GREAT CHALLENGES LIE AHEAD FOR LOW-CARBON LONG-HAUL TRANSPORT

TNO innovation for life

The supply chain of goods delivered in urban areas is larger than the transport associated purely with the 'last mile' in city distribution. In retail, for example, the flow of goods is often routed via regional or national distribution centres. The transport of goods towards and between these centres is often characterized by long-distance trips with heavy loads. This so-called long-haul road transport is by far the most dominant modality and is responsible for nearly half of all CO_2 emissions in heavy-duty freight transport in the Netherlands, as figure 1 shows.

Despite the economic importance of fuel consumption and the large share of long-haul transport in the total CO_2 emissions, the CO_2 emission of individual heavy-duty vehicles (HDVs) is currently neither measured, nor reported or regulated. For this purpose, the European Commission is developing a computer simulation tool called VECTO. With the help of this tool, the European Commission aims to certify, report and monitor CO_2 emissions of newly-registered heavy-duty vehicles. Once this legislation is in force further measures may be considered to curb CO_2 emissions from HDVs. The most apparent option is to set mandatory limits on average CO_2 emissions from newly-registered HD vehicles, as is already done for cars and vans.

Whichever legislation will be considered in the future also requires an impact assessment in terms of the cost-effectiveness of reduction measures, both from an end-user and societal point of view.

For road freight transport operators, for example, decision-making about purchasing the appropriate heavy-duty vehicles and fuel efficiency specifications is part of their core business. Depending on the operation, roughly 30% of their total cost are labour cost, while about 30% are fuel cost and the remaining 40% are depreciation of the vehicle fleet, maintenance and repair and insurance cost. With annual mileages of well above 100,000 km, the utilisation rates of the vehicles are high and the economic lifetime of about 8 years is relatively short.

For shippers, the logistics operation is only a small share of the total costs. Nevertheless, it is important for them to have reliable delivery times, to be able to access congested cities and urban areas and to comply to environmental regulations. Besides, increasingly shippers are taking action to achieve more efficient and more climate-friendly transport.

VECTO

As the European Commission puts it: “VECTO is a vehicle simulation tool tailored to estimate CO_2 emissions from heavy-duty vehicles of different categories, sizes and technologies. Further development and optimization of VECTO and the CO_2 certification methodology requires assessing their capacity to properly simulate specific vehicle technologies and gathering additional feedback on the possibility to capture future technologies which are expected to be deployed on heavy-duty vehicles in the years to come.” [EC, 2016]

The intended use of a vehicle simulation model as a support tool for legislation postulates high requirements for VECTO:

- The standard definition of vehicles and drive cycles used in VECTO should closely relate to the logistics operation of logistics service providers (LSPs) in practice.
- CO_2 reduction rates determined in VECTO should be validated and replicable.
- CO_2 performance of new technologies must be available in the tooling to avoid the risk that the legislation hinders innovation instead of promoting it.

THERE IS NO SILVER BULLET SOLUTION THAT REDUCES CARBON EMISSIONS TO ZERO IN LONG-HAUL ROAD TRANSPORT

Share of CO_2 emissions							Total
Vehicle category	**Service delivery**	**City distribution**	**Regional delivery**	**Long haul**	**Bus**	**Coach**	**Total**
Light commercial vehicle	32%						**32%**
Truck (light and medium)		2%	2%	4%			**8%**
Truck (heavy)		2%	2%	7%			**11%**
Tractor and trailer		3%	4%	36%			**43%**
Bus					4%	1%	**6%**
Total	32%	6%	9%	47%	4%	1%	**100%**

Fig. 1. Share of CO_2 emissions in the Netherlands, differentiated by vehicle category and mission profile [CBS, 2016] [TNO, 2013].

OEMs are challenged to continuously invent and develop new affordable technologies which improve the fuel efficiency and reduce CO_2 emissions. This requires high investments in innovations, the success rate of which is not always known beforehand.

