Guidelines for annotating argumentative student texts on socio-scientific issues

1 Table of contents

2 INTRODUCTION

The argumentative texts to be annotated were written as part of a task on socially controversial topics related to natural sciences, so-called socio-scientifc-issues. These issues form the basis for the content parameters of the annotation (the tasks for which are provided in the appendix). The annotation is carried out in the Inception tool and is performed in 4 steps (called "layers" in Inception) with various sub-steps ("tags"):

1. Content zone.
2. Major claim and decision-making strategies for determining the major claim position.
3. Arguments:
    a. Topic.
    b. Option for action and positioning.
    c. Technical correctness (adequacy & accuracy)
4. Structure of the arguments according to Toulmin's argumentation pattern.

The annotation is required at sentence-level for layers 1, 2, and 3, which means multiple sentences can be assigned with corresponding tags. Annotation for layer 4 should be made at the subordinate clauses; however, as the annotation tool doesn't permit this, it should be performed at token level. Therefore, there are no overlapping tags between the distinct layers. Modifications within layers can be made until the text is finalized.

In general, the aim is to annotate the students' writing as it is intuitively understood when read, rather than interpreting the potential intention behind the words. The primary objective is to provide constructive feedback to students, thereby enhancing their argumentative skills. Therefore, the annotation should lean towards being strict rather than lenient. Being overly indulgent, for example, in terms of technical correctness, does not benefit students.

There is an option to leave comments on each layer. This option should be utilized whenever there is uncertainty. The assigned texts should be reviewed in a sequential manner.

3 LOGIN AND SETUP

- The login is possible via the following link: https://darius-corpus.ipn.uni-kiel.de/inception/login.html
- Login data will be allocated in advance.
- For login and other technical/content-related problems, please contact schaller@leibniz-ipn.de.
- After logging in, select the project DARIUS_BETA.
- To annotate, click on Annotation on the left and select a text.

The following settings should be made manually before the first annotation:

1. Click on the cogwheel (**Preferences**) in the centre of the screen.
2. Set the **editor** to **brat** (**wrapping @ 120 chars**) (for better readability).
3. **Page size**: This setting shows the number of lines per page, enter the number **35.**
4. In **Annotation Layer Preferences**, it is advisable to set the palette value of each layer to dynamic pastel to increase clarity.

 After completing an annotation, finalise the text with the "**Finish Document**" button. Please note that no further editing of the text is possible after confirmation.

4 CONTENT ZONE-Layer

This layer captures the framing and structuring elements of the text. The annotation is based on the guidelines for content zones (Peldszus & Stede, 2017). Content zones have already been reliably annotated and automatically predicted for scientific articles as demonstrated by Teufel and Moens (2002). The three content zone tags introduction, main part and conclusion are annotated. The identification of the content zones is based on the guidelines for writing argumentative texts, which are prescribed in the subject requirements for German SEKI/II.

4.1 Content Zone-Tags:

- **Introduction**: An introduction contains at least one sentence that describes the topic of the text and, for example, the task, the possible options for action or your own position or major claim. It is placed at the beginning of the text and does not contain any arguments. ("*In the following I will...*", "*I am in favour of ABC and will justify this in the following*").
- **Main part**: The main part contains the arguments that should justify your own position in the introduction or conclusion.
- **Conclusion**: The conclusion weighs up the arguments made and derives your own position based on them. Typically, it can be identified by a summarising or concluding word. ("*Summarising*", "*Concluding*", "*Therefore*").

4.2 Directives:

- Each tag must consist of at least one complete main sentence.
- Draw the tag across the entire content zone and do not select each sentence in the zone individually.
- The main part is placed between introduction and conclusion.
- If the major claim immediately follows the introduction, include the sentence to the introduction.
- A major claim at the beginning of the text can be an introduction, but does not have to be: "*I decide on the solar park because it is very environmentally friendly and not very expensive."* Is marked as the main part, for example. The decisive factor would be, for example, whether an argumentation already begins, e.g. by discussing a topic.
- A major claim at the end of the text is only marked as a conclusion if it is accordingly marked with a summarising/concluding word: "*All in all, hydropower plants should be promoted as energy converters."* is marked as a conclusion. "*Hydropower plants are the best*." without further content would be marked as the main part.
- If the conclusion takes a stance but introduces new arguments or claims, this is identified as the main part. Example: "*Although I am in favour of the hydropower plant, we should know where the water comes from. As long as nothing and nobody is exploited for it, it is a good alternative. The plant is a good option.*" This can be indicated if the sentences would function effectively when moved to the main part.
- Extremely short texts, like one sentence, should be marked as the main part. If there are multiple sentences, the annotator should examine whether there is an introduction and if the text was cutoff within the main part, for example.

5 ARGUMENT-Layer

In this section, the individual arguments are labelled in segments according to the guidelines of Stab, Miller, and Gurevych (2018). Ideally, an argument is introduced by a claim and usually addresses a specific topic, in this case, a topic from the material at hand. The scope of an argument usually ranges from outlining the advantages and/or disadvantages of one topic, up until the argumentation addresses the substance of a new issue.

5.1 Topic:

Marks which topics are present in the argument.
The topic-tags mark whether the text refers to the materials for the task and how many of these materials were utilized. At the same time, the content of the argument is recorded. It may be possible to record some of these topics using a keyword search or expert system.

5.1.1 Topics_Automotive-Tags:

- **Operation**: Refuelling time and range.
- **Noise Emissions**: Noise level of the engine during operation.
- **Energy Density**: Mass-related energy density.
- **Availability**: Market maturity/availability of vehicles with the drive under discussion.
- **Greenhouse Gas Emissions**: Greenhouse gas emissions during the production of the vehicle.
- **Efficiency**: Overall efficiency.
- **Other**: Topics that do not originate from the materials or that cannot be assigned.

5.1.2 Topics_Energy-Tags:

- **Efficiency**: Overall efficiency.
- **Yield:** Electricity production in gigawatt hours per year (GWh).
- **Local Emissions**: Noise in decibels, shade/light etc.
- **Price**: Cost of providing/producing the power converter.
- **Lifetime**: Average duration of usability of the power converter.
- **Greenhouse gas emissions**: Greenhouse gas emissions during use.
- **Other**: Criteria that do not originate from the materials or that cannot be assigned.

