eSupplement

Alcohol consumption in Germany, health and social consequences and derivation of recommendations for action

Position statement of the German Nutrition Society (DGE)

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Table e1: Associations between alcohol consumption and non-communicable diseases and selected potential mechanisms of action

Table e2: Factors influencing the environmental sustainability of alcoholic beverages

Table e3: Indicators for assessing the environmental sustainability of alcoholic beverages

Table e4: Alcohol control policies from *Global Information System on Alcohol and Health* (GISAH) [139]

Table e1: Associations between alcohol consumption and non-communicable diseases and selected potential mechanisms of action

Non-communicable disease	Associations between alcohol intake and the disease	Selected potential mechanisms of action
Obesity	• The relationship between the consumption of alcoholic beverages and overweight or obesity is complex and contradictory [1]. • Type of drink (wine risk-reducing, beer and spirits risk-increasing), drinking habits and sex are factors that influence the relationship between alcohol consumption and body weight: in women, light to moderate alcohol consumption is associated with lower weight, while in men moderate consumption is associated with higher weight [2, 3]. • A systematic review with meta-analysis of cohort studies indicated no statistically significant associations [4].	• Alcohol has a very high energy-density, induces less satiety than solid food, inhibits fat oxidation and may stimulate food intake; metabolic and psychological mechanisms are not yet fully elucidated [5]. • The energy supplied by alcohol is often not compensated for by a reduction in food intake; a relatively low dose of alcohol may increase food consumption [6]: Stimulation of fat and protein intake is likely with low alcohol intake; lower carbohydrate intake with frequent, high alcohol intake [7]. • The influence of a genetic predisposition to obesity on the relationship between alcohol consumption and body size is unclear [8-10].
Cancer[1]	• Alcohol consumption increases the risk of cancer of the breast, mouth, pharynx and larynx, oesophagus (squamous cell carcinoma), stomach, liver, pancreas and colon [11–25]. • A risk-reducing association has been observed between the consumption of up to 30 g of alcohol per day and kidney cancer [13, 26]. • The increase in cancer risk with increasing average daily alcohol consumption is linear on an exponential scale; however, the magnitude varies with the type of cancer; overall, no threshold value can be determined for the effects of alcohol consumption on cancer risk [27, 28]	• There are several distinct biological pathways through which alcohol consumption may affect cancer risk. However, the exact mechanisms are often unknown and are likely to vary depending on the specific type of cancer. • The most important biological factor appears to be total tissue exposure to acetaldehyde [27], which has been classified by the IARC as a Group1 human carcinogen [29]; acetaldehyde impairs DNA replication while inhibiting DNA repair mechanisms and DNA methylation; reactive oxygen species formed as a result of alcohol consumption can lead to inflammation in the body, lipid peroxidation and consequently DNA damage [30]. • One-carbon metabolism and folate concentration are also affected by ethanol [30]; the induced folate deficiency can lead to aberrant DNA methylation profiles and thus influence cancer-related gene expression [29]. • Alcohol stimulates the absorption and metabolism of carcinogens and alters the composition of the gut microbiome in a way that increases aldehyde levels [29].

		• Alcohol can affect serum concentrations of hormones and associated signalling pathways, which may lead to an increased risk of breast cancer and possibly prostate, ovarian and endometrial cancer [27]. • Alcohol has a strong interaction with tobacco smoking, particularly with regard to its carcinogenic effects on the oral cavity and oesophagus, as alcohol acts as a solvent for tobacco carcinogens [27]; cigarette smoking and alcohol consumption have a synergistic effect in increasing the risk of cancer at several sites [31, 32]. • Genetic polymorphisms in alcohol metabolism genes lead to variations between individuals in potential carcinogenic effects or cancer risk [27, 33–37]. • Increasing insulin sensitivity (see diabetes mellitus) reduces the risk of kidney cancer; whereas insulin resistance is a risk factor for cancer, independent of other risk factors [27].
Cardiovascular diseases	• The relationship between alcohol consumption and cardiovascular disease is complex: low to moderate alcohol consumption has beneficial and adverse effects, also depending on age and the presence of comorbidities; heavy alcohol consumption increases the risk of a wide range of diseases and cardiovascular-related mortality [27, 38, 39]. • Beneficial effects of low to moderate alcohol consumption are primarily observed in ischaemic diseases, i.e. ischaemic heart disease and ischaemic stroke [39–43]; the protective effects of alcohol consumption on ischaemic cardiovascular disease may be overestimated due to bias in the comparison groups [40, 44]. • Chronic heavy alcohol consumption increases the risk of o hypertension [27, 45–47]; in women, no increased risk was found with low to moderate consumption [45, 46], o atrial fibrillation and flutter [27, 48]; for moderate alcohol consumption, an increased risk was found in men but not in women; for both sexes combined, no associations were found with low alcohol consumption [48],	• (Irregular) heavy alcohol consumption can have adverse effects on blood lipids (with an increased risk of coronary artery disease) and blood clotting (with an increased risk of thrombosis) as well as impairing the cardiac conduction system (increased risk of cardiac arrhythmia). Alcohol-induced acute or persistent hypertension and type 2 diabetes are risk factors for cardiovascular disease and mortality [49–53]. • Excessive alcohol consumption result in clinically significant changes in electrocardiogram (ECG) variables [54] and impaired endothelial function [55]; alcohol consumption is one of the modifiable risk factors for carotid atherosclerosis, which is a risk factor for stroke [56]. • Basic biological mechanisms underlying the beneficial effects on ischaemic diseases are favourable changes in several surrogate markers of cardiovascular risk, including higher levels of HDL cholesterol and adiponectin and lower levels of fibrinogen [51, 57]; moderate alcohol consumption also leads to a reduced risk of atherosclerosis due to alcohol-induced changes in the lipid profile and inflammatory parameters; heterogeneous results may be due to different drinking patterns or genetic influences, particularly ALDH2 polymorphism [27, 58].