A LOT HAS BEEN ACHIEVED OVER THE LAST DECENNIA

Since 1990, the average specific CO_2 emissions of trucks and tractor-trailers on Dutch roads have decreased by 18% to about 750 grams per kilometre in 2015 (see figure 2) [CBS, 2016].

The technological efficiency improvement was actually much higher than 18%, but the increasing rated power of tractors has offset a large share of the technological efficiency improvement. In addition, the remaining vehicle efficiency improvement and resulting CO_2 savings have been largely offset by the increased demand for freight transport. As a result, in 2015, the total CO_2 emissions from heavy-duty road transport were approximately equal to 1990. The current and expected growth rates for freight transport make it obvious that urgent action is needed if CO_2 emission goals in transport are to be achieved.

TRENDS, BARRIERS AND OPPORTUNITIES

There is no silver bullet solution that reduces carbon emissions to zero in long-haul road transport. Instead, the low-carbon roadmap for long-haul trucking relies on the sum of several reduction measures, including on a vehicle level: energy carriers, powertrain options, auxiliaries, reduced road load related to air drag and rolling resistance and light-weighting; and on a system level: driving behavior, traffic systems and logistics. All these measures combined can achieve a reduction of 50% on CO_2 emissions (see figure 3), which is 10% more than the guiding objectives for long-haul freight transport used by ERTRAC, the European Road Transport Research Advisory Council. If emissions are to be reduced even further, very specific biofuels with low well-to-wheel (WTW) emissions must be considered. However, the availability of such fuels on a large scale is and will probably remain limited in the future due to the high demand in biomass as a feedstock for the chemical and energy industry.

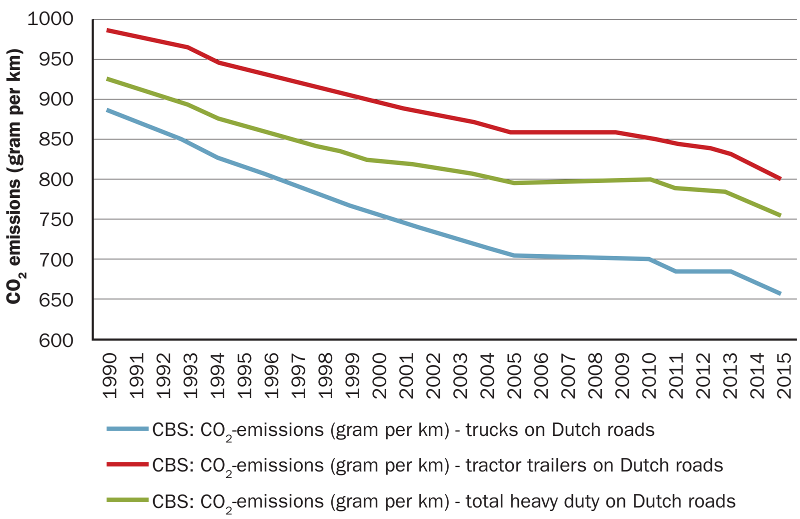

Fig. 2. CO_2 emissions per vehicle–kilometer of heavy duty transport on Dutch roads [CBS, 2016].

