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Article

Towards Road Sustainability—Part II: Applied Holistic Assessment and Lessons Learned from French Highway Resurfacing Strategies

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Abstract: Roads are major transportation infrastructure whose sustainability of maintenance practices has never been holistically assessed due to a lack of a proper method. This paper applies a newly developed assessment method (see article part I) on a 10-km-long section of French highway to fully compare the performance of various types of pavement resurfacing policies, for all the maintenance stakeholders, and considering pavement–vehicle interaction (PVI). After presenting the highway section and the parametrization of the model, four alternative resurfacing frequencies are compared to the French standard maintenance scenario over the pavement lifespan. Results show that increasing resurfacing frequency generates gains in terms of domestic production and employment, environmental damage (health, biodiversity, resources), user budgets, and local residents' health damage created by traffic noise. Conversely, it entails financial losses for the road operator and government (tax revenues and net present value), as well as time losses for users. On the contrary, the consequences of a decrease in this frequency are the opposite. Excess fuel consumption due to PVI governs the scale of the environmental and financial gains or losses of highway maintenance policies. Optima in terms of health returns on investment and user savings appear to be around a 50% increase in maintenance funding: for each additional euro spent by the operator, there is a user gain of 3.5 euros and a human health gain of 710 euros. Sensitivity analyses indicate that the marginal gains are highly sensitive to the thickness of the resurfacing technique for macroeconomic indicators, global Net Present Value, and operator savings, while the gains are proportional to the traffic and International Roughness Indicator deterioration speed for tax revenue, users' savings, time savings, noise, and environmental metrics. The other indicators are either slightly or not sensitive to these parameters. To conclude, the entire road maintenance system must be redesigned, from the tax system and funding schemes to the prioritization of road "green practices", to align all the stakeholders' interests towards a globally more sustainable road system.

Keywords: road maintenance; sustainability; key performance indicators; pavement asset management; public investment policies; life cycle

1. Introduction

Roads are key infrastructures that support most of the world's transportation activity [1,2], explaining the wide corpus of research on their sustainability [3]. However, the studies carried out around sustainability solutions are fragmentary, often approached through the prism of a single discipline, as shown in the literature review of part I of this double article on pavement sustainability assessment [4]. Examining these solutions quantitatively through a holistic assessment to quantify the levers of sustainability is needed to develop sound public policy recommendations. This is the challenge that we address in this article on the issue of road maintenance, by applying the holistic method developed in part I of this double article [4].

As road networks mature, new infrastructure construction becomes scarce [5–7]; this mechanically concentrates growing economic, environmental, and social issues around network maintenance, especially since a road never actually reaches the end of its life [8], and is therefore never entirely rebuilt, but more or less heavily maintained. Thus, studying the sustainability of road maintenance policies seems to us to be the heart of the challenge in moving towards sustainable roads, for instance by using greener materials or construction practices [9]. Moreover, from a functional point of view, the road infrastructure aims to support vehicles. Its function is therefore to allow the movement of goods and people carried by these vehicles. The sustainability performance of a road also encompasses the performance of the vehicles circulating on it, in particular because of the Pavement–Vehicle Interactions (PVI) described in part I of this double article [4], which can generate substantial excess fuel consumption and accelerated deterioration of vehicle suspensions and tires, even under a limited surface condition deterioration [4,10].

The maintenance of a pavement consists of improving the surface or structure characteristics of a road through construction operations [11]. This improvement is achieved through more or less heavy constructive operations, ranging from simple crack filling—which consists of injecting a hydrocarbon binder into road cracks—to major rehabilitation, which consist in rebuilding the pavement over a thickness of twenty centimeters [11–13]. In our article, we focus on asphalt resurfacing operations; in France, it consists of the construction of a 0.5 to 9 cm-thick layer (0.2 to 3.5 inches) of materials on the surface of the pavement, potentially after a planning operation, i.e., a purge of deteriorated road surface materials. According to French road constructors, resurfacing activities represent a major part of their activity and sales. Around ten major resurfacing techniques are used around the world, varying in the materials used—bitumen or emulsion, type of aggregate —, the material manufacturing method— manufacturing temperature, in a plant or on-site— —, the construction process, building machine used, resurfacing type —, and the new rolling course thickness [11]. A maintenance program consists of a succession of resurfacing operations spaced out over time. Today, French road managers mainly have a financial and technical approach to maintaining pavements [12,14–16], and rarely include environmental criteria on carbon footprint, primary energy consumption, or water consumption [17]. Neither the three pillars of sustainability nor the consequences of PVI are considered in French resurfacing targets, due to a lack of knowledge on these two aspects and how to assess them. However, each maintenance operation has direct sustainability consequences linked to the consumption of materials and energy for the construction, and indirect consequences linked to the effect of the works on the subsequent road surface condition, and ultimately on vehicle consumptions.

The first objective of this article is to quantify the sustainability impacts of the maintenance program of a highway from a systemic point of view, i.e., including the consequences of the pavement condition on the traffic which circulates over it. In this article, we assume that road maintenance policies are the key to sustainable roads, a hypothesis that we test for highways through a French case study and multiple sensitivity analyses. We apply the new holistic assessment method developed in part I of this double article to perform a quantitative assessment of the sustainability impacts generated by altering resurfacing periods in a case study, in order to learn lessons on good maintenance practices for highway resurfacing in France (final objective). Sensitivity analyses are also conducted to extrapolate the conclusions from a specific case study to a high variety of representative conditions in France and Europe. The article also aims at demonstrating the practicability of the holistic assessment method presented in part I of this double article [4] on concrete cases. Parameters to customize part I's equations and databases—life cycle inventories, microeconomic and macroeconomic datasets—are developed for that purpose.

2. Case Study Presentation

2.1. A Typical French Highway

2.1.1. Presentation

We chose to study a highway on the French network in open country, which is typical in terms of climate, structure, traffic composition, geometry, and topography. This highway has been anonymized, as requested by its concessionaire. It is a four-lane highway, with two lanes in each direction. This geometry represents around two-thirds of the French highway network [18]. We recovered data records for a 100 km-long section of this highway from the pavement management system of its operator, Cofiroute, updated in January 2017.

