number of aircraft can be sold.
- Subsequently, stakeholders are unlikely to invest in regional aviation and new regional aircraft types as long as new technologies are not available.

Against this background, the major technological change that might occur in the near future with the transition from solely gas-turbine powered aircraft to hybrid-electrical propulsion concepts offers an opportunity to introduce innovations and to exploit the environmental and economic benefits coming from these innovations.

3. Potential business models for 19-seater (hybrid-)electric aircraft

A potential business model for 19-seater (hybrid-)electric aircraft could be services on regional routes characterized by sufficient demand but only limited competition from ground transport services. On such routes, regional aviation may create travel time benefits which – in monetized terms – could exceed the differential in transport costs. Hence, the analytical approach followed in this paper is the quantification of the difference in travel time when regional aircraft are used in comparison to the fastest travel time with conventional modes of transport (car, railway and scheduled aviation).

One key challenge when setting up a business model for regional aircraft is demand aggregation. Schedules can be considered as an instrument to bridge the gap between the desired times by travelers and the need for demand aggregation by the transport operator. The key disadvantage of schedules is their rigidity. This can be fatal for smaller transport operators facing fluctuating demand, like the operation of a 19-seater aircraft as in the focus of this paper's topic. A potential solution to this could be to operate strictly on-demand, as e.g. dynamically applied by ride pooling and ride hailing operators, which collect the transport wishes of passengers and transform these wishes into the trajectory of their vehicle fleets. So far, such demand aggregation engines have become the core element of ground transport service providers like Uber or Lyft (Nökel, 2019), but with the introduction of small-sized aircraft, these business models could extend to the air transport market as well. Future applications for demand aggregation engines could encompass door-to-door travel chains: A journey could start with an airport ground access segment to be operated by ride pooling services like MOIA (a ride pooling service offered by Volkswagen), the air service segment could be operated by the envisaged 19-seater hybrid-electric commuter aircraft, followed by airport egress to be operated again by a ride pooling van. Such concepts would extend beyond the ideas of on-demand air services for urban air mobility, as e.g. outlined by Uber Elevate (2016) or Lilium (2020), as they would include multimodal approaches. With this setup, it may be possible to aggregate sufficient demand without being restricted by rigid constraints of schedules.

4. Analytical framework

In order to analyze the travel time impacts of a regional domestic air transport system between German cities and regions, the following data was used:

- EUROSTAT database with all centroids (coordinates of geographical centers) of the largest city of each German NUTS 3 region (402 independent cities and districts)
- Shortest car driving times between all NUTS 3 regions (161,102 combinations) as derived from the online service HERE Routing API (HERE, 2020)
- Shortest travel times between all NUTS 3 regions by rail as identified using Google Distance Matrix API (Google, 2020)
- Shortest travel times between all NUTS 3 regions by air using Innovata Flight Schedules and Google Distance Matrix API driving times for airport access and egress
- A database including all airports/airfields in Germany, as provided by ourairports.com. All airports with a

runway length of at least 800 m are considered in the analysis. This increases the number of airports with (scheduled) passenger services from some 30 today to 240 airports/airfields as potential origin/destination airports for regional air services. This, in turn, will also substantially reduce the distance and travel time for airport access and egress for a large number of travelers compared to today.
- For the analysis of the travel demand between German cities and regions, the dataset developed for the Federal Transport Masterplan 2030 (Bundesverkehrswegeplan 2030, Intraplan, 2014) was used, which provides a forecast of travel demand in Germany between NUTS 3 regions for the year 2030.

For the calculation of flight time between regions, it is assumed that the commuter aircraft have a full-electric range of 200 km. While the aircraft designed in the course of the project has a jet-fuel powered range extender which allows operating on longer routes, the scope of this analysis is set on locally emission-free operation, hence the limitation to a mission distance of 200 km. The aircraft design resulted in a cruise speed of 160 knots (296 km/h) in electric mode (Atanasov, 2019) and an additional 20 minutes are added for taxi-out, take-off, landing and taxi-in in order to calculate the airport to airport flight time. In case a flight distance is longer than 200 km, 20 minutes are added for each flight leg to account for the time needed for an intermediate stop, including landing, taxi in, battery replacement, taxi out and take-off.

Each origin and destination point has been assigned to the airfield which can be reached in the shortest travel time by car, as calculated with the HERE API. 15 minutes are added for airport process times for both curb to gate at the departure airport and gate to curb at the arrival airport in order to calculate the door-to-door travel time. This can be considered as relatively optimistic, but as only small airfields are used, it is assumed that future passenger processes can be accomplished much quicker than today at airports with scheduled aviation.