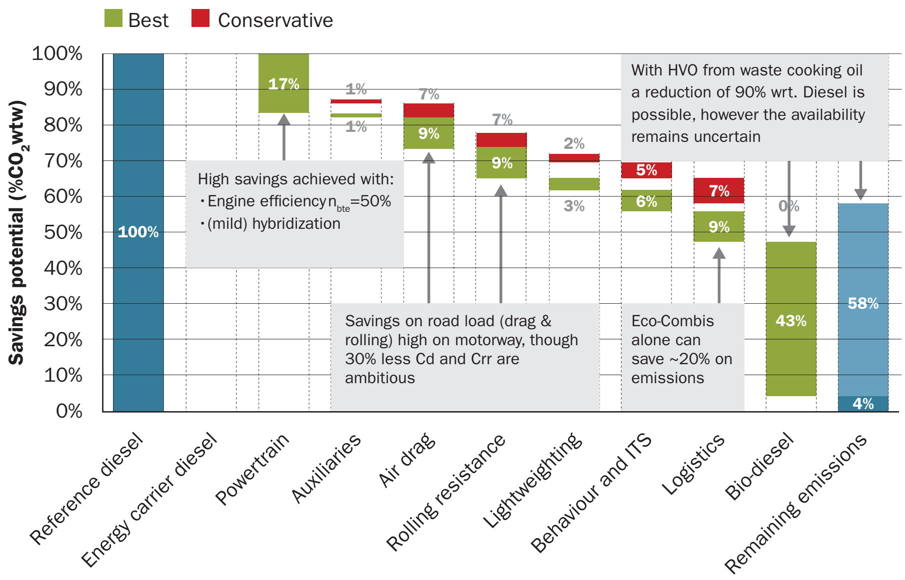

Fig. 3. Assessment of the CO_2 reduction potential of abatement options for long haul tractor-semitrailer transport [TNO, 2016].

ENERGY CARRIERS AND POWERTRAIN OPTIONS

In contrast to urban applications, where electric transport may become feasible in the near future, feasible electric drivetrain concepts still need to be developed for long-haul applications. Promising concepts are already being tested in pilots. In 2016, for example, world's first eHighway segment was opened in Sweden displaying Siemens' catenary power concept for on-road charging of hybrid vehicles on the motorway [Siemens, 2016]. Another cornerstone for electric driving has been laid with the presentation of world's first hydrogen range-extended electric vehicle, the 'Nikola-One' [Nikola, 2016].

Meanwhile, the development of the internal combustion engine (ICE) and improvements in engine efficiency have not yet come to a halt [ERTRAC, 2016] [ICCT, 2015]. As long as continuous improvements provide affordable and competitive efficiency gains in relation to other energy carriers, it is expected that long-haul trucking will still be largely dominated by diesel and gas engines over the next few decades. In this case, a possible development of the engine efficiency for diesel and gas engines could take the following form (see figure 4).

New diesel combustion concepts as presented in the U.S. Future Truck Program with engine efficiencies of 50–55% are expected to become market-ready in the years 2025 and further [ICCT, 2015]. Further CO_2 savings could yet be achieved with improved gas engines. In principle, the efficiency of mono-fuel and dual-fuel engines can profit from the same developments as the diesel engine. Whether these developments will actually take place also depends on the market demand for these vehicles.

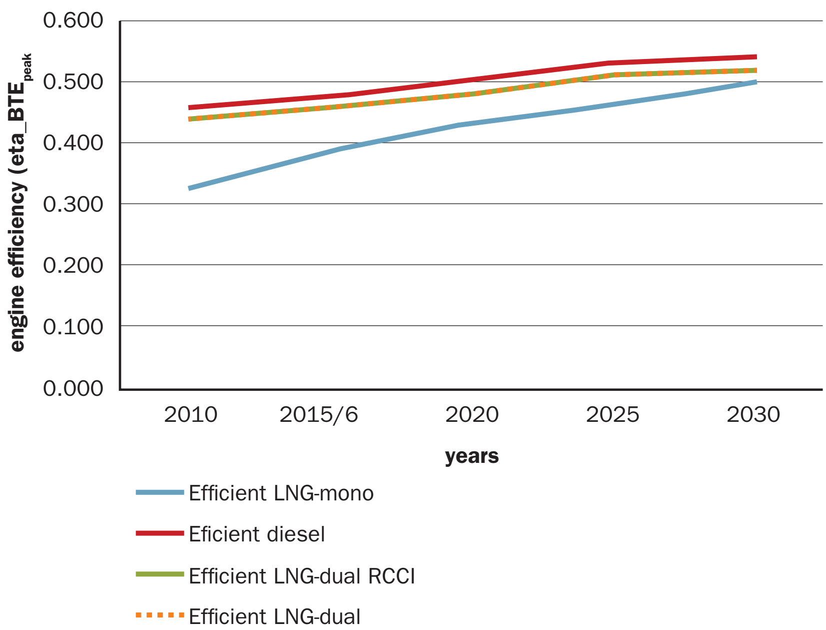

Fig. 4. Expected development of the engine efficiency of diesel and gas engines for long-haul tractor-semitrailers [ERTRAC, 2016] [ICCT, 2015].