2.1.2. Past Maintenance Strategy

We conducted a statistical analysis relating to the age of the road surface materials on the selected section of the highway. Most of the rolling courses of this highway are very thin asphalt concrete overlay (VTACO) or, more rarely, semi-coarse asphalt concrete overlay (SCAO). Figure 1 shows the statistical distribution of the rolling course ages. The average age calculated for the rolling courses is 6.87 years, thus the highway is resurfaced every 13.7 years in average. The analysis also shows that 20% of the rolling course linear is older than 15 years old.

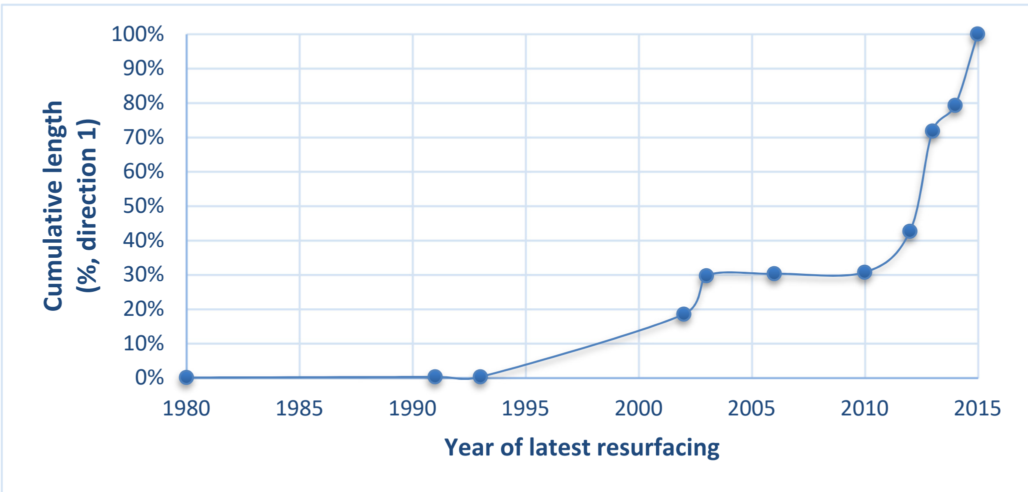

Figure 1. Cumulative percentage of the surfaces of the highway studied, by year of resurfacing, on 1 January 2017.

2.2. Selection and Presentation of the Section Studied

Within the 100 km section of this highway, we selected a 10 km-long section based on the criteria of national representativeness and standard dimensions for a highway maintenance operation.

2.2.1. Structure and Condition of the Section

The 10 km selected are homogeneous in terms of structure (same structural design and rolling course). In 2017, the rolling course was 15 years old, and the pavement structure itself was 37 years old; the section was rehabilitated, and we aimed to find out how to schedule resurfacing over the lifespan of the new pavement to optimize its sustainability performance. The *IRI* before resurfacing was provided by the data monitoring company per subsection of 10 m over the 10 km, and the raw data are provided in the Supplementary Materials for reproducibility purpose. It shows a very low average *IRI* of 0.37 mm/m (see details of the figures and lifetime models in the Supplementary Materials).

2.2.2. Traffic Data

We calculated highway traffic data using the toll payment data provided by the operator. The class 1 toll corresponds to passenger vehicles, class 2 to large vehicles with a total height of more than 2 m and less than 3 m (i.e., only large utility vehicles and caravans), class 3 to trucks with 2 axles, and class 4 to trucks with 3 axles or more [19]. These correspond to the 4 categories of vehicles in our method: Passenger Cars (PC), Light Commercial Vehicles (LCV), Small Heavy Vehicles (SHV), and Large Heavy Vehicles (LHV). The section carries an Annual Average Daily Traffic (AADT) of around 11,000 vehicles in each direction, consisting mainly of around 85% PCs, 5% LCVs, and 10% trucks, 9% of which having 3 axles or more (LHV). We consider traffic composition to be time-fixed, but the traffic itself to increase by 0.44% each year based on Cofiroute's data. Vehicles are considered to have the following number of tires: 4 tires for PCs, LCVs, and SHVs, and 10 tires for LHVs, 5-axle trucks being the most frequent in France. Average speeds are considered equal to 118 km per hour for LV and 88 km per hour for HV (respectively, 73 and 55 miles per hour).

2.3. Selection of Resurfacing Strategies for Comparison

We consider a new pavement commissioned on 1 January 2017. Based on the statistical study made on the rolling course ages (Figure 1), we then compare five maintenance programs that vary according to the range of the operator's resurfacing possibilities. We choose to assess the consequences of each of these resurfacing programs over an empirical road surface lifespan of 39 years. The scope of our assessment includes neither the construction of the initial rolling course in 2017 nor a 39-year resurfacing, since it is considered that the whole pavement will need to be rehabilitated at that time, including the rolling course. The treatment in these five scenarios consists in milling the road surface and replacing it with a 2.5 cm-thick asphalt concrete (VTACO), which is the main rolling course found on highways in France, as shown in a survey carried out with French road operators (see Supplementary Materials).

The characteristics of the five scenarios assessed are described in Table 1. The "REF" scenario corresponds to the reference, classically called the "Business-as-usual" (BAU) scenario. "Max_Field" corresponds to an ambitious practice scenario, i.e., the shortest resurfacing periods observed among French concessionaires. On the contrary, "Invest_Min" represents the longest resurfacing period statistically analyzed in Figure 1. This scenario could cause some problems in terms of waterproofness that could potentially put the structure at risk. Waterproofness could be ensured by crack filling. More problematic issues related to a drop in skid resistance could occur, and could also be corrected by performing sand blasting. Ideally, it would have been interesting to consider these minor maintenance operations, but the road experts highlighted their very low cost and probable negligible impact on the environment and traffic disruption.

Table 1. Specification of different resurfacing strategies tested over the lifespan of the section.

Scenario Code	Details	Number of Resurfacing Nk	Surface Lifespan
Invest_Min	Minimum investment	1	19 years 6 months
REF	Reference	2	13 years
Invest+	Increased investment	3	9 years 9 months
Max_Field	Ambitious approach	4	7 years 10 months
Invest_Max	Maximum investment	6	5 years 7 months

3. Tailored Method Parameterization and Data Development

In this section, we present the different parameters needed or tailored to apply the holistic assessment method presented in part I of this double article [4] to this specific French highway case study. We also present new data, especially the Life Cycle Inventories (LCIs) developed for the French market, to calculate the LCA indicators with better robustness.