5.1.3 Display in Inception

As the texts are consistently assigned to a single category (transport/energy), the topic-tags in Inception are summarised to simplify the editing process:

- **Efficiency**
- **Yield/Energy Density**
- **Local Emissions/Noise Emissions**
- **Price/Operation**
- **Lifetime/Availability**
- **Greenhouse Gas Emissions**
- **Others**

5.1.4 Directives:

- Arguments and topics are only annotated in the main part.
- If multiple topics are directly compared to each other, these are considered as a single argument and not multiple arguments.
- Unfinished sentences at the end of the text are marked as a single argument. As a general principle, all tags should be tagged with "Not applicable" etc., with the exception of the topic-

tag. Example: "*In the case of noise emissions, the*" This would be annotated as follows: Noise Emissions; Unclear position; Not applicable; Not applicable; Unintelligible.

- Texts that are not orientated towards the task, e.g. discuss other aspects of climate change or the meaning of the task in general, are nevertheless marked in full. The topic would generally be "Other", Accuracy and Adequacy should be annotated here with "Not applicable". Example: "*The real problem is not deciding what to build, but when. It's all happening far too slowly.*"
- Only existing topics are marked, not non-existing ones.
- If several topics are mentioned within an argument or it is evident that they are implicated (e.g. reference is made by pronouns), all the mentioned topics are also marked as present.
- Important: The PRICE topic only applies to the energy task. If the price of e.g. accumulator-powered cars is mentioned in a text of the automotive task, this is marked as OTHER.

5.2 Position

Annotation of the selected option and position on the options for action of the respective, following an annotation scheme similar to the one used by Stab et al. (2018). Their scheme achieved an inter-annotator agreement of 0.72, as measured by Cohen's kappa.
A good argumentation should address all positions and, if necessary, also include arguments opposing the major claim.

5.2.1 Position-Tags

Which option for action does the argument refer to? (Options for action are labeled depending on the task).

- **Option A Hydrogen/Hydropower Pro/Con:** Argument refers to hydrogen for the automotive task and to hydropower for the energy task and positions itself in either a positive or negative, supporting or weakening way.
- **Option B E-Fuels/Solar Park Pro/Con:** Argument refers to E-Fuels in the automotive task and to solar park in the energy task and positions itself in either a positive or negative, supporting or weakening way.
- **Option C Accumulators/Wind Park Pro/Con:** The argument refers to accumulators in the automotive task and to wind park in the energy task and positions itself in either a positive or negative, supporting or weakening way.
- **Unclear:** Option for action is mentioned, but position is unclear. "*The price of a hydropower plant is around €59 million. However, the hydropower plant has the highest efficiency of all but also the highest CO2 emissions.*"

5.2.2 Directives:

- An argument can be for or against different positions at the same time (e.g.: Pro|A + Pro|B)
- The tag is clicked (e.g. option A Hydrogen/Hydropower) and the Pro/Con tag is selected.
- If an argument adresses a negative topic (e.g. local emissions), the option that is described as the least negative is usually rated as Pro.
- Example: "*E-cars have a range of 400 kilometres*" mentions e-cars/rechargeable batteries, but does not include a position, so "Unclear position" is selected. On the other hand, "*Electric cars have a range of 400 kilometres, but hydrogen cars have a range of 800 kilometres*" compares two drive systems, so a Pro and a Con position can be derived here.

- Pro A does not automatically mean Contra B/C. The position must be stated implicitly or explicitly. Implicit declarations can be done, for example, by using pronouns like "it", "both", or "others".
  Example: "*Hydrogen is more efficient than the others*.", i.e. Pro A/Contra B/Contra C.
  Example: "*Hydropower has the best efficiency*." = Pro A/Contra B/ Contra C
  Example: "*It is better than e-fuels*." If the pronoun "it" clearly refers to something mentioned in the previous sentences, this option is categorised as Pro.

5.3 Accuracy

Technical correctness of the argument (see Heitmann et al., 2014).
The extent to which a fact from the given material is correctly reproduced and utilised should be annotated. The factual accuracy of content that extends beyond the given material will not be verified (Not applicable). If an argument is identified as incorrect, the student should be directly informed so they can revisit and study the material again.

5.3.1 Accuracy-Tags:

- **False**: Technical terms, data or contexts are used incorrectly: "*The hydrogen battery can be charged faster than an accumulator.*“
- **Correct**: Technical terms and contexts were used correctly.
- **Not applicable**: The argument does not refer to the material; the argument consists only of at least one subjective claim, the accuracy of which cannot be assessed. Example: "*I choose rechargeable batteries because I think Tesla is cool.*"

5.3.2 Directives:

- If a value is quoted incorrectly, the argument is marked as "false", even if the argument itself is reasonable. Example: "*Wind and solar parks are far below this with an efficiency of 25% and 21% respectively*". Although the argument is appropriate, wind farms have an efficiency of 45%.
- If a topic has a range (e.g. "70 - 90 %"), it is sufficient to state the lower or upper part of the range (e.g. "70 %") in order to annotate it as „correct".
- Rounded values are also marked as "correct".
- The argument is marked as "false" if the use of inappropriate verbs (example: "*In the solar or wind farm, a large proportion of the energy is used in energy recovery.*" The correct word in this case would be "delivered" instead of "used"), or an incorrect explanation of the topic (example: "*Accumulators have an efficiency of 70%, which means that 70% of the electrical energy is renewable*.") indicate a lack of understanding, even if the values are correct.
- Spelling errors that alter the intended meaning are also marked as "false". Example "*Wildpark*" instead of "*Windpark*".

5.4 Adequacy

Appropriateness or relevance of the argument. Is the information used relevant to the actual argument or reasoning? Was the information used accurately interpreted, facilitating logical conclusions? Measuring adequacy helps to determine the level at which feedback is necessary. If the students are already struggling with the task itself, or they have not thoroughly read it, giving more in-depth feedback on the quality of argumentation may not be beneficial.

