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Occupational and environmental safety of fluids in chainsaw operations: a review

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The objective of this review is to analyse the risks associated with the use of fluids in chainsaws operations, comparing traditional and eco-friendly materials.
We chose to investigate operations involving the use of portable equipment, particularly those that still use internal combustion engines. Indeed, they pose a high risk to operators due to their proximity to the machine. The scientific literature concerning fuel mixtures and chain oils was studied.
Correlating the examined activities, equipment and machines and their materials, the risks associated with the use of standard and alkylate fuels and mineral and vegetable chain oils in relation to their use in chainsaw operations were analysed.
The risks depend on the use of the fluids in the different work phases. In the liquid state of the fuel, the absence of benzene in alkylate fuels clearly reduces the carcinogenic risk. In combustion products, the literature review shows that, in the case of 2-stroke engines, the emissions of alkylate fuels are lower than those of conventional fuels for most compounds; on the other hand, the concentrations of PM and formaldehyde do not decrease when alkylate fuels are used.
The literature analysis also shows that the adoption of vegetable chain oils is an improvement.
Keywords: *occupational safety, environmental safety, chainsaw operations, eco-friendly fluids, alkylate gasoline, literature review.*

1. Introduction

As far as the chainsaw operations in forestry are concerned, the "Eco-friendly fluids" definition indicates fuels and oils with low impact on the environment and on the operator's health. These impacts were the topics studied by the "ProBest" operational group, financed through the Regione Piemonte PSR (2014-2020).

This review reports the results of the study conducted by the Department of Environmental, Land and Infrastructure Engineering of the Politecnico di Torino aimed to identify the risks associated with the use of standard fluids and the potential benefits related to more eco-friendly alternative fluids.

The forest area intended for wood production has been relatively stable since 1990. Global wood harvest (from forests, other wooded land and trees outside forests) was estimated to be almost 4.0 billion m^3 in 2018 (considering both industrial roundwood and fuelwood) (FAO,2019). Overall, timber harvesting is globally increasing by 1% per year, both in terms of demand, and consumption of wood products, in line with populations and incomes growth; this trend is expected to continue in coming decades. When done in a sustainable way, woods and forests management stimulates the plants regrowth exceeding the withdrawal balance and resulting in a net CO_2 sink (IPPC, 2022).

Many agricultural, forestry, and other land use (AFOLU) options provide adaptation and mitigation benefits that could be upscaled in the near-term across most regions. Conservation, improved management, and restoration of forests and other ecosystems offer the largest share of economic mitigation potential (IPPC, 2022).

The main fluids involved in forestry work are fuels, additive oils for 2-stroke engines fuel mixtures, hydraulic oils, and lubricating oils, particularly chain oils. Forestry machines using these fluids are distinguished into portable equipment such as chainsaws, brushcutters, mowers, etc. and agricultural machines, such as harvesters, forestry tractors, chippers, etc.

For the occupational issue, operations using hand-held equipment were mainly investigated because of the greater risk to operators, due to the operator-machine proximity.

Despite the growing popularity of electric machines, the most common portable equipment still uses internal combustion engines, particularly 2-stroke engines, so gasoline and additive oils mixtures have been identified as fluids.

In addition, chain oil was also considered in relation to portable tree harvesting and cutting equipment such as chainsaws. It appears to be a fluid that could cause a chemical and/or carcinogenic hazard as a result of its continuous emission (spray) in the chain surrounding environment.

Large machines involved in forestry operations, such as forestry

If there are references to colour figures in the text, the articles are available in open-access mode on the site www.geam-journal.org tractors, excavators and harvesters, require significant amounts of oils for their hydraulic circuits. In case of accidental oil tank/pipes leak, they can induce a significant potential impact on the environment.

These fluids are not the subject of this review because they do not affect the environment under normal operating conditions.

Tab.1 shows the correlation between the examined activities, equipment and machines, and related materials that can generate the previously mentioned risks. Therefore, the review analyzes the risks associated with the use of conventional and alkylated gasolines as well as mineral and vegetable lubricating oils in relation to their use in chainsaw operations. The risks examined include both occupational and environmental aspects.

Tab. 1 – Machines and activities involving contact with and/or use of the fluids analyzed.