	○ cardiomyopathy [27], ○ ischaemic heart disease [27], ○ stroke [27, 43].	• In addition to the health-promoting lifestyle associated with wine consumption, the phenolic compounds present in red wine are attributed with antioxidant and anti-inflammatory properties, which may reduce insulin resistance and the effects of oxidative stress. However, the health benefits of red wine on cardiovascular disease in humans have not been clearly elucidated. Furthermore, several litres of wine would have to be consumed in order to achieve a health-promoting amount [59, 60].
Liver diseases	• Alcohol consumption is a risk factor for liver disease (alcohol-related subtypes include alcoholic hepatitis, steatosis, steatohepatitis, fibrosis and cirrhosis); studies indicate a causal relationship between heavy alcohol consumption and an increased risk of liver cirrhosis and liver cancer [40, 27, 61, 62]. • A systematic review with meta-analysis indicates a positive association between alcohol consumption and the risk of mortality from liver disease [12]. • No increased risk of liver cirrhosis was observed with occasional alcohol consumption; however the heterogeneity of the included studies indicates the presence of additional effects of other influencing factors including genetics, diet, body weight, metabolic risk factors and lifetime drinking patterns [63].	• During the process of alcohol degradation in the liver, the formation of reactive oxygen species (ROS) occurs concomitantly with a reduction in antioxidant levels, particularly during the metabolism of ethanol by MEOS; results in alterations to the plasma and intracellular membranes, lipid peroxidation and the release of proinflammatory and profibrotic mediators [64]. • A decrease in the rate of fatty acid oxidation results in an accumulation of free fatty acids within the liver, as well as an accumulation of triglycerides within hepatocytes, and consequently hepatosteatosis [64]. • Alcohol-induced changes in the gut microbiome and the intestinal barrier result in deficiencies, e.g. in short-chain fatty acids and trace elements, which affect immune function and lead to an increased transfer of bacterial toxins from the gut lumen [65, 64]. • The risk of alcohol-induced liver cirrhosis is partly related to genetic factors [66]; several polymorphisms are therefore being studies in relation with the risk of liver cirrhosis [67, 68].
Diabetes mellitus	• Alcohol consumption may be beneficial or detrimental in relation to diabetes mellitus (all forms), depending on consumption habits and the population studied [27]. • Low to moderate alcohol consumption is associated with a reduced risk of type 2 diabetes [40, 69]. • The results on the relationship between the risk of the disease and high alcohol consumption are inconsistent: different publications indicate a higher risk of diabetes mellitus with chronic heavy alcohol consumption [40] or no significant	• Improved insulin sensitivity has been discussed as a potential mechanism of action [40]; with a greater risk-reduction in women [69, 71]. • There is also debate about to whether genetic factors, or the interaction between genetic and non-genetic factors, have an influence on the relationship between alcohol consumption and type 2 diabetes [72–78].

	associations between high total alcohol consumption and the risk of type 2 diabetes [69, 70].	
Dementia	• A risk-reduction for Alzheimer's disease and other dementias has been observed for low to moderate alcohol consumption [27, 79]; however, due to methodological limitations, it cannot be assumed that low to moderate alcohol consumption actually protects against dementia and/or cognitive decline [80]; a 22 % lower risk of dementia has been observed in individuals who abstain from alcohol [81]. • Heavy drinking significantly increases the risk of Alzheimer's disease and other dementias as well as cognitive decline [27, 79, 80]. • A systematic review with meta-analysis indicate a non-linear dose-response relationship between alcohol consumption and the risk of progression from mild cognitive impairment to dementia and an unstable linear dose-response relationship for mild cognitive impairment [82].	• Alcohol is neurotoxic and has structural and functional damaging effects on the brain [83–85], including the inhibition of N-methyl-D-aspartate receptors [11]. • The high concentration of ethanol during binge drinking may alter the oral microbiome; there is evidence that this may lead to the development of Alzheimer's dementia via changes in the permeability of the blood-brain barrier [86]. • Acetaldehyde may also contribute to the pathology associated with Alzheimer's disease, particularly in individuals carrying ALDH2*2 mutations [87]. • Mendelian randomisation studies have not yet provided sufficient evidence for a causal relationship between of alcohol consumption and cognitive performance or Alzheimer's dementia [88–90].