5.4.1 Adequacy-Tags:

- **Adequate**: Example: The long charging time of rechargeable batteries was interpreted as an argument in favour of rechargeable batteries.
- **Inadequate**: Example: Values are stated correctly, but the conclusion drawn from this contradicts the hierarchy of values: Efficiency of A is in the middle, but it is stated that B is best.
- **Not applicable:** No argument, or a given argument does not refer to the materials and cannot be assessed in terms of adequacy. "*With all three options, it depends on the geographical circumstances where something is effective*."

5.4.2 Directives:

- Inadequate if: incomprehensible, illogical or contradictory conclusions are drawn (e.g: "*It is not only the low overall efficiency of 15-20% that speaks in favour of e-fuels, which shows how efficiently the electrical energy of renewable energies is used for driving.*" The efficiency was explained correctly, but the wrong conclusion was drawn from it) and/or topic were misunderstood ("*The mass-related energy density is an important topic, as it is important to look at the extent to which cars need and consume energy*."). The energy density does not provide information about a car's consumption.).
- Adequate if: the argument is technically false (e.g. a value was quoted incorrectly), but the error does not change the argument itself (e.g.: "*The hydropower plant is between the other two energy converters with 11,000t CO2 equivalents*").
- Arguments that draw a false conclusion are NOT ADEQUATE for adequacy (but can be technically correct). Example: "*Even considering the CO2 equivalents of just 12,000 t (3200 more than a wind farm and 23,000 less than a solar park), this once again illustrates the enormous popularity of hydropower plants*." The values are accurately quoted, but the conclusion drawn from them (supporting hydropower) is illogical.

5.5 Clarity

Clarity refers to the use of precise, unambiguous language that steers clear of unnecessary complexity and remains focused on the topic at hand (Aristotle, 2007). An argument is considered unintelligible if it is not comprehensible. If the argument has to be read several times before it is understood, it is complex. An example of an argument that is difficult to understand could be one that heavily relies on nested subordinate clauses.

5.5.1 Clarity-Tags:

- **Understandable:** the argument can be understood on the first or second reading.
- **Difficult to understand:** The argument needs to be read more often until it is understood. "*In terms of lifespan, the hydropower plant is again the best because they expect up to 80 years, with the others it is significantly less, although it is one of the most expensive at 59 million euros, but it has the second lowest greenhouse gas emissions at 12,00 .* "The sentences are highly convoluted and confusing due to the lack of commas, which is why the argument is annotated as "difficult to understand"
- **Unintelligible:** The argument makes no sense; even after reading it several times, it is not clear what is intended. Reasons can be due to spelling, grammar or content. "*Here it can be observed that the hydropower plant has by far the highest efficiency at 70-90%. Then come the wind farms, which have an efficiency of 25-45%, followed by the solar farms, which have an efficiency of just 21%.*" Due to spelling mistakes that change the meaning, the argument can only be understood through interpretation and is therefore annotated as "Unintelligible".

5.5.2 Directives:

- Grammar and spelling mistakes should only be considered if they alter the meaning of the text.

6 STRUCTURE (TAP)-Layer

Annotation of the arguments of the previous step in their components according to Toulmin's Argumentation Pattern (TAP), based on the TAP interpretation by Riemeier et. al (2012). TAP is suitable for identifying the structure of arguments, regardless of their content. The fundamental elements include claim, data, and warrant (explained further below). The more these elements are used in conjunction, the higher the structural quality of the argument. For instance, if a text only contains claims, feedback can be provided to incorporate relevant data. If the arguments already consist of claim and data, it can be suggested that the connection between these elements (warrant) needs to be clarified. Texts that deviate from the task and discuss unrelated topics are also annotated using TAP. It can be inferred that such texts may contain minimal or no data, but claims, warrants, and rebuttals can still be identified and recorded.

6.1 TAP-Tags:

- **Claim**: Assertion that characterises the position taken. "Hydrogen is the best option, ..." An explicit agreement (or disagreement) with a statement that the student is convinced of (Riemeier et al., 2012).
- **Data**: Fact that justifies a claim: "...*because accumulators have a charging time of 30 minutes*...". Data proves a claim or explains that something is a certain way.
  →Factual information (from the available materials) is mentioned, which refers to a specific claim (Riemeier et al., 2012).
- **Warrant**: Requires a claim and a data and/or optionally a rebuttal. Important: the claim does not need to be part of the argument and can, for example, be the major claim of the content. Aspect that explains to what extent a data supports a claim: *"...and are therefore much less practical in everyday life...*". Warrant explains why something is one way or another. It not only indicates that a Claim and Data are linked, but also explains how they are connected, e.g. explaining why it is positive or negative that a certain value is mentioned in the data. Simply linking a claim and data with a "because" ("*I am in favour of hydrogen because it has the highest values in topic 1.*") is not sufficient (Riemeier et al., 2012).
- **Rebuttal**: An objection to a presented data and/or warrant: "*Although the price is a counter-argument, if you calculate the price of a wind farm or solar park over its lifetime, you get almost the same result*." "*Wind farms and hydropower plants emit noise and infrasound, but this is not very harmful to people*."
  → One element of justification may be contradicted, but it is not necessary to object to the entire underlying claim (Riemeier et al., 2012).
- **Not applicable:** the sequence cannot be recognized as part of an argument or does not fulfill the purpose of claim/data etc. Example: "*Let's move on to the next topic*." "*Now consider the individual topics listed in the table on the left*...".

6.2 Directives:

- TAP is marked at subordinate clause level and only in the main part.
- Facts are only annotated as "data" if the information is based on the material. Data that goes beyond the material should be annotated as "claim".

- Facts that are stated too vaguely/roughly are annotated as "claim". "*The hydropower plants also have a fairly promising annual yield.*", "*In the topic of greenhouse gas emissions, the hydropower plant is in the sound midfield*."
- If 2 elements appear to apply equally, the higher element in the hierarchy is selected. Claim <- Data <- Warrant/Rebuttal.
- An element is often both data and claim, i.e. it has an opinion but is based on facts. In this case, the hierarchically higher element, i.e. „data“, is selected.
- If a sentence (part) has a structural explanatory function, it is annotated as a "warrant", even if there is no additional content. "*Accumulators are available in mass production. Availability plays a major and significant role. Because it is important how much and how quickly the cars can be brought to market.*" The last sentence explains why availability is important and is therefore annotated as "Warrant".
- No rebuttal if it is the beginning of an argument.
- No rebuttal if options are weighed up within a topic. Example: "*Furthermore, they produce 39 GWh per year, which is significantly more than a solar park, but slightly less than a wind park*." The last part is not annotated as a rebuttal.
- If something is proven from the material but the content is incorrect, it should be marked as a claim.
- Questions such as "*How much electricity can they produce per year?*" are annotated as "not applicable".