The different sections follow the same order as the equations developed in part I for ease of reading.

3.1. International Roughness Index (IRI) Progression Models

All the impact calculations in the assessment method depend on the surface condition of the road section in question. The company that collects this highway's condition data provided the *IRI* data for the section. These data are "two-track", in other words, we were provided with two datasets per direction: one dataset for the left-hand strip and one for the right-hand strip, for the slow lane only, corresponding to the highest traffic densities (cross-sweep). Then, we calculated the surface profile of the pavement over time. The average *IRI* for the section in year 1 is calculated by averaging the scores for the left- and right-hand strips. Then, evolutions of the *IRI* are calculated over the whole lifespan of the pavement: changes excluding roadworks, and changes before/after roadworks. Between two resurfacing operations (=excluding roadworks), the *IRI* is considered to change at a rate of +0.05 m/km.yr, based on the historic *IRI* data for the entire highway. The *IRI* evolution between two resurfacing operations thus follows the following Equation (1), with t in year:

$$IRI(t) = IRI(\mathrm{t} = 0) + 0.05\mathrm{t} \tag{1}$$

The effect of resurfacing work on *IRI* is estimated by calibrating the American progression model established by Wang et al. [20] using the *IRI* data for the highway to which our studied section belongs. We used Equation (2), where e = 0.3 and g = 0.15 m/km.

$$IRI(t_{R+}) = e.IRI(t_{R-}) + g \tag{2}$$

The graphic of the *IRI* evolution model developed for the highway section is presented in the Supplementary Materials. It shows an average reference *IRI* equal to 0.77 m/km on this highway, a value that is considered for the calculation of excess fuel and tire consumption.

3.2. Consumption and Emission Parameters

3.2.1. Resurfacing Works Demand

The width ω of the pavement is equal to 11 m, composed of 3.5 m for each lane, as well as 3 m for the emergency lane and 1 m for the left flattened band. The length λ of the section studied is equal to 10,000 m. N_k, the number of resurfacing operations of type k over the assessment period, is indicated for each scenario presented in Table 1.

3.2.2. Excess Vehicle Consumption Parameters

The models to account for excess consumption and wear are presented in part I of this combined article and its Supplementary Materials [4]. Wear factors affecting tires and suspension systems over a vehicle's lifespan are considered for each vehicle category (see combined article's Supplementary Materials). Nevertheless, *IRI* remains below 3 m/km in our different scenarios; no excess suspension wear is observed. The standard lifetime mileage of the tires on highways is indicated in Table S9 of the Supplementary Materials. However, some parameters are still needed for excess fuel consumption calculations.

Excess fuel consumption is calculated based on average consumptions by type of vehicle on highways in France, using the French model CopCETE [21]. CopCETE is a tool developed for the French Ministry of Transportation. It uses COPERT V4 equations [22] and considers French average speeds on specific networks. It simulates the consumptions of different kinds of energies (and 26 types of pollutants emitted). The average consumption per type of vehicle category varies over time with technological evolutions. Technological evolutions are taken into account by considering predictions developed for the French fleet by the governmental research center IFSTTAR [23] (type and quantity of energy consumed).

3.3. Noise Emission Parameters

The average sound powers during the day (Wj) and night (Wn) are calculated using daily traffic data presented in Section 2.2.2.; the hourly repartition in the day and nighttime from the French governmental technical center Sétra are presented in Table 2 [24], with the additivity method of the noise line sources and the general methodology detailed in part I of this double-article publication [4].

Table 2. Equation to calculate q(véh,i), the hourly traffic of light and heavy vehicles on an interurban highway.

Time of the Day	Day: 6 A.M.–10 P.M.	Night: 10 P.M.–6 A.M.
LV	AADT(LV)/18	AADT(LV)/82
HV	AADT(HV)/20	AADT(HV)/39

LV = Light Vehicle; HV = Heavy Vehicle.

To add the line source's noise levels, Sétra estimated [24] that their noise levels can simply be added by considering one single line source in the middle of the pavement, under the condition that the noise receptors are in direct reception and farther than 2.4 times the width of the road platform, i.e., 40 m away from the line source for 2 × 2-lane roads, a condition that is respected for the studied highway.

3.4. Environmental Metrics: Life Cycle Inventories

To calculate the environmental impact of each maintenance strategy, we use equation 13 from the article's part I. The flows of consumption $flow_c$ are listed in the corresponding consumption life cycle inventory (LCI). We specifically develop LCIs for the French context [25], summarized in the Supplementary Materials.

For roadworks, it consists of road resurfacing processes for 1 m^2 of resurfaced pavement, for each of the eight most frequent resurfacing techniques in France, from cradle-to-laid, i.e., from the extraction of raw materials—e.g., bitumen, aggregates—to construction on site. Models have been developed based on statistics calculated from the annual data of a major French road constructor, providing around one-third of the national road construction. Each resurfacing technique consists of a first tack coat with 500 g per square meter of 65% bitumen emulsion (i.e., 325 g/sm of residual bitumen, including SBS polymers and phosphoric acid), covered with a layer of asphalt mixture. Average materials production, transportation, and use of the building machines on-site are considered based on the road company's statistics. The building machines used for the hot asphalt mixtures (HMA) are a sprayer, a roller, and a finisher. HMAs are made of 4.8% of non-modified bitumen, mixed with aggregates at around 165 °C, e.g., the average hot mixing temperature in France. The average road aggregate in France comes at 76.4% from hard rocks and 23.6% from lose rocks, transported mainly by trucks, but also partly by rail and barges. The average French asphalt mixing burner consumes heavy fuel and natural gas in the amount detailed in the Supplementary Materials. Cold techniques (double-layer micro-surfacing, double-layer dressing, double prechipped surface dressing) are made of a cold asphalt mixture (CAM), or, directly, aggregates and emulsion, and are either built with a CAM spreader/vacuum sweeper, a small loader/roller/finisher, or a binder sprayer/gravel spreader/roller on tires. Polycyclic aromatic hydrocarbon (PAH) emissions are also calculated based on simplified convection models (see Supplementary Materials). For dressing and CAM techniques, the 65% bitumen emulsion is also used. One ton of CAM contains 103 kg of this emulsion, e.g., 6.7% of residual bitumen in the mixture. The asphalt mixture density after compaction is considered equal to 2.4 t/m^3.