With the parameters outlined above, for each of the 161,102 combinations of NUTS 3 origin and destination points travel times are calculated. In order to calculate the potential travel time savings of the regional air service, benchmark travel times have been calculated assuming a door-to-door travel chain by car, train and scheduled aviation.

5. Results

Figure 2 depicts the individual travel time benefits for each NUTS 3 region/city pair in dependence on the great circle distance of each region/city pair. It shows that the average maximum travel time benefit that hybrid electric regional aircraft can reach occurs at a distance band around 400 km. Direct car travel is often the fastest for short distances below 100 km. On very long region pairs, scheduled aviation is in many cases the fastest mode, as the flight speed of scheduled aviation is typically higher than of the commuter aircraft while the longer distances can be accomplished without intermediate stop. The commuter aircraft has a full electric range of only 200 km and needs to make intermediate stops on longer mission distances.

Nevertheless, it is astonishing to see that, given the relatively well developed ground transport infrastructure, extensive high-speed railway network and dense domestic scheduled air transport network, the electric commuter aircraft can achieve travel time benefits on 110,592 out of 161,202 region pairs.

The results shown in Figure 2 only provide the individual travel time benefits, which are highest on medium distances. For instance, the region pair with the highest individual travel time benefit is the connection between Saalfeld-Rudolstadt in Thuringia and Aurich in the far northwestern part of Lower Saxony, with a benefit of 210 minutes on a distance of 410 km. However, the demand on this region pair in 2030 is estimated to be only 2,160 passengers per year, so the overall economic benefit can be considered low, as well as the commercial viability to offer a service on such a very thin route.

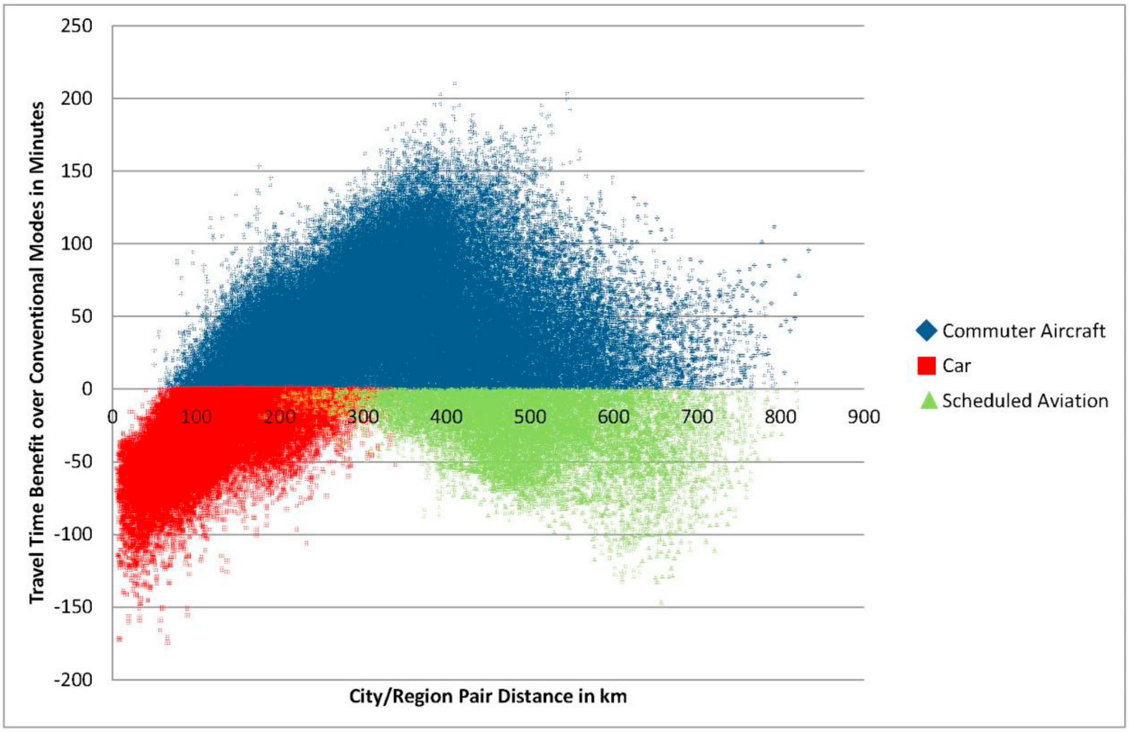

Fig. 2. Individual travel time benefits of regional aviation compared to car and scheduled aviation.

Figure 3 depicts a more detailed analysis, on how the travel time benefits are distributed over the 110,592 region pairs where the commuter aircraft can achieve travel time benefits. Only a comparably small number of region pairs offer substantial travel time benefits, which might lead to a modal shift, given the assumption that air transport services with small aircraft will result in a significant difference in fares compared to conventional modes.