7 DECISION-MAKING STRATEGIES-Layer

Major Claim: refers to the author's final position on the given topic and is the root of the argumentation, upon which the author bases their decision (Stab & Gurevych, 2015). Feedback can be given to write a major claim or to take a summarising position. If a major claim is given, the decision can be justified via a trade-off strategy, a cut-off strategy or unfounded. A trade-off strategy is often an indication of a more complex argument, as it involves weighing up and comparing arguments. (Eggert et al., 2009). The feedback depends on whether the major claim was formed in a compensatory or non-compensatory manner (see below).

Note: A major claim is always structurally a claim, even if it is in the introduction/main part.

7.1 Major Claim-Tags:

- **Major Claim present:** The argumentation either begins or concludes with a clear stance on the options for action: "*For these reasons, I think that accumulators should be specifically promoted as an energy source*".
- **Major Claim not present:** The final position of the argumentation is not explicitly stated.

7.2 Decision-Making-Strategy-Tags

- **Trade-off** (compensatory): This strategy is formed by considering all the arguments presented, weighing up at least one positive and one negative topic from the material of a position, or balancing the entirety of the factors of one position against those of the other two positions E.g.: "*Despite the high price, the hydropower plant outweighs the others in terms of efficiency, service life and price, which is why I would ultimately support it*."
- **Cutoff** (non-compensatory): One topic/reason or a collection of topics is regarded as being particularly important. The major claim is therefore formed from one argument that outweighs all others. E.g.: "*Hydropower plants are clearly the better choice, as they outweigh all others in*

terms of both lifespan and effectiveness." The main difference to the trade-off is that the topics are not weighed against each other positively and negatively for the decision.

- **Unfounded**: is annotated if no strategy can be identified, no reason is given for the decision. *„In conclusion, I decide in favour of hydropower plants“*.

7.3 Rules:

- The major claim can be marked several times (typically at the beginning and end of the text).
- The major claim may also be found in the main part of the text. If there is no major claim, no strategy is annotated.
- The part of the text containing the major claim is annotated.
- The decision strategy is identified depending on the position of the major claim: If the major claim is in the introduction, only the introduction is considered; if it is found in the conclusion, only the conclusion considered. However, if the major claim is in the main part, only the sentence of the major claim is taken into account when determining the strategy. The reason for this is that a major claim in a strong argument should not appear in the main part; experience has shown that this is a sign of a non-existent/unfinished introduction/conclusion.

8 References:

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9 Appendix a) Task: The future of automobility!

Greenhouse gas emissions from passenger transport are to be drastically reduced in order to achieve climate neutrality. Politicians are therefore calling for a ban on the sale of new petrol and diesel cars starting in 2035.

Specifically, it is being discussed whether a shift to cars with

1. accumulators,
2. hydrogen or
3. e-fuels (synthetic fuels)

should be specifically promoted as energy sources.

Discuss the energy sources mentioned against the background of climate change on the basis of at least three criteria from the materials on the next page. Strengthen your arguments by explaining the relevance of the criteria for your assertions.

You have 15 minutes to read the materials and write your argumentation. You will then receive feedback and a further 10 minutes to revise.

Hints for a very good argumentation:

In your argument, you should

- clearly take a stand in favor of one of the energy sources,
- consider all three energy sources for each topic you mentioned,
- support the significance of the facts with reasons and
- compare the importance of the criteria for your decision.

9.1 Materials

9.1.1 Description of the energy converters

All three energy sources are considered climate-neutral if electrical energy from renewable sources is used.

- **Accumulators** are rechargeable electrochemical cells that are currently manufactured on the basis of lithium compounds. Accumulators can be charged by connecting them to the mains. Accumulators can only be used in specially designed cars with an electric motor. Accumulators are permanently installed in these cars in order to operate an electric motor. No substance is released during the chemical reaction that takes place in the accumulator.
- **Hydrogen** is a pure substance that exists as a gas under standard conditions. Hydrogen is produced by means of water electrolysis. Hydrogen can only be used in specially designed cars with a fuel cell and electric motor. In these cars, hydrogen is transported in pressurised tanks and converted with oxygen in a fuel cell to power an electric motor. The chemical reaction that takes place in the fuel cell produces water as a product.
- **E-fuels** are mixtures of hydrocarbons that exist as a liquid under standard conditions. E-fuels are produced from hydrogen and carbon dioxide extracted from the atmosphere. E-fuels can be used in conventional cars with combustion engines. In these cars, e-fuels are transported in liquid tanks and converted with oxygen in combustion engines. One of the products of the combustion reaction that takes place in the engine compartment is carbon dioxide. Overall, the same amount of carbon dioxide is removed from the atmosphere during synthesis as is released during combustion.

9.1.2 Comparison of the energy converters:

Table 1. Decision-making matrix

Topic	**Accumulators**	**Hydrogen**	**E-fuels**
Energy density	~ 0,88 MJ/kg	~ 120 MJ/kg	~ 46,4 MJ/kg
Efficiency	64 – 70 %	25 – 28 %	15 –20 %
Greenhouse Gas Emissions	~ 13,1 t CO_2 equivalents	~ 13,6 t CO_2 equivalents	~ 7,8 t CO_2 equivalents
Availability	Mass production	Mass production	Mass production
Operation	Charging time: 30 min Range: < 400 km	Charging time: 30 min Range: < 400 km	Charging time: 30 min Range: < 400 km
Noise emissions	~ 57 dB at 30 km/h	~ 57 dB at 30 km/h	~ 61 dB at 30 km/h

9.1.3 Topic 1: Energy density

The energy density indicates how much energy can be stored per mass of a substance or system. The energy density is the decisive factor for the mass of an energy storage device (in this case a tank or accumulator). The higher the mass-related energy density, the more energy can be stored for the same mass. The use of energy sources with a higher energy density could therefore enable the construction of cars with a lower mass or greater range, among other things.