MEOS: Microsomal Ethanol Oxidising System; IARC: International Agency for Research on Cancer

[1] The World Cancer Research Fund is conducting research to establish the correlation between influencing factors, such as alcohol consumption, and cancer. The findings of this research are subject to regular update: https://www.wcrf.org/

Table e2: Factors influencing the environmental sustainability of alcoholic beverages

Factor	Influence
Agricultural production	• The environmental impacts of cultivating of raw materials containing sugar and starch, especially grapes, fruit, barley, rye and potatoes [91, 92], are primarily due to changes in land and soil use [93, 94]. • Ploughing up carbon dioxide (CO_2)-rich soils, such as grasslands and peatlands, releases climate-relevant gases such as CO_2 into the atmosphere [93]. • The cultivation of raw materials necessitates significant energy expenditure, primarily for the production of fertilisers and the preparation of land [93, 95]. • Fertilisers and pesticides have an impact on quality and economic yields on the one hand and they concomitantly contribute to biodiversity loss, eutrophication, and water contamination, etc. [93, 95, 96].
Processing of raw materials	• Processing into alcoholic beverages is product specific and can include mechanical, thermal and enzymatic processes [97, 98]. • In beer production, the initial step is the production of malt, which requires a high energy input, followed by the brewing process and bottling [99, 98]. • In wine production, mechanical and enzymatic processes predominate, encompassing crushing and pressing of the grapes, fermentation, bottling and subsequent storage [97, 100]; in red wine production, the mash is heated to extract phenols [97, 101]. • The production of spirits necessitates a substantial energy input due to the distillation process, followed by the maturation and storage of the products [101, 102].
Packaging	• Bottles made of green, white or amber glass or PET, cans made of steel or aluminium and coated cardboard packaging are used for packaging [103, 104]; to assess the packaging, the life cycle assessment of the packaging type should be considered, including the extraction of the packaging raw materials, production, logistics and disposal [105]. • The Institute for Energy and Environmental Research (*Institut für Energie- und Umweltforschung*, IFEU) has conducted life cycle assessments of beverage packaging for fruit juices and milk; in the overall assessment, composite packaging and deposit glass bottles showed significant advantages over PET bottles in the juice and nectar segment, while beverage cartons showed advantages over deposit glass bottles and non-returnable PET bottles in the fresh milk segment [105]. • The manufacturing and distribution processes for packaging materials are constantly evolving; in addition, and both the distribution channels and the recycling rate of the packaging play an important role. Consequently, it is not feasible to make generalised statements about the life cycle assessment of a particular type of packaging [106].
Transport	• The environmental impact depends on the mode of transport, the distance, the necessity for refrigeration and the weight of the product [107, 108]. • Motor vehicles such as lorries and cars the most commonly used forms of transport, though aircraft, trains and ships are also employed [109–111]; the use of trains and ships is considered to be environmentally preferable due to their lower environmental impact [107]. • In the context of transport, the type of packaging plays an important role due to weight-related physical properties; deposit glass packaging is heavier, which can limit the quantity transported per unit, or the higher weight results in higher emissions due to fuel consumption.

Table e3: Indicators for assessing the environmental sustainability of alcoholic beverages