The environmental impact of the techniques used in this case study and calculated with the characterization IMPACT World+ and ReCiPe are presented in Table 3, including SCACO, very thin or thin asphalt concrete overlays (resp. VTACO and TACO, that are

2.5 and 4-cm thick in France), and double prechipped surface treatment (ST). The impact of other operations can be found in a Supplementary File S1.

Table 3. Damage to the environment from resurfacing operations over 1 m^2.

Damage	Unit	Milling	SCACO	TACO	TACO	VTACO	Double Prechipped ST
Health	DALY	2.49×10^{-5}	3.51×10^{-3}	2.37×10^{-3}	1.52×10^{-3}	9.45×10^{-5}	7.01×10^{-5}
Biodiversity	PDF.m^2.yr	2.77×10	1.18×10^{2}	8.01×10	5.19×10	3.29×10	2.75×10
Resources	USD	1.53×10^{-1}	1.71×10	1.17×10	7.59×10	4.85×10^{-1}	4.98×10^{-1}

DALY = Disability Adjusted Life Years; PDF = Potentially Disappeared Fraction.

For vehicles, LCIs relate to fuel consumption, as well as tire and suspension wear. LCIs per kilometer traveled for the use of internal combustion engine vehicles take account of forecast technological developments based on IFSTTAR's prediction model for France's vehicle fleet [23]. Trucks remain 100% diesel, while light vehicles show evolving shares of technologies overtime (see Supplementary Materials). These processes consider emissions of 26 types of substances—heavy metals, gaseous pollutants—specified in the Supplementary Materials, using the French Department of Environment's CopCETE software [21]. Linearity between the energy consumed and the quantity of each pollutant emitted are considered per type of energy, due to a lack of a more accurate model. Diesel and petroleum densities are assumed equal to respectively 0.85 and 0.75 kg/L. The environmental damage from fuel supply and combustion is presented in the Supplementary File S1.

Finally, an in-house environmentally extended input–output analysis is developed to assess the damage from using garages to maintain the vehicles, based on statistical garage expenses, activities, and revenue [26], synthesized in the Supplementary Materials. Shock absorber and tire LCIs are also presented in the Supplementary Materials. The environmental impacts of maintenance operations are presented in Table 4.

Table 4. Damage to the environment from vehicle maintenance.

Functional Unit		One Kit of Shock Absorbers for One Vehicle				One Kit of Tires for One Vehicle				Maintenance Service
Damage	Unit	PC	LCV	Small HV	Large HV	PC	LCV	Small HV	Large HV	EUR 1
Health	DALY	1.27×10^{-3}	2.71×10^{-3}	3.19×10^{-3}	9.47×10^{-3}	4.57×10^{-3}	1.42×10^{-2}	2.16×10^{-2}	9.38×10^{-2}	3.88×10^{-8}
Biodiversity	PDF.m^2.yr	1.69×10	3.59×10	4.23×10	1.29×10^{2}	9.94×10	2.95×10	4.19×10^{2}	1.80×10^{3}	1.79×10^{-4}
Resources	USD	2.45×10	5.21×10	6.13×10	1.85×10	7.67×10	2.38×10	2.84×10	1.22×10^{2}	1.02×10^{-5}

3.5. Social Metric Parameters

3.5.1. Road Noise Health Impact Indicator

The residents' health damage due to traffic noise is calculated over the 39 years of the assessment period according to Equation (15) of the article's part I, using noise emission parameters calculated previously.

3.5.2. Time Loss Parameters

- Roadwork time losses

Roadworks are carried out by means of daytime lane closures, with all the traffic of the highway sent the same way, each direction having one lane instead of two. Average resurfacing construction speeds are taken to be 800 m per day, full width.

Light vehicle speeds are reduced to 90 km/h maximum, instead of 130 km/h normally. We consider this maximum speed to equal the average speed during the resurfacing works. The HV speed is not affected by this new speed limit. No congestion, only reduced speeds, is noted on the section during the roadworks, as a result of being a low-traffic highway. In this simple case, the time loss in work zones is considered relational to a reduction in the authorized speed on the section maintained, in free flow. We use the time-saving formula shown in Equation (3) to calculate the time loss by a vehicle of type i passing through a work zone with its length, $Length_{road\ section}$, the reduced speed due to roadworks for the type of vehicle i, $v_{reduced,i}$, and the standard speed on the section, $v_{standard,i}$.

$$Time_{saved,works,\ i} = Length_{road\ section} \cdot \left[\frac{1}{v_{reduced,i}} - \frac{1}{v_{standard,i}} \right] \quad (3)$$

To calculate the time losses due to roadworks for each alternative road maintenance, we use Equation (17) from the double article's part I [4], by calculating the hourly traffic using Table 2.

- Consumptions time losses

The operation duration of maintenance activities OD_j, which is considered to calculate vehicle consumption time losses, is indicated in Table 5, and explained in the Supplementary Materials.

Table 5. Estimates of the duration of the various operations and maintenance activities.

OPERATION Duration	PC	LCV	SHV	LHV
Tire replacement (min/veh)	120	150	150	480
Suspension replacement (min/veh)	330	330	30	30
Fueling (min/100 L)	40	25	1.9	1.1

3.6. Economic Metric Parameters

3.6.1. Discount and Inflation Rates

The default discount rates for the different stakeholders considered are as follows: 2.5% for society, 1% for government and households, and 8% for Cofiroute, the rate of return for this highway operator being 8.28% in 2018. To account for dynamic economic evolutions, inflation rates are estimated based on linear regressions applied to INSEE's time series for monthly inflation rates (see Supplementary Materials), INSEE being the French national institute for statistics and economic studies. The inflation rate for roadworks is selected based on trends in the Consumer Price Index in France since 1966 [27], i.e., 1.4%, in the absence of consistent trends for the costs of roadworks or even construction works. The inflation rate for service station vehicle maintenance costs is taken to be 6% between 1998 and 2015 [28].

3.6.2. User Cost Parameters

The first step in our calculation of user costs over a given period is to calculate for each year, each type of vehicle, and each type of expenditure, the annual expenditure in current euros for all users. To do this, we multiply the volumes of goods consumed by the unit prices of these goods in current euros. We thus arrive at a table containing, for each year, the sum of the costs in current euros for all traffic.

