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The effect of climate change on inland waterway transport

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Abstract

Generally, inland waterway transport (IWT) is characterised by a high degree of reliability and safety compared to other transport modes. Against the background of the climate change debate however, new concerns are starting to raise attention. IWT is expected to be more sensitive to climate change aspects than other transport modes, e.g. in terms of water level fluctuations and resulting effects on costs and reliability.
The present paper specifically addresses the topic of adaptation to climate change, taking IWT as a case-study. The results figuring in the paper are based on the results of the EC funded ECCONET project, which is an interdisciplinary project combining the expertise gained from climatology, hydrology, transport-economics, ship building and inland waterway management. A quantitative approach is applied, using the results of existing climate ensembles, hydrological results from KLIWAS and the transport network models TRANSTOOLS and NODUS.
The paper starts first with an overview of expected effects of climate change on the Rhine and Danube. Adaptation measures are evaluated in function of their cost-effectiveness, given the expected impact of climate change on the navigation conditions.
The main concern for adaptation is coping with periods of low water levels, as these were empirically established as the most influential for the sector. We consider four focal points for adaptation: fleet- and transport related strategies, operational concepts, improvement of forecasting tools and adaptation of production procedures and storekeeping.

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Keywords: climate change; inland waterway transport; adaptation

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1. Introduction

1.1. The impact chain of climate change on the inland waterway sector

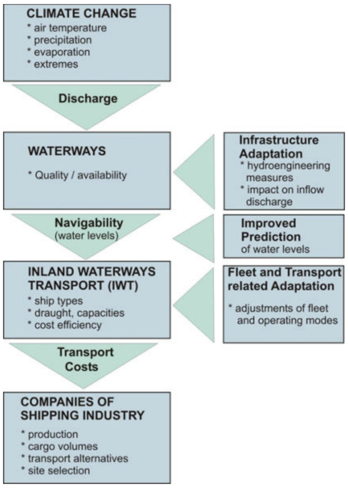
The publication of the IPCC-report 2007 outlines possible climate change scenarios as well as expected impacts. In this light it seems to be necessary to closely loom this topic. This on the one hand refers to mitigation strategies, which aim at affecting possible causes of climate change, like for example the decrease of CO_2 emissions. On the other hand, approaches of how to meet impacts of a possible climate change are concerned, aimed at adaptation to new climate conditions. This paper refers to the latter.

Generally, inland waterway transport (IWT) is characterised by a high degree of reliability and safety compared to other transport modes. It is also known for its low environmental impact, compared to the more polluting road transport. The role of IWT and its potential as an alternative transport system for freight transport evokes interest but also concern from an environmental point of view within Europe. The raising interest is confirmed by the official view of the European Union, which rates IWT as a less energy-intensive, cleaner and safer transport system and encourages changes in policy that would move a larger part of freight flows on the inland waterway network (COM(2006) 6 – final, report NAIADES).

To some extent IWT has always been dependent on climate conditions. Against the background of the climate change debate, new concerns are starting to raise attention. IWT is expected to be sensitive to climate change aspects, e.g. in terms of water level fluctuations and resulting effects on costs and reliability. Several studies and conferences address this topic. Examples are the on-going studies CLAVIER and KLIWAS, as well as Jonkeren, 2009. However, further substantiated information is needed.

Changing climate conditions and a rise of extreme weather periods could trigger an impact chain with the result that navigation conditions for inland vessels change, cost advantage and reliability of waterborne transports decrease, thus impairing competitiveness of in particular those sectors which rely on cost-effective transport of especially bulk and containerized cargo.

Targeted adaptation measures e.g. investments (ship building or hydraulic engineering) and operating measures (e.g. transport concepts including water level forecasts) can contribute to reduce or even to overcome the sensitivity of IWT to climate change. Investments in IWT, e.g. in new ship tonnage adjusted to changed infrastructure conditions, investments in hydraulic engineering buildings or questions related to the site selection of the shipping industry, will generally have a long service life and can cover the needs of the sector for several decades.