9.1.4 Topic 2: Efficiency

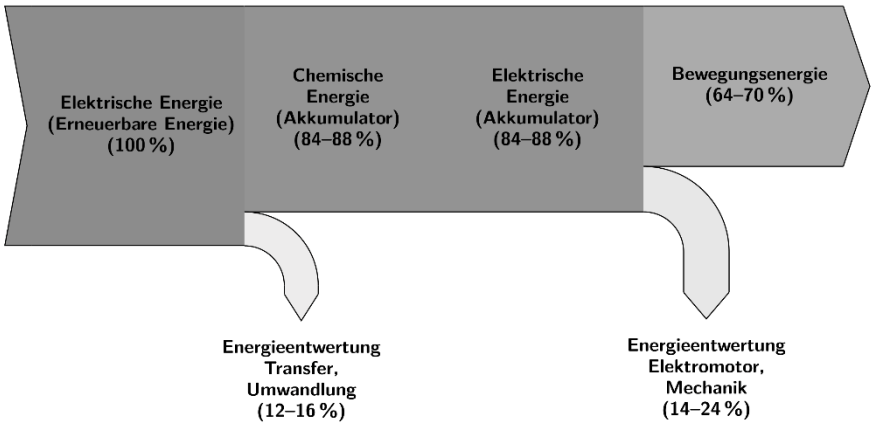
The overall efficiency quantifies how efficiently the electrical energy from renewable energies is utilised for driving. The entire process from the provision of energy (e.g. by wind turbines) to its utilisation for driving is included in the calculation of the overall efficiency (more precisely: ratio of "utilised" kinetic energy and supplied electrical energy). The higher the overall efficiency, the less energy is released into the environment during the process. The lower the overall efficiency, the more electrical energy must be supplied to travel the same distance.

In accumulator-powered cars, the electrical energy is used directly to charge the accumulator, which then powers the electric motor.

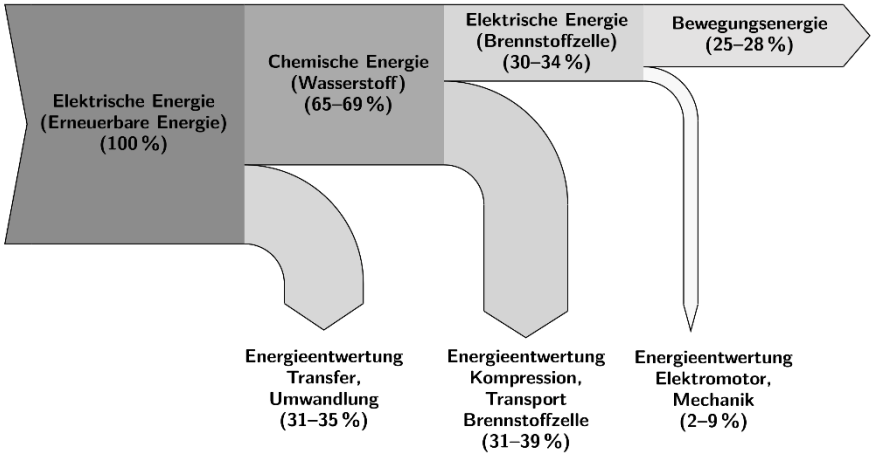
In hydrogen-powered cars, electrical energy is used to produce hydrogen through water electrolysis. The hydrogen then reacts with oxygen in the car's fuel cell, converting chemical energy into electrical energy that powers the electric motor.

In cars powered by e-fuels, hydrogen provided by water electrolysis is converted into e-fuels using carbon dioxide filtered from the ambient air. These e-fuels are then used to power the car's combustion engine.

Akkumulator



Wasserstoff



E-Fuels

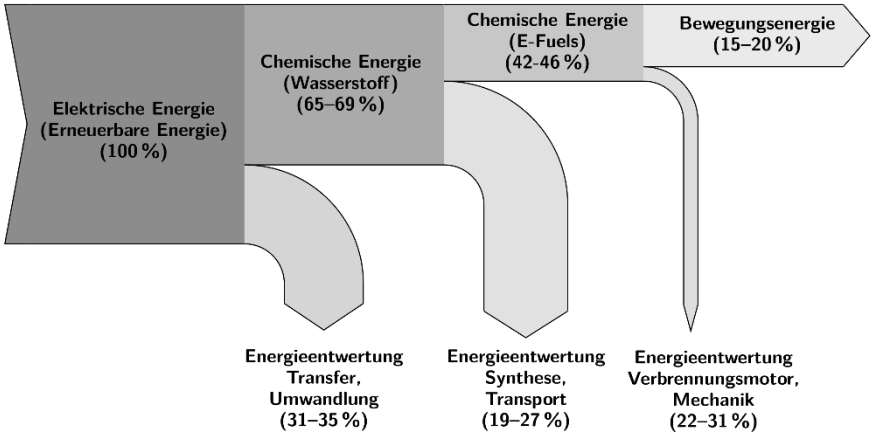


Abbildung 1 Energiekette je Energieträger

9.1.5 Topic 3: Greenhouse gas emissions from production

CO_2 equivalents are a measure used to standardize the climate impact of different greenhouse gases, expressed in tonnes (t).

Car production is an energy-intensive process that emits greenhouse gases. The calculation of these emissions includes those from the extraction and preparation of raw materials and their subsequent processing in the car manufacturing process.

In accumulator-powered cars, a large proportion of greenhouse gas emissions is caused by the processing of lithium and the production of the accumulator. The larger the accumulator, the more greenhouse gases are produced. For small and medium-sized cars, the production of a hydrogen-powered vehicle with a fuel cell results in more greenhouse gas emissions than a car with an accumulator (refer to table). However, the production of a luxury-class car with a accumulator generates more greenhouse gas emissions (18.6 tonnes of CO_2 equivalent) than a hydrogen-powered vehicle with a fuel cell (13.5 tonnes of CO_2 equivalent).

In the case of hydrogen-powered cars, the majority of greenhouse gas emissions are caused by the processing of platinum and the production of the fuel cell. The additional accumulator is much lower in this case.