For the case of the maintenance of suspensions and tires, we developed models of kilometric costs, including tax in 2017 euros, which are presented in the Supplementary Materials of the article part I [4]. To transform these costs into current euros, we use the INSEE series statistics, which follow the inflation of goods (see Supplementary Materials).

Fuel price is made up of the price excluding crude oil taxes set by the market, the cost of refining, transportation and distribution, and taxes, following Equation (4). The taxes levied by the government in France are the Value Added Tax (VAT) and the Domestic Consumption Tax on Energy Products (TICPE). These components vary depending on the fuel considered. The VAT rate on the consumption of natural gas and petroleum products is the normal rate as of 24 January 2018, i.e., 20%. VAT applies to the product itself and the

TICPE. Prior to 1 January 2014, VAT was set at 19.6%. The fuel price formula is therefore that of Equation (16).

$$FuelPrice,\ including\ tax_{\ year\ i} = (FuelPrice,\ excluding\ tax + TICPE)_{year\ i} \times (1 + VAT)_{year\ i} \quad (4)$$

The price of diesel and petroleum in January 2017 was, respectively, 1.27 and 1.48 EUR/L, including tax (current euros). Based on statistical analyses and linear regressions carried out on the INSEE statistical series (see Supplementary Materials), fuel markets are quite volatile, but we studied trends in the price of a barrel of oil (Brent), margins and processing, then taxes. Between 1990 and 2018, we find the following annual trends for diesel: +0.007 EUR/L for the "barrel" part and +0.004 EUR/L for the "margin and transformation" part, i.e., +0.011 EUR/L on the price, excluding tax.

The TICPE is likely to vary in France over the next few years for two reasons. First, a tax catch-up was planned between diesel and gasoline between 2017 and 2022, diesel having so far been fiscally advantaged, despite its leading role in atmospheric pollution. This results in an increase of 4.33 cents/L.year for diesel and 2.02 cents/L.year for petroleum for the 2017–2022 period. Then, an ambitious carbon tax increase was proposed by the Quinet commission [29], generating an increase of 1.78 EURcent/L.year after 2023.

3.6.3. Road Operator Costs

In the absence of a quality cost database, we propose to consider as resurfacing costs the current costs of the French techniques, calculated based on the responses collected in our survey of French interurban road managers (Table 6).

Table 6. Costs of resurfacing techniques in constant currency, including tax (2017 euros).

Cost	SCACO	TACO	VTACO	CMA	ST
Average (EUR/m^2)	18	14	10	5	3

From the database of prices of resurfacing techniques inclusive of all taxes, we obtain the basic price for roadworks, deducting 20% for VAT, together with an 8% profit margin, based on the national economic data for the "civil engineering" branch obtained from INSEE.

3.6.4. Macroeconomic Datasets

- General calculation

To assess the impact of a variation in the final demand for a product on the production of the entire economic system, we use the Leontief inversion relationship presented in this article's part I to make our production calculation. Finally, depending on the demand vector of the maintenance scenario to be assessed, this vector is evaluated with the costs in basic prices (which, for simplicity, are considered equivalent to the price, excluding VAT, even if this is an approximation) of consumption in vehicle maintenance, fuel, and civil engineering. The total output of the system studied is obtained by summing all the terms of the vector P.

- Production dataset

We obtained from the Department of National Accounts of INSEE three types of tables for the years 2010 to 2013, with a disaggregation into 138 branches and products. These tables are confidential data and not supplied in this study. The supply–use balance table (ERE) quantifies the effects of imports for each product (total imports, customs duties, territorial adjustment, subsidies, transport, and trade margins), as well as taxes and duties. It also informs about the market aspect (stocks and investments). The Intermediate Inputs table (TEI) indicates the intermediate product consumption of each branch. It is often rectangular, because a branch can produce several products, and presents basic prices, i.e., the price invoiced by the producer. plus any subsidy minus taxes on each product. TES outputs are shown at base prices (i.e., the amount the producer receives from the buyer per unit of good or service produced, minus taxes on products, plus subsidies on products. The base price excludes transport costs, invoiced separately in current euros (EUR2010 to EUR2013). In this modeling, we consider the matrix of technical coefficients obtained with the most recent economic data, i.e., those of the year 2013. We consider that this matrix is stable, which is approximate, especially in the long term. Finally, we do our calculations in current euros.

- Employment dataset

INSEE supplied the table of domestic employment content by branch in thousands of Full-Time Equivalent jobs over one year (FTE.year) of the 2013 French economy in 88 branches (confidential data). According to the advice of INSEE experts, the employment content assumedly depends linearly on the added value of the same sub-branch in accounting for 138 branches—data to which we also had access through INSEE. We thus broke down the 88 branches' employment content into the 138 production branches to get vectors of the same dimensions to perform our calculation. Employment content calculated are respectively 16.4, 14.4, and 7.2 FTE.year per million euros of demand, excluding tax for garage maintenance, road maintenance, and fuel demand. These figures are consistent with the French literature [29,30].

3.6.5. Tax Revenues

The taxation of road fuels has been detailed in the fuel price model, and consists of the TICPE and the VAT, the latter applying both to the price excluding tax of the fuel and the TICPE. HVs from the European Union can benefit, on request, from a flat-rate partial reimbursement of the TICPE. In the second half of 2017, this rate was EUR11.42/100 L. We consider this to be fixed-rate, without adjusting it for inflation in our model, in the absence of forward-looking data on the evolution of this fixed reimbursement.

The taxation of vehicle maintenance concerns tires, as well as suspensions. In our model, both for the maintenance of tires and suspensions, we propose to retain a VAT of 20% on passenger cars, and 0% for other vehicles, although the rate of exempt professional vehicles is probably not 100%.

Finally, taxes on maintenance operations are not taken into account in the calculation of the government's fiscal surplus because there is a company–government transfer; these taxes are said to be "neutral" [31].

3.6.6. Integrated National Economy

Based on the generic equation presented in part I, the overall financial indicator for road maintenance programs must take into account maintenance (manager) and operating (manager, users) expenditure, as well as government expenditure and revenue. We only count tax receipts for the government, in the absence of data on corporate tax receipts and savings made by job creation (savings in unemployment allowances). Rates of return can be calculated in constant or current euros, however, financial and economic profitability would only make sense in "real terms", i.e., in nominal terms taking inflation into account [31]. The assessment of the overall societal cost is based on values excluding tax at constant euros [32]. To calculate the cost, the opposite of the Net Present Value (NPV) is calculated, using a single discount rate for society at 2.5%, which is the risk-free discount rate recommended by the French Ministry (we consider a risk premium of 0% instead of the 2% recommended) [29].