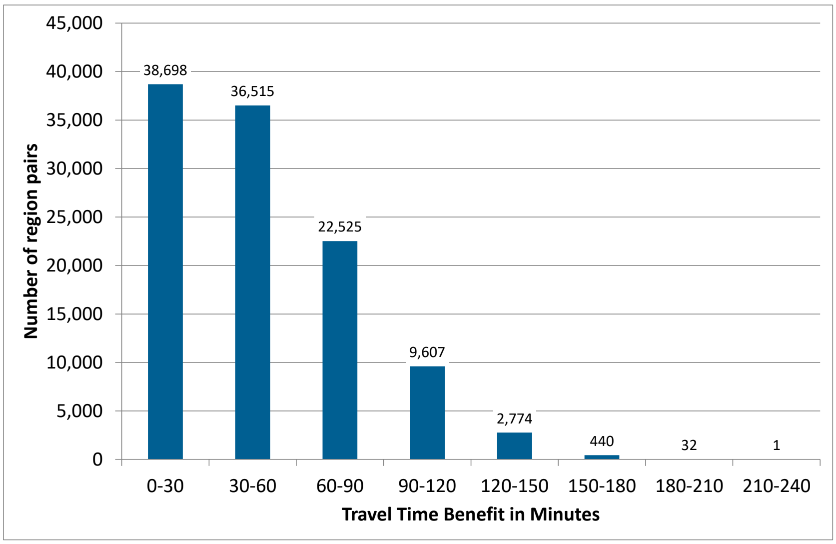

Fig. 3. Distribution of travel time benefits by region pair.

Figure 4 presents the average travel time benefit for each NUTS 3 region. The average is calculated by the sum of travel time benefit from each region to each other region, divided by 401 (the total number of destination regions). The highest gains can be observed for peripheral regions further away from large metropolitan areas. From these regions, average distances to other regions and driving times to airports providing scheduled services are comparably long. For instance, travelers to/from Nordfriesland in the far northern part of Germany close to Denmark would be able to reduce travel time on 379 out of 401 origin-destination region pairs with the commuter air service. The large metropolitan areas, in contrast, are already today well connected to motorways and have airports with scheduled domestic aviation services close by. Hence, the travel time benefits of the commuter air transport system are comparably low, for e.g. Hamburg, Berlin, the Rhine-Ruhr area around Düsseldorf, Frankfurt and Munich.

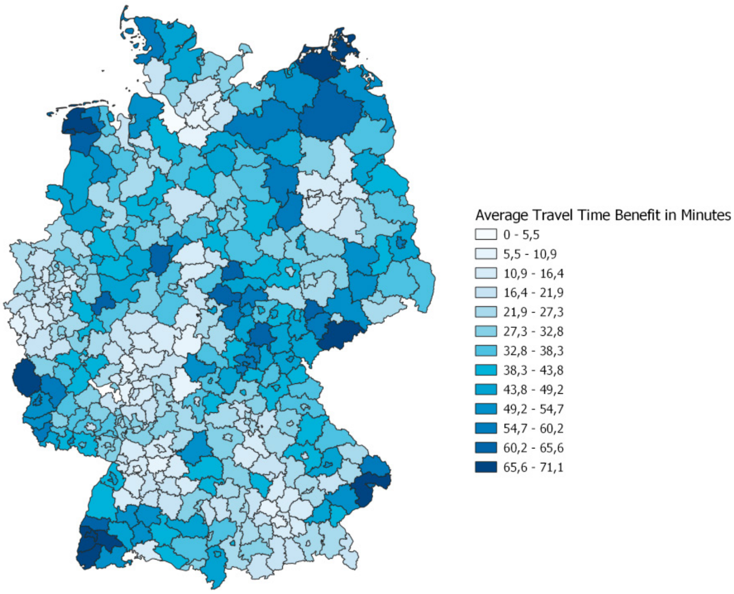

Fig. 4. Average travel time benefits through commuter air services by region.

In order to evaluate both the contribution to economic welfare and the viability of a business model, the individual travel time benefit has to be put into relation with the number of travelers. Hence, we have assumed that the regional air service can achieve a 5% modal split share, which is in line with long-term forecasts for regional air mobility (e.g. as shown in Roland Berger, 2018). We then multiplied the number of travelers, which are estimated to take the commuter air service with the travel time benefit compared to the fastest conventional air transport mode. The results with the highest total time saved are shown in Table 1.