THE EMERGENCE OF THE INTERNET-OF-THINGS AND ARTIFICIAL INTELLIGENCE ALREADY HAVE A STRONG IMPACT ON OUR CURRENT UNDERSTANDING OF MOBILITY

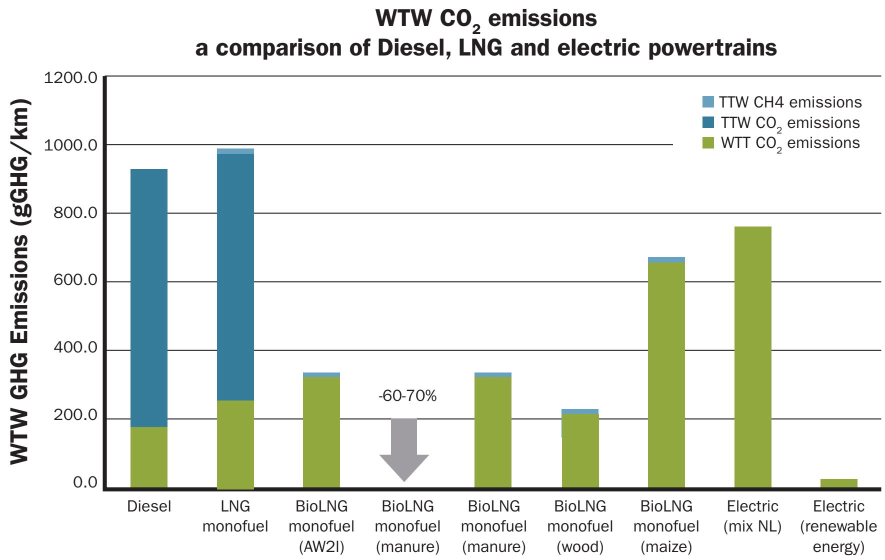

Fig. 5. Comparison of WTW CO_2 emissions of three different energy carriers: diesel, (bio-)LNG and electric.

Biofuels and renewable energy sources are easily perceived as quick-win low-carbon solutions, since their overall well-to-wheel (WTW) carbon content is generally lower than for conventional fuels. The usage of biofuels should always consider three aspects:

- **a** the origin of the energy source as well as the chemical composition of the fuel is crucial,
- **b** large-scale availability is not yet covered, meaning at this point they cannot offer a solution for the whole vehicle fleet, and
- **c** the blend determines the emission.

The importance of the origin of the source is illustrated in figure 5. BioLNG from manure woody biomass and waste offer large CO_2 reductions in comparison to diesel, whereas bioLNG from maize yield much lower reductions. The same applies to the use of electricity. Electric vehicles currently only offer limited WTW CO_2 emission reductions due to the large shares of coal used in the electricity production mix in the Netherlands.

When using renewable sources like wind and sun, the WTW savings are nearly 100%.

DRIVING RESISTANCE

Apart from the engine and the energy carrier, the fuel efficiency of a vehicle primarily depends on the vehicle road load (air drag and rolling resistance), the inertia (braking and acceleration) and the gradient of the road (slope). See figure 6.

There exists a great range of commercial products that aim at the reduction of the driving resistances, such as low-rolling-resistance tyres, aerodynamic side skirts and boat tails, light-weight cabin design, etc. Whether these innovations are (cost-) effective or not always depends on the context of the use case. Aerodynamics measures, for example, are most effective on motorway driving. Light-weight options are most effective for urban driving cycles with high levels of acceleration and deceleration. Low-rolling-resistance tyres are most effective for vehicles with a high payloads.