In the case of cars powered by e-fuels, the majority of greenhouse gas emissions are attributable to the processing of platinum and palladium and the manufacture of the combustion engine and the catalytic converter.

9.1.6 Topic 4: Availability

Accumulator-powered cars are already mass-produced and sold by almost all manufacturers.

Hydrogen-powered cars, are only being further developed and produced by a few manufacturers and only in extremely limited numbers. Only two different models are available for sale in Germany. At present, many manufacturers are not developing hydrogen cars.

E-fuels can be used to power all conventional cars with combustion engines. These cars are being further developed, produced, and sold by almost all renowned manufacturers on a grand scale. Furthermore, pre-owned cars can also utilize them.

9.1.7 Topic 5: Operation

Important factors for the operation of a car are its range and the refuelling and charging time. On average, people in Germany make three trips per day by car, covering between 30 and 40 kilometres. Only around 1% of all car journeys are longer than 100 kilometres. On average, cars are parked for more than 23 hours a day, with over 20 of those hours spent at home.

9.1.8 Topic 6: Noise emissions

Cars that run on accumulators and hydrogen produce the same level of noise emissions. At low speeds, below 30 km/h, these emissions are less than 57 dB. At higher speeds, the noise generated by rolling friction and wind resistance predominates.

Cars that operate on e-fuels produce noise emissions of approximately 61 dB at low speeds of less than 30 km/h. This is partly due to factors such as rolling friction, wind resistance, and the noise generated by the combustion engine. Higher noise emissions typically occur during acceleration, for instance, at traffic lights. As speeds increase, the noise generated by rolling friction and wind resistance becomes increasingly prominent.

Noise is a stress factor and can have negative impacts on health, as it activates the autonomic and hormonal systems. Road noise can lead to sleep disorders, elevate blood pressure, and increase the risk of heart attacks by up to 20-30%

9.1.9 Topic 6: Local emissions

Local emissions	None	Water	Carbon dioxide, nitrogen oxides & soot particles

Accumulator-powered cars are considered locally emission-free.

Cars that run on hydrogen emit water. Even if the water vapor in the car only partially condenses, this has no significant impact on the climate.

Cars that run on e-fuels emit carbon dioxide, soot, and nitrogen oxides, among other substances. These emissions can lead to cardiovascular diseases and promote the development of lung cancer if they are heavily concentrated in the air.

10 Appendix b) Task: Concrete energy transition!

Greenhouse gas emissions from the energy sector are to be drastically reduced in order to achieve climate neutrality. The politicians of a district in northern Germany are therefore calling for the district's energy requirements to be covered entirely by renewable energies.

Specifically, it is being discussed whether the construction

1. of a wind farm,
2. a solar park or
3. a hydropower plant

should be specifically promoted as an energy converter.

Discuss the energy converters mentioned against the background of climate change on the basis of at least three criteria from the materials on the next page. Strengthen your arguments by explaining the relevance of the criteria for your assertions.

Hints for a very good argumentation:

In your argument, you should

- clearly take a stand in favor of one of the energy sources,
- consider all three energy sources for each topic you mentioned,
- support the significance of the facts with reasons and
- compare the importance of the criteria for your decision.

10.1 Materials

10.1.1 Description of the energy converters (power plants)

All three energy converters (power plants in everyday language) are classified as renewable energies as they do not require fossil fuels or nuclear fuels. The planned energy converter should be able to supply 12,000 households with electricity. The energy requirement of 12,000 households is estimated at 15.6 gigawatt hours per year (GWh/a).

The three energy converters have the same theoretical output, i.e. if they could be operated "around the clock" at full capacity.

- **Wind farm**: The planned wind farm is to be built on land and comprises two wind turbines (wind turbines). Wind turbines use a generator to convert the kinetic energy of the wind into electrical energy.
- **Solar park**: The planned solar park (ground-mounted photovoltaic system) is to be built on land and comprises 25,000 solar modules. Solar modules consist of monocrystalline silicon solar cells and convert radiant energy from the sun into electrical energy.
- **Hydropower plant**: The planned hydropower plant is to be built on a nearby river. The river would have to be dammed and regulated by a weir. A hydropower plant uses turbines to convert the kinetic energy of the water into electrical energy.

10.1.2 Comparison of the energy converters:

Table 2. Decision-making matrix

Topic	**Wind farm**	**Solar park**	**Hydropower plant**
Efficiency	45 %	21 %	70 - 90 %
Annual yield	40 GWh per year 4.000 full load hours	19 GWh per year 1.900 full load hours	39 GWh per year 3.900 full load hours
Local emissions	Noise Shadows	None	Noise
Service life	20 years	30 years	80 years
Price	€14 million	€6 million	€59 million
Greenhouse gas emissions from production, operation and dismantling	8.800 t CO_2 equivalents	35.000 t CO_2 equivalents	12.000 t CO_2 equivalents

10.1.3 Topic 1: Efficiency

The efficiency indicates how efficiently the energy converter works. It indicates the ratio of the electrical energy fed into the power grid and the energy supplied (kinetic energy of the wind, water or solar energy) and is therefore always less than 100 %. The higher the efficiency, the less energy is released into the environment during the process. The energy chains for the three energy converters are shown below.