FRE 1

Figure 1: Impact chain of climate change on Inland Waterway Transport

Following the approach described by Figure 1 **Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.**, possible climate induced shifts from IWT to other transport modes - which would run contrary to congestion- and environment-related goals, since for years an intensified consideration of waterborne transport is claimed on national as well as on EU level - could be avoided. Furthermore, with the help of targeted adaptation measures, IWT could contribute to solve future transport tasks in spite of expected climate changes. Targeted adaptation measures could contribute to maintain IWT as a sustainable and reliable transport mode and to enable IWT to overtake parts of the predicted future increases of transport demand, considering the expected capacity restraints of road and rail infrastructure.

1.2. The ECCONET project

The results presented in this paper are based on the intermediate results of the ECCONET project. ECCONET is a 3-year Coordination and Support Action funded by the European Commission (DG MOVE) in the context of the 7th Framework Programme.

The approach of ECCONET is unique as it takes into account the full impact chain of climate change (cfr. paragraph 1.1), integrating the work of climate change specialists, hydrologists, transport-economists, ship building specialists and policy makers. This paper explains the methodological issues enabling the cooperation of such a diverse consortium and discusses how the data from climatological and hydrological modelling can be processed for economic evaluation and policy advice.

The first step of the ECCONET project is to assess the navigation conditions in the future on the Rhine-Main-Danube corridor, as projected by current climate models. As there is no single best climate model, ECCONET uses many different models to assess the current state of knowledge on climate change. The wet and dry scenarios that can be defined reflect the range of possible future navigation conditions, with special emphasis to low water situations.

Low water level situations are emphasised because it was proved empirically (cfr. the situation on the Rhine river in 2003) to have the most impact on inland waterway transport. (see also Jonkeren O., 2008). While high water levels pose mainly short term (1-2 days) problems for navigation, low water conditions can involve problems for passage of (mainly) larger freight ships for longer periods of time. Other climate related changes, such as changed ice formation, are assessed only briefly in ECCONET.

The target period for the simulations proving the basis for the considerations related to adaptation and economics is 2021-2050 denoted as “near future” or “2050”. Projections with respect to navigation conditions in the “far future” will be provided for the period 2071-2100 (also denoted as “2100” hereafter). All future changes are expressed with reference to a “control period” from 1961 to 1990. (Schweighofer et al., 2010)

The next step of the project is to estimate the effect of climate change on the transport network.

Therefore, a reference scenario needs to be defined. This scenario consists of O/D-pairs with associated freight flows, under known conditions (i.e. transport costs and capacities of 2005). In the case of ECCONET, the O/D matrix is taken from the TRANSTOOLS European transport model. It is then fed into the NODUS model, a virtual network model for freight transport. Then we superimpose a set of representative results from the climate/hydrology modelling onto the transport reference scenario, processed to be handled by the economic model. This results in a set of transport-economic scenarios, including the effect of climate change.

An alternative transport background scenario is added for reasons of sensitivity, and consists of a projection of 2050 transport volumes.

In parallel, the ECCONET project identifies and assesses adaptation strategies for coping with possible climate change effects on IWT, with respect to their applicability. Both qualitative and quantitative criteria are taken into account and combined into a multi-criteria analysis (MCA).

This leads to another round of calculations with the transport economic model NODUS, where variations to the climate change scenarios through adaptation measures are added (i.e. the adaptation scenarios).

In the end ECCONET produces an assessment of the cost-effectiveness (CEA) of adaptation strategies, combined with the results of the multi-criteria analysis, leading to policy guidelines and a development plan for inland waterway transport. The aim is to identify measures that are both effective and robust, by comparing their expected effects over the different scenarios.

This paper will start by presenting the evaluation of the climate change projections for the ECCONET impact studies. Then it will explain how the data from the hydrological models will be processed for the transport economic models. Next, it will elaborate on possible adaptation strategies. Finally, it explains how the results are currently applied in the project.

2. GOING THROUGH THE IMPACT CHAIN

2.1. Comparing the different models and approaches

The transport-economic models used in ECCONET are stationary. Their focus lies on annual and sub-annual conditions in costs, prices and transport modes. The development of scenarios of future circumstances is thus essential. Climate change however involves a very large time span, and must be evaluated on climate parameters with a 30-years average. Hydrological models operate on small to large time scales and are able to handle the climatological models quite well. However they produce an enormous database, which needs to be processed in a scientifically sound way.