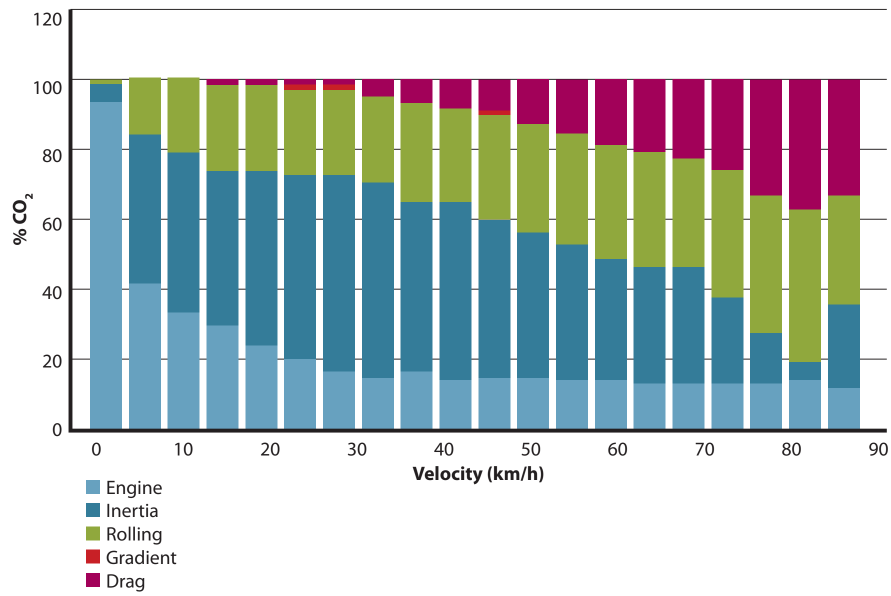

Fig.6. Contribution of driving resistances to the vehicle's CO_2 emission at different velocities.

SAE level	Name	Execution of steering and acceleration/ deceleration	Monitoring of driving environment	Fallback performance of dynamic driving task	System capability (driving modes)
Human driver					
0	**No automation**	Human driver	Human driver	Human driver	n/a
1	**Driver assistance**	Human driver and system	Human driver	Human driver	Some driving modes
2	**Partial automation**	**System**	Human driver	Human driver	Some driving modes
Automated driving					
3	**Conditional automation**	System	**System**	Human driver	Some driving modes
4	**High automation**	System	System	**System**	Some driving modes
5	**Full automation**	System	System	System	**All driving modes**

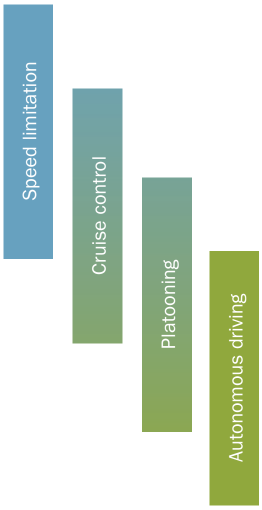

Fig. 7. SAE levels for mobility automation [TNO, 2015].

With the knowledge of the vehicle type and the vehicle operation and the use of vehicle simulation models, the energy demand and CO_2 emission of a vehicle can be unraveled and analyzed.

The use of such models enable an a priori evaluation of the efficiency of measures which are specific for each use case.

CONNECTED AND AUTOMATED DRIVING

Analysis of fleet management data shows that driver behavior plays a crucial role on the fuel economy of heavy-duty vehicles. Driver training can therefore be a very effective measure to improve the fuel economy. Technologies which support or replace driver functions can have the same effect.