The resulting city/region pairs with the highest total travel time savings can be classified in at least two major groups: the first is long-distance relations between major cities (in the top ten, Berlin and Hamburg) and secondary metropolitan areas (e.g. like Dresden, Bielefeld or Kiel), which are not well connected by rail or road, and distances between 300 and 400 km. Here, individual travel time benefits are in the order of 60-100 minutes compared to the fastest conventional transport modes. The second is regional pairs with distances of 50-100 km, which feature very high demand levels, mostly by daily commuters. However, individual travel time savings here are relatively low (in the order of less than 20 minutes). It is highly questionable whether such a small travel time saving could lead to a modal change and if the assumed 5% share could realistically be achieved. However, there are reports that even this segment is currently being tackled by air taxi ventures, at least in Los Angeles, where the projected service by operator FLOAT plans to help commuters bypassing L.A.'s "infamous" traffic jams (Wolfsteller, 2019).

The range limitation of 200 km full electric flight provides further implications for the business model. With the need of having additional stops on longer flights, the opportunity arises that passengers can embark and disembark, so that also transfer hubs could be operated, where the demand on particular flights would be aggregated. This way, more city/region pairs could be offered with a given number of flights.

Table 1. City/region pairs with the highest total travel time benefit.

Origin Region	Destination Region	Forecast Number of Travelers 2030	Potential travelers per day for air taxi (5% modal split share)	Distance (GCD in km)	Shortest Travel Time Conventional Mode (min)	Travel Time Electric Commuter Aircraft (min)	Travel Time Benefit Electric Commuter Aircraft (min)	Total Travel Time Saved (5% Modal Share, hours)
Berlin	Bremen	432,050	59	321	255	178	77	27,597
Ludwigslust-Parchim	Lüneburg	1,638,731	224	96	109	92	17	22,828
Dresden	Hamburg	232,022	32	377	310	204	106	20,521
Ortenaukreis	Rottweil	2,125,688	291	63	97	89	8	14,230
Steinburg	Cuxhaven	425,372	58	55	126	86	40	14,014
Kiel	Berlin	215,022	29	297	247	170	77	13,695
Berlin	Bielefeld	246,815	34	335	243	185	58	11,901
Elbe-Elster	Nordsachsen	1,282,225	176	94	120	109	11	11,629
Rendsburg-Eckernförde	Berlin	174,714	24	319	261	182	79	11,395
Meißen	Berlin	622,434	85	134	141	119	22	11,108

6. Conclusion

The authors find that even in a country with dense ground transport like Germany, regional air services operating from smaller airfields could create travel time benefits over car or train traffic on a multitude of region pairs. A valuable contribution towards the Flightpath 2050 4-hour-goal can be achieved, as small commuter aircraft could operate on routes with lower demand and from smaller airfields, reducing ground transport distances for airport access. Moreover, when operating from smaller airfields, passenger handling processes could be expedited compared to major airports.

However, the main challenge associated with the proposed business model will be cost-efficiency, as the operation of regional aircraft with 19 seats is associated with relatively high costs already today. The total cost per block hour for aircraft with less than 20 seats are about the same as those for turboprop aircraft and regional jets with up to 60 seats (FAA, 2016). Considering the number of passengers transported per block hour as well as the current low total market volume of 19-seater aircraft, this indicates higher cost per available seat kilometer for these aircraft types. Electrification alone, even if substantial future carbon price levels and/or increasing conventional jet fuel prices are assumed, will most likely not lead to a large-scale re-vitalization of regional aviation. However, locally emission-free regional flights could become a valuable addition to established means of travel for time-sensitive travelers and may even become part of seamless door-to-door travel chains when combined with (autonomous) ground transport rides.

However, the authors of this paper remain skeptical when it comes to the question whether electric propulsion alone can lead to a revival of regional aviation in Europe or elsewhere. The mere replacement of petroleum-based fuels by electricity as energy carrier will most likely not change the cost situation in the operation of regional aircraft substantially. Moreover, when changing the focus from the operation of a single flight or a single aircraft to the operation of a regional airline, indirect or fixed costs like the set-up of a continued airworthiness maintenance operation, the post-holders for flight operations or for marketing, sales and customer relationship management will remain the same, irrespective of the aircraft technology used. For a regional airline, operating with small aircraft over short distances, such costs are more difficult to amortize than for an operator flying aircraft with 150-200 seats and operating over 1000 km or more on average.

From the perspective of current research, it seems reasonable to conclude that further technologies are required to cut costs up to a point where it is commercially viable to operate small regional aircraft in future transport systems. For instance, if autonomous flight can be achieved without adding too high capital costs, cash operating costs can be reduced substantially. In the current set-up, crew costs have a substantial share in operating costs per available seat kilometer of regional aircraft. But even if more substantial cost cutting efforts were achieved, such a transport system would probably only be affordable for the most time sensitive travelers and not immediately turn into a mass transport system.

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