This chapter treats the processing of climate change information through the impact chain, as summarised in Table 1. In paragraph 2.2, we explain how relevant climate scenarios were selected. In 2.3 we treat the hydrological modelling and in 2.4 we explain how the hydrological results can be processed for economic evaluation.

Table 1: Comparison of model approaches within ECCONET

	Time span	Important output variables	Complications
Climatological models	30 year-averages for example:1960-1990, 1991-2021, 2021-2050, 2040-2070, etc.	precipitation, temperature	Bias-prediction, regional climate scenarios, large set of model chains (ensembles), uncertainty
Hydrological modelling	Daily and even hourly variations for all modelled years (30 years)	water levels/water depths on different river stretches based on nature of river	Added uncertainty due to regional variance and anthropogenic factors. Large running time
Transport-economic modelling	Based on an OD-matrix for 1 year. Predictions should be based on averages or should be composed of different characteristic situations	Flow of goods by transport mode (inland waterways are 1 of the modes) Costs of transport (minimized by model)	Difficult to handle sub-annual information (for example seasonal variance) Uncertainty in OD matrix. Only a limited set of model runs is possible

2.2. Defining climate change scenarios as a meteorological basis for impact studies

Climate modelling is and always has been a domain where firm conclusions are hard to come by. The simulations, which are the mostly physics- and process-oriented tools for description of the future climate evolution, include several uncertainties: (1) the internal variability is a natural characteristic of the climate system, (2) the future human activity is quantified in the projections as different GHG and aerosol emission scenarios; (3) the differences in the formulation applied by the global and regional climate models (GCMs and RCMs, respectively) introduce further uncertainties in the climate change simulations. A key point of view at planning the research efforts in ECCONET was that all the impact studies conducted within the project should be comparable with each other by basing them on a common meteorological basis.

In ECCONET, an effort is made to address these uncertainties by determining “representative projections” or “model chains” for the Rhine and Upper Danube catchments. These “model chains” attempt to represent both the lower and upper signals of consistent simulations of hydrological parameters by most of the ensemble members for two future time horizons, 2021–2050 and 2071–2100. In the

KLIWAS programme, a major part of the currently known spectrum of uncertainty was taken into account by utilizing hydrological impact models and an ensemble of different GCMs and RCMs. For the Upper Danube, using the same thorough method as KLIWAS was not feasible in ECCONET due to resource and temporal constraints; therefore, a correlation analysis was applied between (lowest winterly 7-day mean) discharge and climate variables (September-January precipitation sum) as a proxy.

As a result of this selection method, altogether 5 regional climate model simulations are selected as representative for the lower and upper bounds in the hydrological conditions for the near and far future over the two target regions.

2.3. Climate change impacts on navigation conditions on Rhine and Danube

Within the ECCONET project, the impact of climate change on the performance of inland waterway transport including considerations related to economy and the reliability is being analysed for the Rhine-Main-Danube corridor.

In that light, it is necessary to provide projections about possible future navigation conditions at critical locations – the “bottlenecks” of the inland waterway transport system – consisting of information for the different river stretches on:

- discharges,
- stream velocities,
- mean and minimum water levels,

Based on the bias-removed climate projections as input for discharge simulations, hydrological models are applied to link discharges to water levels at relevant downstream locations.

2.3.1. Rhine

Comprehensive results of the KLIWAS programme are used for the Rhine within this project. An ensemble of 20 bias-corrected climate simulations has been used as meteorological input for the semi-distributed HBV hydrological model and further linked to the hydrodynamic SOBEK river model. Two climate scenarios have been selected for the near future (time horizon 2050) and two scenarios for the distant future (time horizon 2100).

2.3.2. Danube

At the beginning of the ECCONET project, available hydrological and hydrodynamic model results did not cover the entire study area of the Upper and Central Danube. As a result of the efforts made within the project, the VITUKI NHFS hydrologic and hydrodynamic modelling system has been extended and improved, and now it is available for the Danube drainage basin downstream to the Hungarian-Croatian border (gauge Mohács).

2.3.3. Results

The given phase of the work will result in continuous daily time series of discharges, water levels and flow velocities on the Danube and the Rhine rivers readily available for the economic analysis within the ECCONET project.