Sustainability indicator	Examples of the impact of the production of alcoholic beverages on the sustainability indicators
Land use	• The cultivation of raw materials for alcoholic beverages necessitates the utilisation of land that has already been previously developed for agricultural purposes or even the ploughing up of original, native areas (e.g. by clearing, ploughing up peatlands, etc.) [93]. • The requisite area for cultivation varies according to the specific raw material: about 0.57 m^3/year is needed to produce one litre of beer, 0.53 m^3/year to produce one litre of wine and 0.89 m^3/year to produce one litre of whiskey [112]. • As land is an essential prerequisite for the production of raw materials, it is important to examine the economic and ecological criteria of conversion projects and to create new ecosystems, for example in the form of reforestation [93].
Soil and water protection	• In particular, nitrogen and phosphorus fertilisers are used in the cultivation of raw materials, which, if applied in excess, can endanger the quality of groundwater, lead to eutrophication and acidification of soils [113] and endanger the soil microbiome [114]. • The legal requirements of the Fertiliser Ordinance (*Düngemittelverordnung*) [115] are in place to prevent overuse. Thresholds for nitrate and phosphorus are set in the Groundwater Ordinance (*Grundwasserverordnung*) [116].
Biodiversity	• The utilisation of pesticides and herbicides is imperative for the protection of plants from predators and competition [117]; the employment of fertilisers and pesticides, in conjunction with other measures of agricultural industrialisation such as the eradication of hedges and other habitats have a negative impact on biodiversity [118]. • One pesticide frequently used in viticulture is copper, which can have toxic effects and a negative impact on human and soil organism health [117, 119, 120]; pH value, climatic and geographical conditions as well as organism-specific characteristics and copper resistance influence toxicity [121]. • A substantial proportion of raw material production for alcoholic beverages is conducted in monocultures (e.g. vineyards, fruit orchards, hops) which is a further contributing factor to the decline in biodiversity [122]. • Especially in steep vineyards, minimal tillage and the utilisation of ground cover can be conductive to biodiversity [123]; orchards, which provide raw materials for fruit wines and spirits, can also contribute to species and nature conservation [124].
Energy consumption	• Approximately 0.12 kWh is required to produce one litre of beer [125]; the energy input for wine varies between 0.4 and 2.1 kWh/l and depends on the organisation, size, location and production capacity of the winery as well as the type of wine [126]; spirits production requires an energy input of approximately 0.22 kWh per 750 ml bottle due to the energy-intensive distillation process [101, 127]. • Winery heating, cooling, ventilation and lighting are particularly energy-intensive, and the age and energy efficiency of the systems and equipment used also affect energy consumption [126].
Water consumption	• Green, blue and grey water[1] are included in the calculation of water consumption [128]. • The total water consumption for the production of one litre of beer is about 300 litres of water [128]; the consumption for the production of one litre of wine is between 600 and 1850 litres of water and, like the energy consumption, depends on a variety of factors [128–130]. • In addition to water consumption, the water stress index, which takes into account the impact of water use on water quality and quantity, must also be considered [131–133].
CO_2 equivalents	• The greenhouse gas balance is also referred to as the CO_2-equivalent footprint [93, 134] and takes into account the entire life cycle of a product [135]. • The CO_2 footprint of beer can vary between 0.4 and 1.5 kg CO_2 equivalents per litre [99, 112, 125, 136, 137]; for wine CO_2 emissions of 1 to 2 kg of CO_2 equivalents per litre were

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	calculated [100, 108, 112, 137, 138]; the production of one litre of spirits generates between 1 and 4 kg of CO_2 equivalents [102, 112, 127].

[1] Blue water is defined as the volume of groundwater or surface water used utilised in the manufacturing of products or foodstuffs. Green water refers to rainwater used. The term grey water refers to the quantity of freshwater required to dilute water pollution to such an extent that the water quality meets the legal or agreed requirements [128].

Table e4: Alcohol control policies from *Global Information System on Alcohol and Health* (GISAH) [139]

Measures	Concretisation
National policy	• National drinking guidelines • National legalisation to prevent illegal alcohol sales • National legalisation to prevent the illegal alcohol
Advertising and product placements Restrictions	• Restrictions on advertising and product placements on national and cable television, on the internet and national and local radio, in print media, at cinemas, in films/movies and at point of sale
Alcohol service/sale: Age limits	• Age limits on-premise service and off-premise sales
Use in public places	• Restrictions on alcohol use in public places
Community action	• Government support for community action
Drink driving	• Legal blood alcohol concentration (BAC) limits • Penalties for drink driving • Random breath testing (RBT) use • Sobriety checkpoints
Licensing requirements	• Licensing required for imports and exports of alcoholic beverages • Licences required for the production and retails sales, wholesale/distribution of alcoholic beverages
Price measures ans sales promotion	• Penalties for marketing infringements • Restriction of sales promotion from owners of pubs and bars (alcohol for free), from retailers (sales below cost) and from producers (parties, events)
Taxation measures	• Excise tax on alcoholic beverages • Duty paid or excise stamp on alcohol containers • Value added tax (VAT) on alcohol (%) • Taxation of ethanol production • Tax incentives for production no/low alcohol content beer
Monopolies	• Monopoly on imports and exports of alcoholic beverages • Government monopoly on production and retail sales, wholesale/distribution
Selling off-premise and on-premise	• Off-premise sales and on-premise sales restrictions: on days, on hours, on outlet density, places, at specific events, at petrol stations
Sponsorship	• Restrictions on the sponsorship of sporting events and youth events
Warnings and consumer information labels	• Health warning labels on alcohol advertising • Health warning labels on alcohol containers • Consumer information about calories, additives, etc. on containers • Number of standard drinks displayed on containers • Alcohol content displayed on containers • Health warning labels on under-age drinking and on pregnancy • Health warning labels on drink-driving • Legal requirement for size of health warning labels

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