The emergence of the internet-of-things (IoT) and artificial intelligence (AI) already have a strong impact on our current understanding of mobility. Companies worldwide have embraced the concept of connected and automated driving with the aim of making vehicles smarter and more autonomous. The Society of Automotive Engineers (SAE) differentiate between six levels of automation, as figure 7 shows. Technologies like speed limiters, predictive and adaptive cruise control and truck platooning are innovations which all contribute to the same overall goal: connected and autonomous driving [TNO, 2015]. Interestingly, these technologies partially compete with each other. For the same reason, the savings potential of each individual technology cannot simply be combined or added up.

OPTIMAL VEHICLE DESIGN IS HIGHLY DEPENDENT ON THE DEVELOP-MENT OF THE FUEL PRICE

THE PATH TOWARDS ZERO-EMISSION LONG-HAUL ROAD TRANSPORT IS YET UNCERTAIN AND HIGHLY DYNAMIC

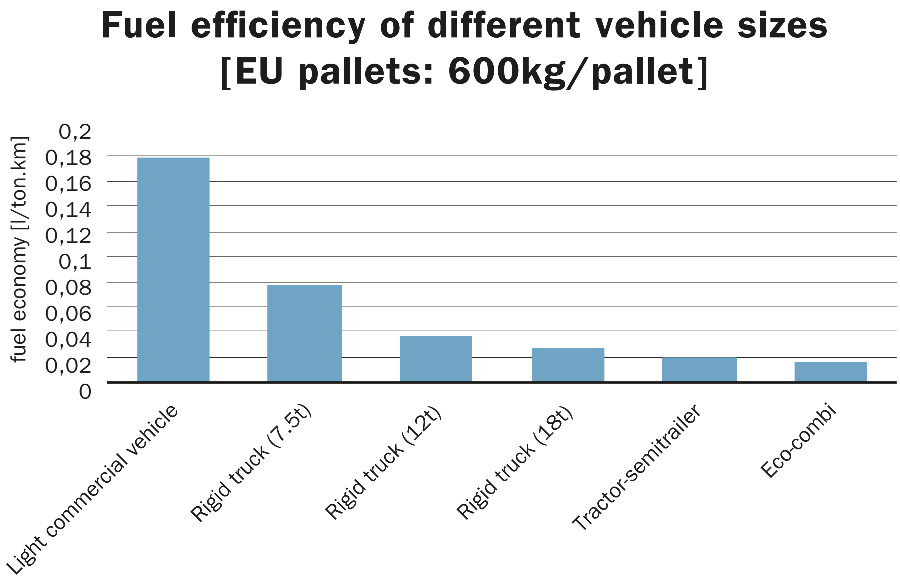

Fig. 8. Average fuel consumption (L/t-kms) of different vehicle sizes [ACEA, 2009].

LOGISTICS

Optimization of the logistics supply chain can have a large impact on a fleet's total CO_2 emission. Yet logistics options are very sensitive to the specific operation. Whatever works for one operation is not necessarily applicable to another. The choice of the right vehicle type in relation to its route is one aspect that can be considered. Long heavy vehicles (LHVs), for example, yield an increased vehicle utilization and therefore higher fuel economy per freight unit, see figure 8.

Yet the applicability of such a measure depends on several boundary conditions: the logistics network, the planned route as well as the specification of the goods in terms of freight density, different legislation across member states for maximum vehicle dimensions and weight. In some cases, the right boundary conditions must yet be created. Additional hubs and decoupling points, for example, are a prerequisite to enable bundling of goods, which in consequence leads to higher utilization rates.

THE WAY FORWARD

The path towards zero-emission long-haul road transport is yet uncertain and highly dynamic as different technology routes compete with each other whilst others form synergies. The success of all technologies cannot yet be evaluated accurately since neither the final investment costs when introduced at scale nor the fuel efficiency benefits can be predicted. As the following example illustrates (see figure 9), the cost effectiveness of different technologies and therefore the optimal vehicle design is highly dependent on the development of the fuel price. Sensitivity analyses like the one shown make decision making more transparent and provide perspectives for action.