Mixture for two-stroke engine (gasoline and additive oil)	Chainsaw	Manual felling
		Manual sectioning
		Manual limbing
		Pruning
		Supply
	Brushcutter	Supply
		Forest clearance cut
Chain oils	Chainsaw	Manual felling
		Manual sectioning
		Manual limbing
		Pruning
	Harvester	Mechanized felling
		Mechanized sectioning
		Mechanized limbing

2. Main reference legislation for the aspects under review

This part of the review identifies the main current regulations in forestry and chainsaw operations. The product regulations governing the fluids under analysis are recalled from time to time in the following paragraphs related to the different risks identified.

Regarding occupational safety, reference is made to Title IX of Legislative Decree 81/08: for chemical risk from exposure to hazardous substances present in mixtures and chain oils, the current reference is Article 223; while for carcinogenic risk, due to exposure to hazardous substances possibly present in mixtures and combustion products, Article 235 is the applicable reference.

Concerning the fuel used for machinery and equipment, there are many regulatory references dealing with environmental safety, sustainability, containment of climate change and greenhouse effect. In addition to the Directives related to occupational safety, these include Directive 2002/3/EC on ozone in the air, Directive 2008/50/EC on ambient air quality and its Italian transposition with Legislative Decree 155/2010. Regarding environmental aspects, reference is made to Directive 2009/30/EC. It, while regulating minimum specifications for fuels for road and non-road transport, introduces, by amending Directive 98/70/EC, important requirements for environmental impact assessment of fuels and biofuels, reiterating general shared aspects also valid for the present study and adoptable by analogy both for the identification of minimum quality (emissions) targets for gasoline/blends (alkylate gasoline) and for the assessment of the overall impact and greenhouse effect of bio-oils (chain oil and hydraulic oil).

Another regulatory reference is Directive 2009/28/EC on the promotion of the use of energy from renewable sources, which, although not relevant to the present study, is important for general criteria and target reference values. Important to mention is Regulation 2016/1628, in which new emission limits for gaseous and particulate pollutants and type-approval for internal combustion engines for non-road mobile machinery are set to achieve the Union's air quality objectives and to reduce emissions from non-road mobile machinery and agricultural and forestry vehicles.

Other regulations related to the type-approval of agricultural and forestry machinery are Directive 2003/37/EC (Agricultural and forestry machinery); Regulation (parent standard) EU 167/2013/EC (Non-road machinery engines); and EU Delegated Regulation 2018/985/EC (Forestry machinery environmental performance). The latter, in Article 3, indicates the adoption of environmental performance as per Regulation 2016/1628/EC also for forestry machinery engines; Article 5, on the other hand, similarly indicates the performance of engines with regard to fuel consumption as per UNECE Regulation No. 120.

Not secondary are the regulatory constraints related to the storage phase of the product, as well as the transport phase in tanks outside those installed on the equipment. The regulations do not change in the case of conventional or alkylated gasoline and their respective blends; in all cases, the legal limits expressed for maximum quantities that can be stored, the types of storage, the characteristics of suitable containers certified for transport, and the maximum quantity that can be transported must be respected, also depending on the distances to be covered.

The facility of finding gasoline with which to produce the blend locally, close to the operating sites, may mitigate storage and transportation problems. This could disadvantage an increase in products, such as alkylate gasoline blends, that need to be purchased in advance, temporarily stored, and then transported from the company location to the operating site. However, since the difficulty of storing and transporting combustible products (gasoline, blending oils, lubrication oils and hydraulic oils) is a generalized problem, it is hoped that centralized institutional intervention action will be issued, thus encouraging in parallel the use of innovative products, the development of storage areas and transport containers and a greater territorial spread of product distribution points.

3. Methodology

The objective of this review is to assess the benefits of alternative fluids and, in case of multiple options, to focus on those with the best environmental performance, at the same level of human health protection.

The environmental analysis of an action such as the substitution of a material within a production cycle must extend to the entire life cycle of the new product to be adopted, examining local and global impacts, short and long-term effects, and considering both pollutant emissions and resource use. It is also important to check the specific consumption of the products involved. At a reduction in environmental impact due to the change of substance, the increased consumption of resources, or the increase in emissions elsewhere in the system, should not lead to a negative overall environmental balance.

The analysis method adopted can be summarized as follows:

– description of the reason why the material change is desired;
– estimation of the positive employment and environmental impacts of the action on local and global scale;
– identification of any negative spillovers (e.g., packaging, storage, transportation, disposal, etc.) on local and global scale, also considering the product supply chain.