4. Results

The calculations for the application of the method described in part I of this double article [4] to the case study described in this part II article were carried out using Scilab. This free multiplatform software offers an appropriate environment for scientific applications and uses a programming language designed for high-level numerical calculation. The Scilab code is made available on Github [33] and can easily be adapted to MATLAB language for further usage.

4.1. Comparison of Alternative Maintenance Programs

4.1.1. Sustainable Performance Trends

Figure 2 represents the gains achieved by altering the maintenance program from the highway resurfacing practices currently employed in France (reference scenario). It shows the gains from each of the four alternative maintenance programs on the eleven impact indicators, gains normalized by the maximum gain in each impact category. The darker the color of the bars in the histogram, the higher the level of investment required for the maintenance program it represents. Two groups of indicators emerge, which behave in opposite ways in response to a change in the level of investment in maintenance: two-thirds of the indicators show benefits that grow as the amount invested in maintenance rises, whereas one-third of the indicators shows losses that grow with rising investment. The batch of performance indicators improving with increased maintenance encompasses savings for users, domestic employment and production, as well as health protection related to noise and other environmental impacts, natural resources, and biodiversity. The batch of performance indicators deteriorating with increased maintenance consists of four indicators: tax revenues, savings for the operator, global NPV, and time saved by users.

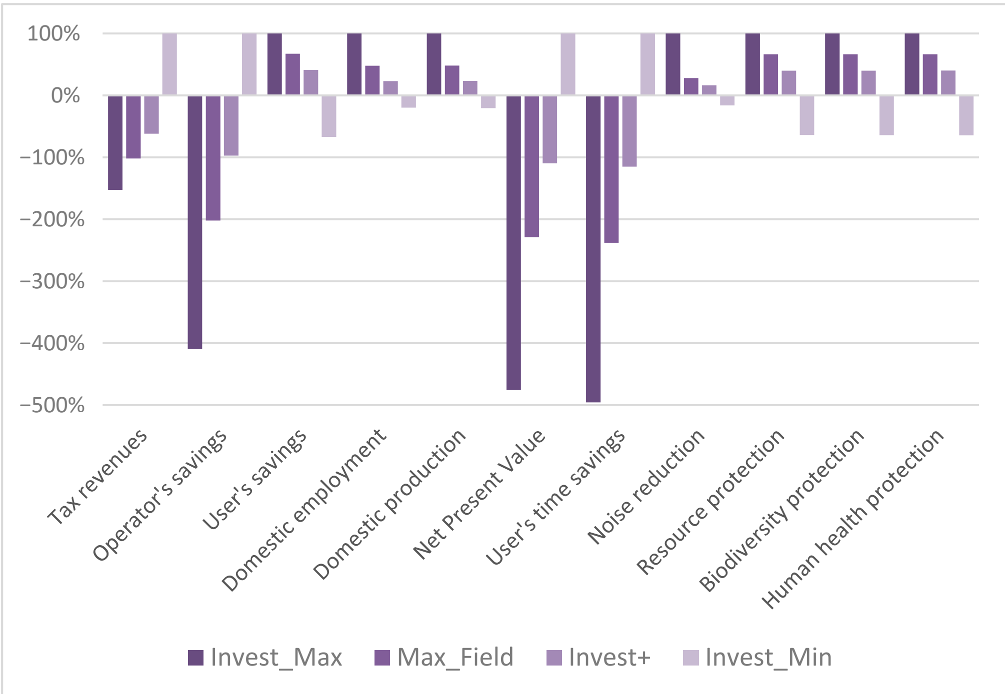

Figure 2. Advantage in choosing the variant relative to the standard program (mathematical normalization by the maximum gain for each indicator).

For the first batch, halving the investment in maintenance compared with current practices generates losses whose absolute value is at least the same as the gains generated by increasing the current maintenance budgets by 50% (noise-related health damage or macroeconomic indicators) and at most equivalent to the level of the gains generated by doubling the maintenance budgets (savings for users, savings in nonrenewable resources, protection of public health). For the second batch, the importance of the loss (in absolute value) caused by tripling the investment in road maintenance even exceeds the gains produced by halving the maintenance budgets.

In this study, the damages to human health due to local pollution from road transportation and traffic noise evolution are compared for the first time. It shows that the evolution of traffic noise due to maintenance strategies has a very low impact on human health damage compared to the evolution of local pollution.

4.1.2. Sustainable Gains' Values

The values of gains and losses over the 39 years of the study period are shown in Table 7 for the financial and economic indicators, and in Table 8 for the social and environmental indicators. These tables show that for the highway and maintenance programs studied, tripling the current level of investment in the maintenance of highway road surfaces would lead to gains of 3.21 million euros for users, 42 FTE years of employment (FTE.yr), almost 9 million euros at 2017 values in French production, the equivalent of almost two DALYs in local environmental noise reduction, and, finally, savings of 120 million US dollars in natural resources, 480 million PDF.m^2.yr in biodiversity, and almost 7700 DALYs as a result of pollution reductions. On the other hand, this tripling in the maintenance budget would lead to losses of 1 million euros in tax revenues, 1.64 million euros for the road operator, 2.13 million euros for society in terms of NPV, and a cumulative time loss of 3.15 years for users. These figures show that the financial gains on a standalone basis exceed by far the losses under a tripled maintenance budget: the gains reach 123 million euros when summing users' gains and natural resources gain, while the losses are limited to 2.64 million euros when summing tax revenue losses and road operator losses. As the positive impacts also include substantial gains in terms of biodiversity and human health protection, a high increase in road resurfacing investment effort is undoubtfully of public interest.

Table 7. Values of the financial and economic gains resulting from a change in the maintenance schedule.