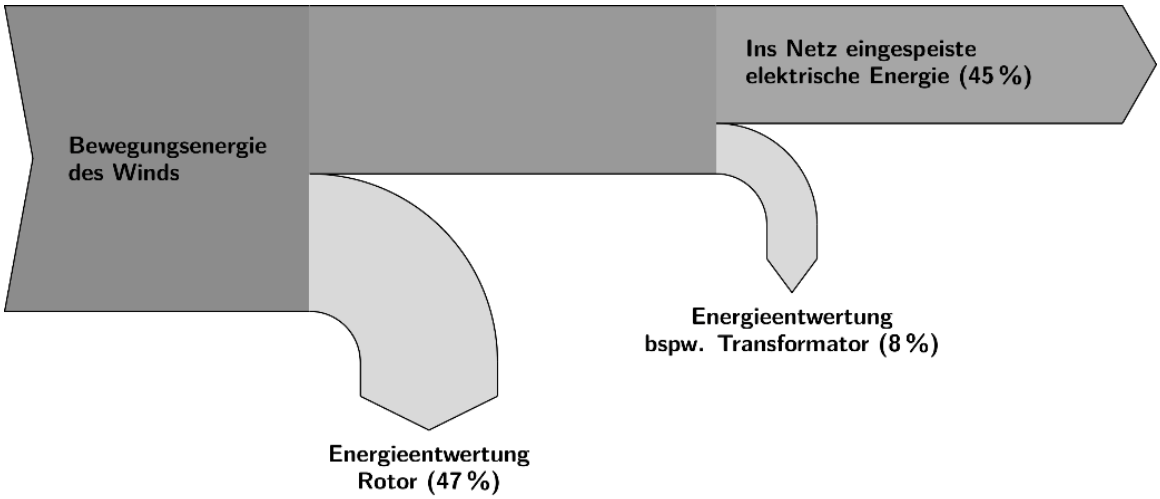


Illustration 2 Energy chain wind farm

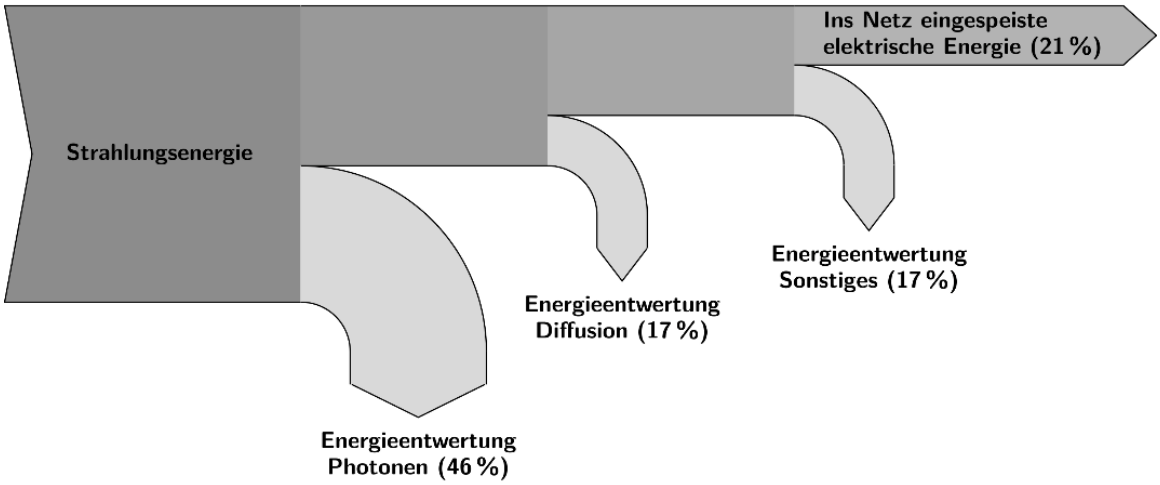


Illustration 3 Energy chain solar park

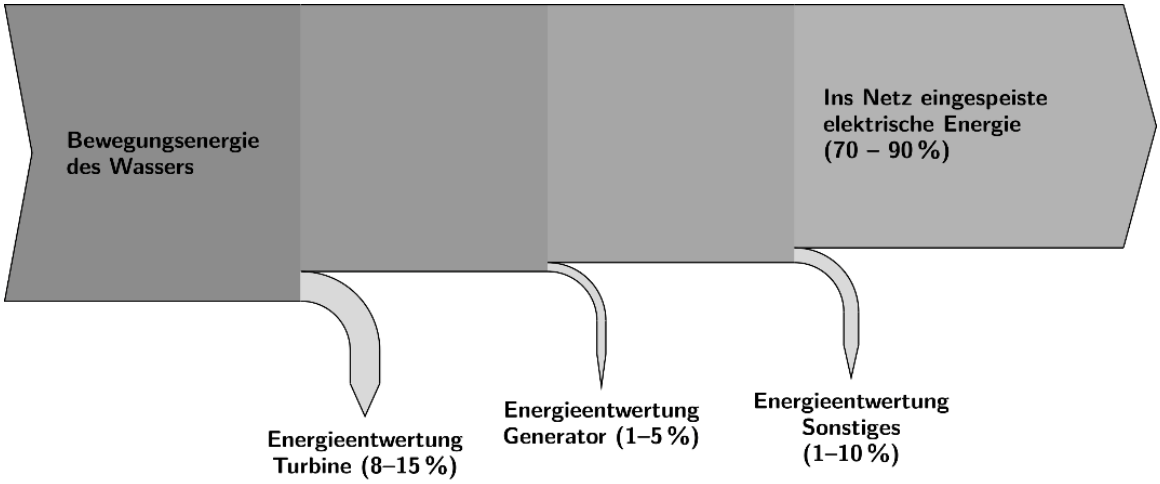


Illustration 4 Hydropower plant energy chain

10.1.4 Topic 2: Annual yield

The forecast annual yield depends on the number of full-load hours as well as maintenance work and operational downtimes, among other things. The higher the number of full load hours, the higher the annual yield.

The full load hours indicate the time for which a system would have to be operated at nominal output (here 10 MW) in order to achieve the assumed annual yield. The higher the number of full load hours, the more effectively the energy converter can be operated. The maximum number of full load hours in one year is 8760 hours.

Deviations from the maximum are due to restrictions, e.g. due to fluctuations in wind speed, solar radiation or water flow velocity.

The wind speed is subject to constant fluctuations. On the one hand, this is seasonal (higher wind speeds in fall to spring) and on the other hand, it varies from day to day. The fluctuations are not periodic and predicting the wind speed is imprecise. Wind speed minima cannot be compensated for by regulation.

The intensity of solar radiation is subject to constant fluctuations. The majority of these fluctuations are periodic, i.e. seasonal and dependent on the time of day. This part of the fluctuations can be easily calculated. A smaller proportion of the fluctuations is not periodic (e.g. shading due to cloud cover) and a prediction of this proportion is imprecise. Solar irradiation minima cannot be compensated for by regulation.

The water flow in a hydropower plant is only subject to negligible seasonal fluctuations, which can be attributed to higher precipitation in the fall to spring and snow melt. The amount of water flow can be regulated so that these fluctuations can be balanced out.