4. Materials involved

The 2-stroke engine is fueled by a gasoline-oil mixture with varying composition depending on the machine (usually the concentration of the oil/fuel mixture is 2%). It is therefore important to keep in mind, as already shown in Table 1, that contact with hazardous substances may occur not only during refueling through the possible inhalation of fuel vapors, but also during operation through the inhalation of exhaust gases.

The main categories of compounds present in exhaust gases generated during the operation of portable equipment potentially dangerous for the operator health are volatile organic compounds (VOCs) identified as aromatic (e.g., benzene) and aliphatic (e.g., methane) hydrocarbons, polycyclic aromatic hydrocarbons, carbon monoxide (CO), nitrogen oxides (NOx) and other oxides and aldehydes.

Assuming personnel exposure to various hazardous chemicals in the exhaust gases of the equipment used (All. V Legislative Decree 81/08), the presence of carcinogens such as benzene should be highlighted, being such chemical compound classified as carcinogenic to humans, belonging to Group 1 according to the IARC (International Agency for Research on Cancer) classification. Alternative fuels to conventional gasoline, called alkylate gasoline, are available on the market: they propose a potential improvement because they do not contain benzene. This review analyzes the validity of this alternative as an occupational environmental safety improvement.

4.1. Alkylated gasolines

For fuel used for manual forestry equipment such as chainsaws and brushcutters, the risk of emission of toxic products can be represented as high probability, medium magnitude, and correlated with some weighting factors ki such as: k1 (type of fuel used), k2 (type of blend oil used), k3 (2 or 4-stroke engine type), k4 (engine seniority), k5 (combustion quality), k6 (type of activity), k7 (hourly consumption), k8 (packaging mode), k9 (storage/availability mode), k10 (need for decanting), k11 (transportation mode).

Alkylate fuel, commonly used in hand machinery, is rich in short-chain, single-bond hydrocarbons and has a low content of alkenes, oxygenates and aromatic compounds. A.A. Zardini, in research conducted in 2019, certifies not only the components of fuels, but also those of additive oils in the two-stroke mixture (A.A. Zardini, 2019). He evinces how alkylated gasolines (fuel and/or blend) resulted non-carcinogenic material/input to the production cycle, unlike conventional gasolines.

Concerning the environment, alkylate gasolines are nonrenewable since they are of mineral origin, and therefore derived from petroleum, even if produced from the last stages of distillation. The full safety data sheets show the hazard pictogram for the aquatic environment: H411 and H413 environmental potential classification apply, indicating long-lasting harmfulness and potential toxicity to aquatic life, as well as for conventional gasolines.

Regarding combustion products, emissions are regulated as follows: some emissions (such as CO, THC, PM, PN or PAHs, SOx, FAME) are regulated directly by the type-approval laws of the adopted powertrain and/or fuels of forestry machinery; other substances, which do not have specific limits for emissions in forestry, are controlled in the context of adopted fluid quality and/or air quality (such as benzene, SOx, CO_2, O_3); other constituents, while coded as harmful to humans and/or to the environment, are not explicitly regulated and their presence is controlled within the broader scope of quality and health objectives (such as aldehydes, VOCs, the precursors of O_3), as well as sustainability and containment of climate-altering gases (especially CO_2, N_2O, CH_4).

In (A.A. Zardini, 2014) the regulated and unregulated emissions of a 2-stroke and a 4-stroke engines were characterized for both conventional and alkylated gasoline. Standard gasoline and synthetic lubricating oil were replaced with an alkylate fuel with low aromatic compound content and an ultra-clean lubricating oil with low ash-forming potential. A reduction in emissions was observed for several gaseous and particulate species, particularly carbon monoxide, particulate mass, aromatic compounds, and secondary organic aerosol (A.A. Zardini, 2014).

The alkylate fuel and ultra-clean oil combination causes a large emission reduction for regulated and unregulated compounds, SOA included, with some exceptions, formaldehyde, for instance (A.A. Zardini, 2014).

In the previously mentioned study by Zardini, from which Figure 1 was extrapolated, lower emissions of alkylate gasoline compared to conventional gasoline are confirmed for regulated compounds, and for PM (A.A. Zardini, 2014).