Scenario	Tax Revenues (k EUR)	Operator Savings (k EUR)	User Savings (k EUR)	Employment (FTE.yr)	Production (k EUR 2017)	Total Savings (k EUR 2017)
Invest_Max	-1.06×10^3	-1.64×10^3	3.21×10^3	4.24×10	8.83×10^3	-2.13×10^3
Max_Field	-7.10×10^2	-8.07×10^2	2.16×10^3	2.03×10	4.25×10^3	-1.02×10^3
Invest+	-4.31×10^2	-3.88×10^2	1.32×10^3	9.75×10^2	2.06×10^3	-4.90×10^2
Invest_Min	6.96×10^2	3.99×10^2	-2.16×10^3	-8.35×10^2	-1.82×10^3	4.47×10^2

Table 8. Values of the social and environmental gains resulting from a change in the maintenance schedule.

Scenario	Time Saved (Days)	Noise Reduction (DALY)	"Resource" Gains (USD)	"Biodiversity" Gains (PDF.m^2.yr)	"Health" Gains (DALY)
Invest_Max	-1.15×10^3	1.79×10	1.20×10^8	4.80×10^8	7.69×10^3
Max_Field	-5.52×10^2	5.00×10	7.96×10^7	3.19×10^8	5.12×10^3
Invest+	-2.67×10^2	2.92×10	4.78×10^7	1.92×10^8	3.08×10^3
Invest_Min	2.32×10^2	-2.91×10	-7.67×10^7	-3.08×10^8	-4.95×10^3

Conversely, halving the investment in resurfacing the 10 km highway section studied over 39 years would lead to a loss of 2.16 million euros to users, 8.4 FTE.yr in France, and 1.82 million euros at 2017 values in national production, and cost the equivalent of 0.3 DALYs from increases in local environmental noise, 77 million US dollars in non-renewable resources, 308 million PDF.m^2.yr in biodiversity, and 4950 DALYs from other health damage. In return, this decision would result in an extra 0.70 million euros in tax revenues to the state, savings of 0.40 million euros for the operators, a cumulative time saving of almost 8 months for users, and savings to society of 0.45 million euros. In this decreasing resurfacing frequency scenario, gains reach less than one million euros, while losses account for almost 80 million euros. This comparison consolidates the conclusion that we should increase highway resurfacing to adopt a more sustainable pathway, based on this case study.

4.1.3. Key Factors of the Composite Indicators

The indicators that we call "composite" depend both on the intensity of roadworks and the vehicle consumption in fuel, tires, and suspensions. They are, namely, the gains in time for users, domestic jobs and production, NPV, as well as the three environmental gains. We propose to study the composition of these gains and losses (excluding NPV) in only three alternative scenarios to show the trends in the contribution variability, depending on the maintenance policy direction chosen. The results are presented in Figure 3. The number and name of the maintenance strategy is indicated in the legend after the name of the composite indicator. They show that, for the section of highway studied, the environmental gains and losses depend exclusively on fuel consumption. Road construction operations and tire replacement have a negligible contribution. Conversely, the macroeconomic gains or losses, as well as those in user time, depend mainly on roadwork operations; they bring around 80% of the gain for the scenarios study. Then, the influence of fuel consumption ranges from 5% to 20% of the impact changes. Tire wear has minimal impact on time wasted or gained (<2%), but accounts for up to 7% of the total absolute values of job gains and losses, in the minimum investment scenario. We recall that suspensions do not appear among the contributors, since the *IRI* in this case study remains under 3 m/km over the pavement lifespan, whichever scenario considered, i.e., under the *IRI* threshold to see early deterioration of shock absorbers.

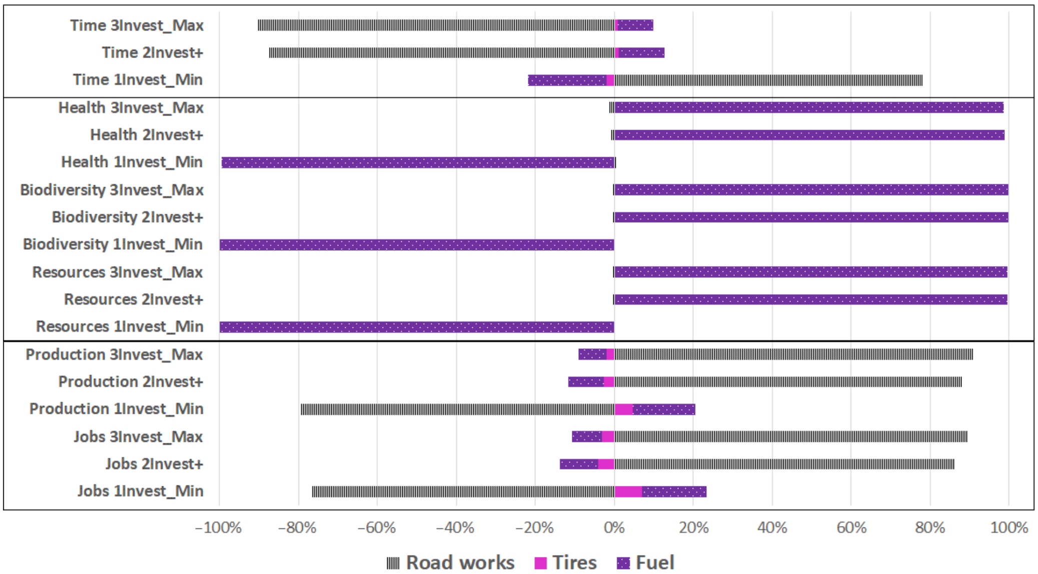

Figure 3. Composition of the composite gains for three of the alternative maintenance scenarios.

Nevertheless, at the scale of the road section, the key factors depend on the level and composition of the traffic, and the infrastructure considered (maintenance schedule, speed of deterioration in *IRI*, and vehicle speeds). The main contributors may be different on different road networks.

4.2. Additional Economic Analyses

4.2.1. Multi-Actor Financial Savings Consideration

Figure 4 gives a continuous smoothed representation of the discrete savings generated by changing the road surface lifespan for the set of financial stakeholders {operator + users + government}, to show the trend in the gains depending on maintenance frequency. Here the personal discount rate of each type of the three stakeholders are considered, as discussed before. Investing more in resurfacing generates global financial savings, up to 0.65 million euros for four additional resurfacings over 39 years, while investing less leads to financial losses, up to 1.05 million euros, when one resurfacing operation is canceled over the highway's lifespan. The figure shows a global financial optimum between one and four extra resurfacing operations (e.g., for a road surface lifespan of between 5.6 and 9.75 years). Nevertheless, this optimum applies under the current tax system, which is a politically adjustable variable.