2.4. Extracting representative years out of the hydrological database

Transport modelling with the transport economic model NODUS depends on the development of water levels / water depths by year. The nature of the model requires that ‘representative years’ are extracted from the database, which would be consistent with the new climatological conditions. Therefore it was chosen to extract 3 ‘types of conditions’ representing the conditions of the inland waterway network in the future. (Lingemann I. et al, 2011)

In ECCONET we focus on low water level situations, this means that we focus on the ‘dry’ situations under several climate scenarios. We create a ranking for each modelled year under given climatological conditions, based on the ‘water level situation’. We order each year based on the number of days a certain set of water levels is exceeded. This can be understood as thresholds and allows us to define 3 ‘characteristic years’ for each climate scenario.

- Median year: This is represents the hydrological conditions of a ‘standard’ year under ‘normal’ conditions.
- D5 year: This is a ‘dry’ year occurring each 5 years under the given climatological conditions
- D10 year: This is a ‘dry’ year occurring each 10 years under the given climatological conditions

An example of how this table can look like is given in Table 2. This table presents the amount of days per year a certain a water level is not exceeded. In this way representative ‘years’ or water level conditions can be selected as a basis for economic evaluation.

Once the representative years are selected, the information in Table 2 can be transformed into a histogram that represents the occurrence of water levels within a certain bandwidth.

Table 2: Processing of hydrological data for economic modelling- extract representative years

	2005 ‘reference’			Near future 'dry' scenario		
Water depth	Median	D5	D10	Median	D5	D10
1.6	0	0	0	0	4	24
1.8	0	20	36	5.5	55	74
2	14	61	86	28.5	79.5	121.5
2.4	133	192	221	135.5	203.5	234.5
2.6	182	260	273	216	259.5	307.5
3.25	301	334	344	324	365	365
3.55	328	351	352	344	365	365

2.5. Using the transport- economic model NODUS

2.5.1. Taking into account the future of transport

There is one certainty about climate change, it happens in the future. In the meantime however, we can expect some changes in the transport network and O/D flows, not related to climate change, but with importance for our evaluation.

ECCONET uses two transport scenarios as a basis for evaluation of climate change effects and adaptation measures, as outlined in Table 3. The first is a standard scenario is which all variables are known. As the project is intended to provide policy guidance to EC officers, starting with a scenario of this nature permits policy makes in the first instance to avoid a complex abstraction of largely unknown circumstances on a timescale at the edge of the possibilities of standard economic reasoning (40-90 years in the future). This scenario will be represented by the TRANSTOOLS baseline for 2005, and consists of Origin/Destination pairs, with the associated flows of goods (divided by NSTR class) for each, and with the infrastructure/physical links of that year.

The goal of using a second transport background scenario is twofold. Firstly, it allows the use of certain assumptions to construct the possible economic conditions of the year for which the climate change projections are made, i.e. 2050. (Chen M. et al, 2011) The most important argument for using this alternate scenario is that it will serve as an immediate sensitivity analysis of the results obtained from the simulations of the first scenario. In other words, the robustness of the adaptation measures under different circumstances is tested, so that policy makers can assess the risk of applying such measures. This scenario will be based on the 2011 EC sponsored study “Medium and Long Term Perspectives of IWT in the EU” (Quispel, M. et al, 2011).

Table 3: Overview of ECCONET scenarios

Economy	Baseline	Dry scenario	Wet scenario
Standard conditions	Known OD-matrix based on 2005	Representative years extracted like explained in 2.4 for near and far-future	
Future economic conditions	Change to transport network (Perspectives study) Change to OD-matrix	Climatological conditions are assumed to be independent from economy.	

2.5.2. Application of the NODUS model

NODUS is an elaborate transport network model, which optimises/minimises costs through a modified shortest-path algorithm. NODUS then is set up to handle different ship types and predicts both transport cost and good flows on the entire transport network. Intermodality and modal change can be assessed directly from the model. (Beuthe M. et al, 2010)

The cost functions associated with each link are highly detailed and for IWT, use the ship’s load factor as the main parameter. The final outputs from the climate change related work of ECCONET are (see 2.4) histograms of water levels for the near and far future for a wet and dry climate scenario. Cost functions for all relevant ship types are available in the model, for both the Rhine and Danube basin. In the set-up of the cost functions, we follow Jonkeren (2009).