From an occupational safety perspective, F. Neri's study (F. Neri, 2016) investigates the inhalation exposure of forestry workers to polycyclic aromatic hydrocarbons (PAHs) and BTEX (benzene, toluene, ethylbenzene, and total xylenes) contained in the exhaust

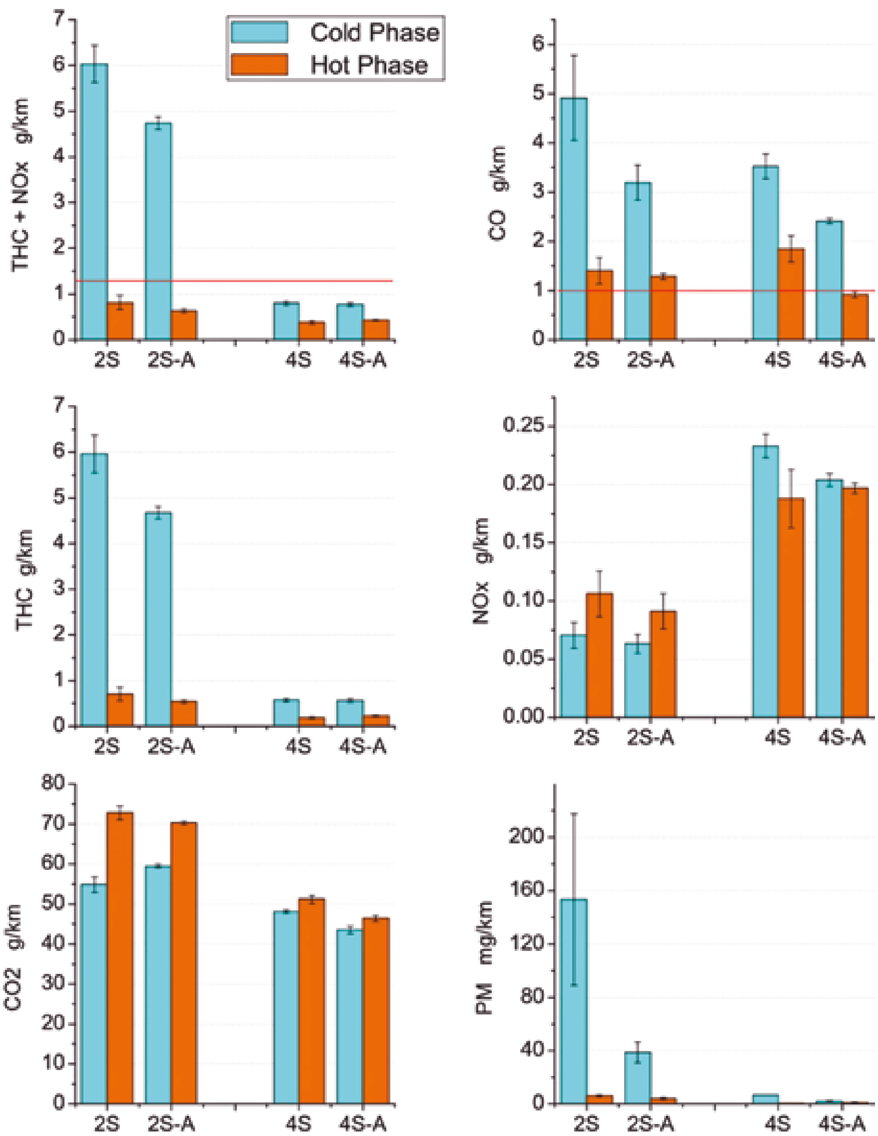

Fig. 1 – Average emission factors (mass/distance) of regulated compounds grouped by scooter and fuel types, and split into cycle phases. The 2-stroker (2S) emits more THC, CO, and PM (dominated by cold phase emissions) than the 4-stroker (4S). The use of the alkylate fuel reduces THC, CO, PM and NOx of the 2S (2S-A, where A stands for alkylate) and CO, PM, NOx of the 4S. From: (A.A. Zardini, 2014).

gases released by chainsaws in order to suggest possible safeguards. It compares, over four different silvicultural treatments (clear cutting, conifer thinning, conifer pruning, and sanitary cutting), three different types of chainsaw fuel, specifically a normal two-stroke gasoline blend and two alkylate fuels. Statistically significant differences in inhalation exposure to PAHs and BTEX were recorded when using different types of fuel. In particular, inhalation exposure to PAHs and BTEXs was generally an order of magnitude lower when using modern alkylate fuels than when using the traditional blend of 2-stroke oil and unleaded gasoline. The study indicates that while forestry workers are exposed to PAHs and BTEX, the maximum values found are generally well below the limits indicated for occupational exposure.