The evaluation of abatement options demands for a standard approach which takes into account the technology design under different sector-representative vehicle operations. Collaboration between private and public stakeholders is key in this process, since often the knowledge base is fragmented between parties:

- OEMs and developers of new abatement options in general have technical and operational knowhow of specific solutions.
- Transport shippers and carriers have detailed knowledge of the operation of their vehicle fleet varying from light to heavy vehicles and operations in both short-haul and long-haul transport.
- Local authorities, like cities and mainports, have an overview of all transport movements within their geographical borders.

The combination of data from different parties builds the basis for effective discussions and is the cornerstone of smart logistics solutions. New insights and perspectives can be gained from the following examples:

- (limited) measurement data of a specific technology under case-specific conditions can be used in combination with operational data from fleet management systems (FMS) to estimate the performance of the technology under fleet-specific operation.
- Data from Automatic Number Plate Recognition (ANPR) cameras in combination with FMS data can be used to identify large transport flows in a region.
- FMS data in combination with vehicle simulation models can be used to derive and monitor new key performance indicators (KPIs) relevant for operation such as the payload.

TNO developed a toolset that allows to systematically make the many trade-offs depicted in this paper and to match the specific logistics characteristics of the operator with state-of-the-art technology insights, options and costs. Making the complexity manageable is TNO's key market proposition.

Key in making the right choices in the transition is to account for all stakeholders involved. It is TNO's ambition to shape the transition towards zero-emission transport together with private and public partners. We want to do this by taking away uncertainties in the performance of innovative technologies and logistics solutions by providing insights into the expected costs and benefits.

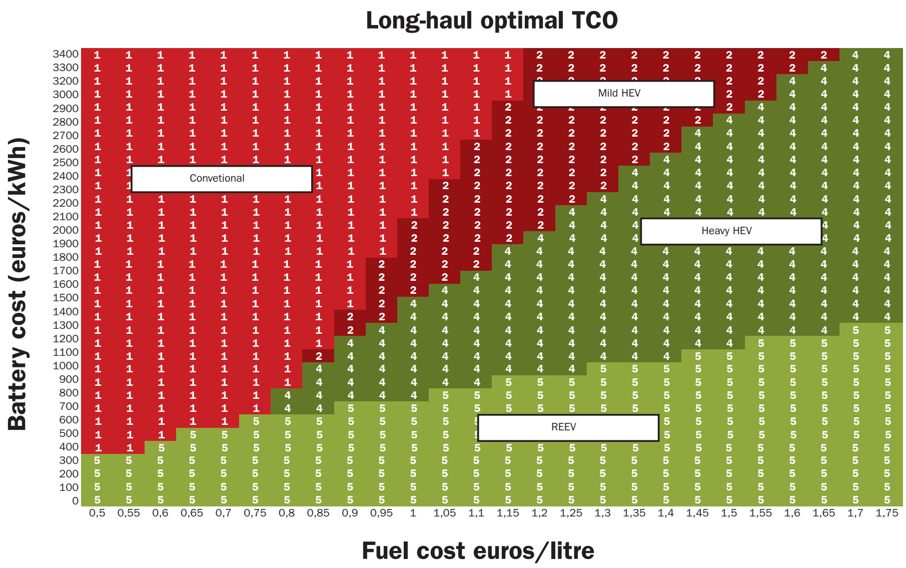

Fig. 9. Long-haul optimal total cost of ownership (TCO) when comparing the different technologies conventional diesel, mild hybrid, heavy hybrid and range-extended electric vehicles (REEVs).

MAKING THE COMPLEXITY MANAGEABLE IS TNO'S KEY MARKET PROPOSITION

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LIVING ENVIRONMENT

As part of the Living Environment theme, we apply ourselves to devising innovations for vital urban regions. We work together with partners to create solutions for today and opportunities for tomorrow to enhance the viability, accessibility and competitiveness of these urban regions.

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