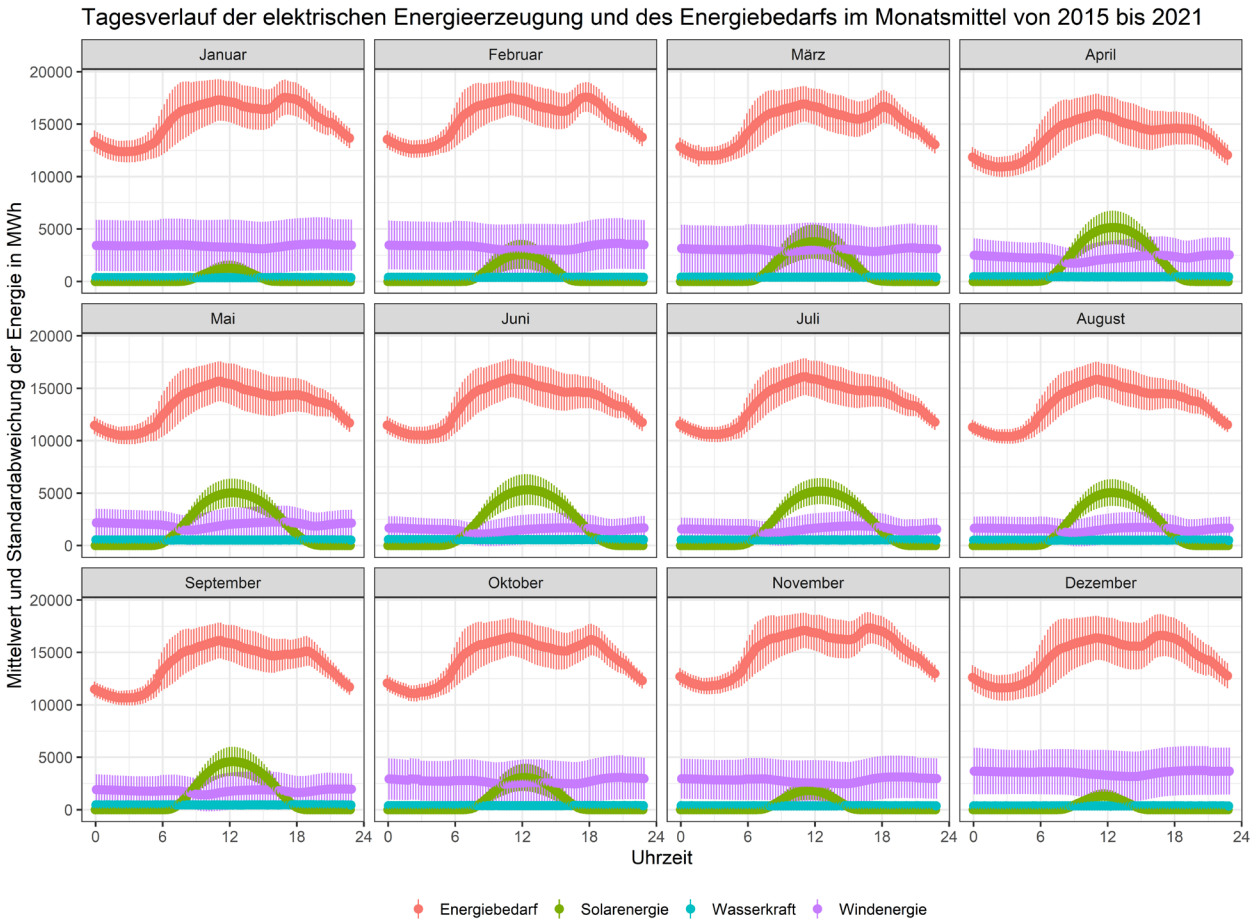


Illustration 5 Monthly average of daily curves

10.1.5 Topic 3: Local emissions

Local emissions such as noise or shadows can be perceived as disturbing.

Wind turbines and hydropower plants emit audible and infrasound. The disturbance caused by audible noise is perceived differently by individuals. Measurements at a distance of 1 km showed a volume of 30 dB for wind turbines and hydropower plants of the same type. Studies have shown that the majority of people surveyed in the vicinity of an existing wind farm or hydropower plant did not find the noise annoying.

Wind turbines also cause shading. The movement of the rotor blades creates a periodic shadow cast in sunlight, which can be up to 2,800 meters. The shadows cast are particularly disturbing for local residents and can cause headaches, nervousness, nausea and sleep disorders.

10.1.6 Topic 4: Service life

Due to wear and tear, the energy converters only have a limited service life.

Wind turbines are subject to high mechanical loads, which can lead to wear or, in the worst case, to the destruction of rotor blades and gearboxes, for example. However, the foundations of the wind turbines could be reused when the turbines are replaced .

Solar systems exhibit wear and tear and a reduction in yield of approx. 5% during their service life due to module failure.

Hydropower plants can be operated for up to 80 years before the structure needs to be replaced. However, the electrical systems such as the turbines need to be replaced after around 40 years.

10.1.7 Topic 5: Price

The investments are made up of the expenses ex works, the costs for transportation and installation, for the foundation and for the grid connection as well as other costs. The cost structure is largely determined by the size of the system and the local conditions. Due to new manufacturing processes, prices for solar installations are subject to a steady decline (by around 62 % between 2012 and 2019), meaning that the costs of the solar park could be lower than calculated .

10.1.8 Topic 6: Greenhouse gas emissions

CO_2-equivalent is a quantity for standardizing the climate impact of the various greenhouse gases and is given in the unit tonne (t).

Greenhouse gas emissions are calculated from production, operation and dismantling. Greenhouse gas emissions during operation are based on the expected service life. Greenhouse gas emissions during operation can be caused by maintenance work, for example.

Around 64% of the greenhouse gas emissions from the wind farm are attributable to production (42% of which is attributable to the tower and 27% to the generator and rotor).

Around 95% of greenhouse gas emissions from the solar park are attributable to production (83% of which is attributable to module production).

Around 64 - 76 % of greenhouse gas emissions from hydropower plants are attributable to their construction. In addition, water must be dammed for the operation of hydropower plants. Organic material decomposes at the bottom of the river due to a lack of oxygen, producing methane (a powerful greenhouse gas) which is released as it flows through the hydropower plant.