Dimitrakopoulos's study (N. Dimitrakopoulos, 2020) plots emissions of HC, CO, NOx, and SOOT, as a function of engine load, comparing conventional with alkylated gasolines. As shown in Figure 2, the results for alkylate gasolines compared to conventional gasolines indicate similar emission values for HC, lower CO and NOx figures, but higher SOOT amount (in fact, exhaust soot in the case of alkylates is almost double, especially as engine load increases). More complex is the interpretation of data for PM dust and SOOT ash: the improvement introduced by alkylate gasoline is not so clear.

Therefore, the literature analysis shows that for most of the regulated combustion product compounds of two-stroke engines, the emission factors of alkylate gasolines are lower than those of conventional gasolines, although a significant spread in emissions reduction can be noticed across the different tests.

Also, for most of the non-regulated compounds several studies indicate that, the emission factors of 2-stroke engines powered by alkylate gasolines are lower than those of conventional gasolines. On the other hand, the emission factors of CH_4 (and CH_4 CO_2(eq)) and aldehydes (acetaldehyde and formaldehyde) remain more critical, with higher combustion products for alkylate gasolines com-

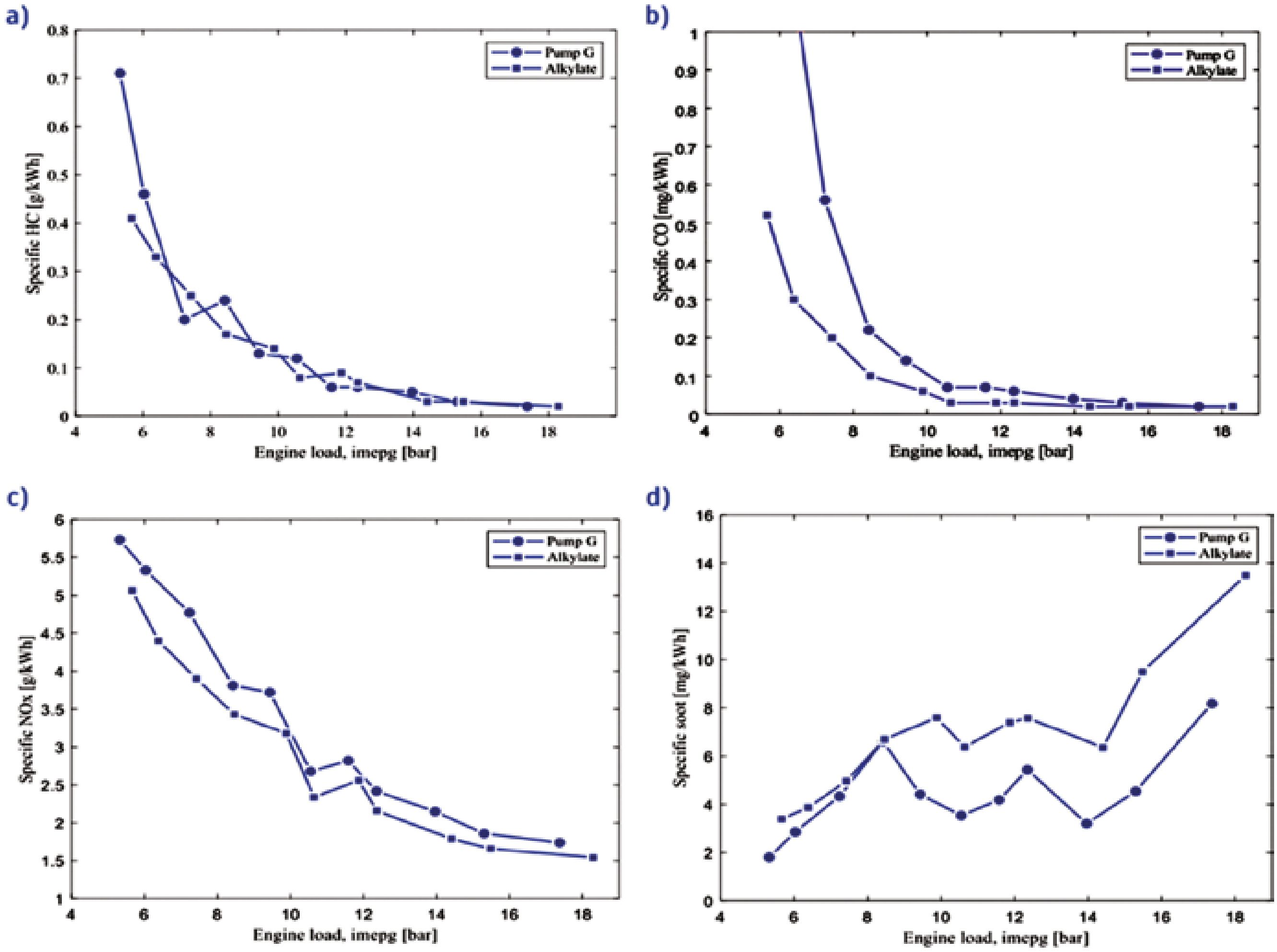

Fig. 2 – Emissions of the different compounds for the two types of gasoline. a) HC, b) CO, c) NOx, d) SOOT. From: (N. Dimitrakopoulos, 2020).

pared with conventional gasolines. In particular, the presence of formaldehyde, which is more critical to worker health, requires further investigation and future monitoring. Another important element to observe is the presence of ozone precursor compounds, the measurement of which is explicitly required in Annex VI of Directive 2002/3/EC.

4.2. Chain oils

The use of oils of vegetable origin is aimed to reduce the toxic substances release into the environment around the processing site, both for the environment and the operators protection.

In the presence of materials with environmentally toxic characteristics, the scenarios describing the emissive dynamics are different whether we are talking about chainsaws rather than harvesters or other agricultural machinery. In the case of chainsaws, chain oil dispersion occurs when the machine is used: the lubricant is supplied to the sawchain causing the projection of a suspension consisting of droplets and volatile part of fluid into the blade surrounding environment, with the associated generation of continuous environmental pollution which also involves the operator.

So for the dynamics of environmental (as well as occupational) risk, which may account for the emissive condition of the chainsaws lubricating oil, the risk function can be explicated as a relationship between high probability, low magnitude, and ki weighting factors such as: k1 (type of oil used), k2 (flux density g/m^2), k3 (amount of wood cut/h), k4 (sensitive forest environment), k5 (critical biodiversity), and k6 (type of environment in which it operates).

5. Conclusions