It is assumed that the main element of economic importance for each ship type (by CEMT class) can be reduced to the maximum load that the ship can carry under specific water level conditions. Under this assumption we are able to focus only on a few critical points on the network. The reason for this is, that ships having to pass the critical point (for example Kaub on the Rhine river), will have to suffer from a reduced load for the entire trip passing the critical point. This means that the conditions on the critical point have an influence on all ships and all O/D’s passing through that particular critical point. The link between water level – ship draught – load factor is relatively straightforward to set up. As such, it is unnecessary to analyse the conditions for each stretch and make only marginal use of complex non-linear equations, giving the relation between water depth and fuel consumption.

In ECCONET, 2 critical points are chosen on the Rhine river (Kaub, Ruhrort) and 2 on the Danube river (Wildungsmauer and Pfelling). The total O/D-matrix is split up and only the trips passing through one (or multiple) critical points are taken into account. Then the NODUS model is applied for in 6-8 water level situations, ranging from normal (unconstrained traffic) to severely low water levels. Then, each water level situation is reweighted to represent the situation of the transport network for a certain number of days, given the water level histogram developed in 2.4.

2.5.3. Uncertainty in the impact chain

When combining a large amount of models as ECCONET does, uncertainty increases with every step. To increase robustness of the final results, an attempt is made to cover uncertainty by delivering multiple scenarios, and then checking the variability this causes in the next phases of the project. From that perspective, it was decided to work with 3 climate scenarios and 2 transport scenarios. The robustness of adaptation measures is secured when it gives positive results in all or most combined scenarios.

3. EVALUATION OF ADAPTATION STRATEGIES

3.1. Identification of adaptation strategies

In parallel with the meteorological, hydrological and economic evaluation of climate change, potential adaptation strategies are identified, constructed and assessed.

At present, the project is in the identification phase. The focus is on the following points:

- Fleet- and transport-related strategies covering technical approaches, e.g. adjustment of the fleet, operational concepts as well as logistic chains including other modes of transport e.g. rail;
- Infrastructure measures (adaptation of waterway infrastructure) in order to maintain minimum water depths;
- Improvement of water level forecast methods e.g. on seasonal time-horizon in order to support the shipping industry on questions as explained below;
- Measures and options for the shipping industry, e.g. in terms of short- or mid-term storekeeping, shifts to other modes or adaptation of production procedures.

In general, adaptation measures can be assessed based on the following target:

The cost of the investment needed to keep the same transported volume per ship as nowadays, thereby compensating the assumed mean drop of water level.

This objective can be achieved by the following strategies, following Zigic B. et al (2011) (14).

- increasing the payload of a ship keeping the L x B x T unchanged (lightweight structure);
- reducing the number of days per year when the navigation of a ship is physically not feasible
- increasing the fleet capacity by adding new ships of principally conventional design, but with the appropriate application of measures like adjustable aprons/blisters or lightweight structure;
- increasing the fleet capacity by substituting conventional units with newly designed vessels;
- increasing the annual number of operating hours by passing from day- and semi-continuous into continuous mode of operation, also for smaller vessels;
- optimising the capacity potential through a joint-venture with rail mode (if and where feasible) by passing a part of the own volume to the railway during the unfavourable navigation periods and taking back more than the part of the railway volume during the favourable nautical periods.

As for climate change effects, the quantification of the adaptation measures for further modelling is based on the assumed drop of the water level as an independent variable, with 5 centimetre intervals: 5, 10, 15, 20, etc. This approach enables all proposed measures of very different nature to be assessed impartially and in a mutually comparable way. However, some measures will demonstrate good effects only for smaller, and others only for bigger water level changes. Anyway, the results will enable the choice of the proper strategy and the combination of adaptation measures to cope with the estimated (selected) waterway change scenario. The scheme of the probably feasible measures to match the water level changes (reduction of annual average water depth, increase of variation amplitude) is given in the table below:

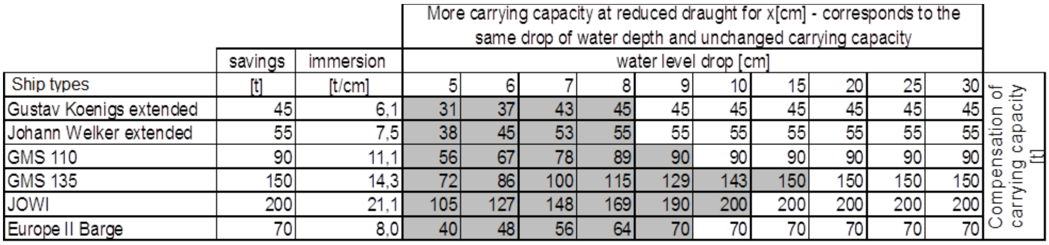
Table 4: Overview of fleet, transport and logistics adaptation options (Zigic B. et al, 2011)

A	Fleet units	B	Operation	C	Logistics
1	Lightweight structure	1	Continuous instead of daytime operation	1	Strategic alliances between IWT and railways
2	Adjustable tunnel (retractable tunnel aprons)	2	Implementation of coupling trains instead of pushed trains		
3	Side blisters	3	Implementation of smaller instead of larger vessels		
4	Flat hulls (multiple screw push boats)				

3.2. Assessment of adaptation

ECCONET integrates the full database on adaptation options and calculates the cost effectiveness of each adaptation option. This means that the final output on adaptation will be the ratio of extra goods flow each adaptation option is generating, compared to the cost of each respective adaptation option. The output of our identification strategy in 3.1 is linked to the results of the NODUS simulations in 2.5.2 by increasing the resistance of ship types to low water levels. Given certain adaptation options, the adapted ships can have a higher maximum load than the non-adapted ships. This means that for the entire trip, more goods can be transported on the inland waterway network. In Table 7 we show an example for one adaptation option, own-weight savings for our selected ship types on the Rhine river.

Table 5: Example of effect of weight savings on carrying capacity (Rhine vessels) source: Zigic B. et al. (2011)



			More carrying capacity at reduced draught for x[cm] - corresponds to the same drop of water depth and unchanged carrying capacity										
	savings	immersion	water level drop [cm]										
Ship types	[t]	[t/cm]	5	6	7	8	9	10	15	20	25	30	
Gustav Koenigs extended	45	6,1	31	37	43	45	45	45	45	45	45	45	Compensation of carrying capacity [t]
Johann Welker extended	55	7,5	38	45	53	55	55	55	55	55	55	55	
GMS 110	90	11,1	56	67	78	89	90	90	90	90	90	90	
GMS 135	150	14,3	72	86	100	115	129	143	150	150	150	150	
JOWI	200	21,1	105	127	148	169	190	200	200	200	200	200	
Europe II Barge	70	8,0	40	48	56	64	70	70	70	70	70	70	

GMS: Großmotorschiff

4. CONCLUSIONS

ECCONET is an ambitious and intensive interdisciplinary project that attempts to make an integrated analysis of the climate change related impacts and to bring together the vast experience of experts within different fields of research and policy making. The methodology of ECCONET is a product of intensive discussion and hard work and is now in the final stage of implementation. Within 1 year, final results for the economic evaluation of both the climate change impact and adaptation will be available.

The approach presented in this paper is an example on how an interdisciplinary project has assessed the problem of adaptation to climate change, taking the inland waterway transport network as a case-study. Based on the concept of an impact chain, a common interface between the model methodologies is determined and applied. The key to good cooperation here is to take into account the different time frames and terminologies of each model.

The main question for the climatological and hydrological work was to extract representative information on the navigation condition, which can be handled for economic evaluation. It was decided to work with "representative years" according to their expected occurrence under wet and dry climate scenarios for the near and distant future.

The respective predictions on occurrence of water levels can be used by the transport model by applying a cost function focussed on the maximum load factor of different ship types under each water level condition. Using load factors, instead of local transport costs on different river stretches, greatly simplifies the use of the transport economic model (NODUS) as the analysis can be limited to a few critical points on both Rhine and Danube.

Adaptation options are identified in parallel to the impact chain analysis and enter into the economic evaluation by allowing a larger maximum load factor for lower water levels. The extra flow this is able to generate is assessed in respect to the cost of implementing the adaptation option.

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