Having identified from the local-scale study for portable forestry equipment an improvement for both the human health and the environment associated with the use of alkylate gasoline in place of conventional gasoline, a global scale impact estimation of this substitution is definitely needed to close the environmental balance sheet. In order to support the adoption of alkylate gasolines, management actions for the critical points that could result from their widespread use should be planned.

In particular, improvement actions are to be developed to address:

– the environmental issue induced by the presence of the blend packaging containers (additional use of resources and disposal of plastic materials), imposed at this time due to the absence of "bulk" sales outlets for gasoline, which is the standard situation for conventional gasoline;
– the greater storage problems compared with traditional fluids caused by large quantity/cost effective purchasing and stock issues whose management require upgrades in companies organization and processes; fire and explosion safety problems to third parties are also to be addressed;
– the transportation problems, especially when forestry sites are located far away from populated areas;
– the fossil origin of alkylate gasolines include these fuels in the nonrenewable resources category, and their environmental impact remains that of fossil fuels, with a particularly high energy rating for their derivation from pushed degrees of distillation.

In general, the environmental balance improves by decreasing the products consumption and waste; alkylate gasolines guarantee this with consumption comparable to that of conventional gasolines while granting longer shelf life in storage (even in the machine fuel tank). Referring to chain oils, vegetable origin oils have much lower direct environmental toxicity characteristics than classical mineral or synthetic oils.

As can be observed from the safety data sheets of the substances, many environmental hazards and/or risk statements present in classic oils documentation no longer appear for the proposed alternative vegetable oils. In terms of balance, all aspects that may be involved in the replacement of classic oils with vegetable oils are to be carefully evaluated.

On a local scale, the replacement of synthetic oils with vegetable oils (unlike the alkylate fuels) brings positive spin-offs from both the employment and the environmental point of view (without any impact on packaging, storage and transportation issues). However, socio-economic aspects related to the higher cost of plant products remain open, which requires supporting actions to improve and ensure socio-economic sustainability over time as well. On a global scale, it is necessary to initiate major actions to improve the bio-fluid production sustainability, identifying the impacts of the entire product chain. The reference points for the analysis of the impacts on the global environmental system are already present in the comments of international recommendations, particularly in the EU recommendation sentences of the Biofuels Directive.

For the verification of the environmental balance, bio-fluids must meet the sustainability criteria already referred to for lubricating vegetable oils, as well as set out in Directive 2009/30/EC, namely on sustainability and limitation of the greenhouse effect of bio-fuels (including oils).

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