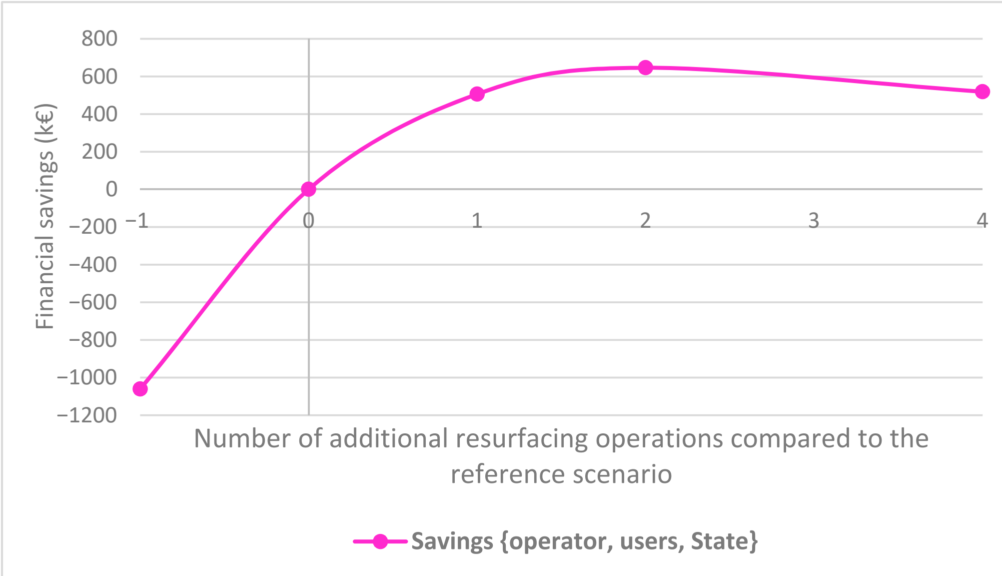

Figure 4. Multi-actor financial gains associated with changes in resurfacing strategies (reference: 13 years).

4.2.2. Cost Effectiveness of Maintenance for Users

We calculated the ratio of the savings made by users from the additional amount invested in resurfacing by the highway operator. This discrete cost effectiveness is represented by continuous smoothing, relative to the additional resurfacing operations to the standard in Figure 5.

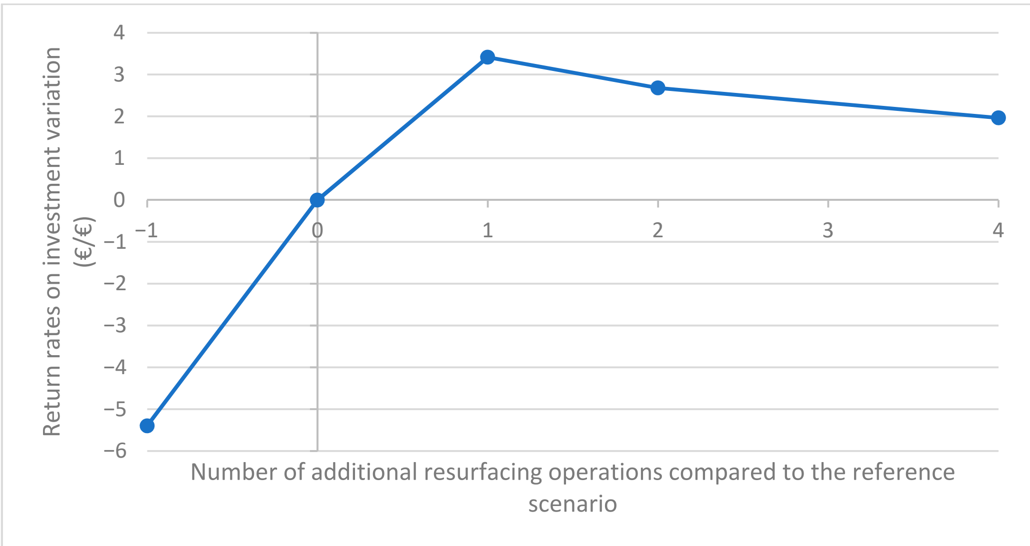

Figure 5. Users' savings for each additional euro invested in maintenance by the road operator (relative to the standard maintenance level).

This figure indicates that each additional euro invested in maintenance generates a saving of between EUR 2 and EUR 3.5 for users. From a practical point of view, maximum cost effectiveness in this case study is achieved by moving from two to three resurfacing treatments over 39 years, i.e., from a road surface lifespan of 13 years to slightly less than

10 years. Mathematically, however, the optimum could be situated between two and four resurfacing operations over 39 years. In the case of a reduction in maintenance, each euro saved by the operator in the minimum investment scenario costs users up to EUR 5.4.

4.2.3. Cost Effectiveness of Maintenance in Health Terms

The notion of cost effectiveness as applied to the financial aspect of maintenance can be extended to public health. Some governments use Values of Statistical Life (VSL) in their socio-economic calculations; in France, the Ministry uses the value of EUR 115,000 (at 2010 values) per year of life [29]. One DALY is equivalent to one year of quality life lost; by equating one DALY of impact on human health with EUR 115,000 at 2010 values, one can calculate the cost effectiveness of investment in resurfacing. By discounting the average VSL for 2017–2056 at a rate of 1%, i.e., leading approximately to EUR 89,000/DALY at the end of the period, one can estimate a "health cost effectiveness", i.e., the cost effectiveness in terms of global public health of marginal investment in maintenance for the road surfaces on our section of highway. Figure 6 shows the ratio of savings made in terms of monetized human lives on the additional amount invested in resurfacing by the highway operator, according to the number of additional resurfacings carried out relative to the standard (i.e., two over 39 years). This "global health return" on investment in highway resurfacing is significantly higher than the financial return; each additional euro invested in maintenance leads to a saving of between EUR 420 and EUR 710 in terms of human life value (respectively, for four to one additional resurfacing operations over 39 years). The maximum return in this example is achieved by moving from two to three resurfacing treatments over 39 years, i.e., from a road surface lifespan of 13 years to slightly less than 10 years. In Figure 6, we can also see that one euro saved in the minimum investment scenario relative to the standard scenario generates a loss of EUR 1100 in human life value.

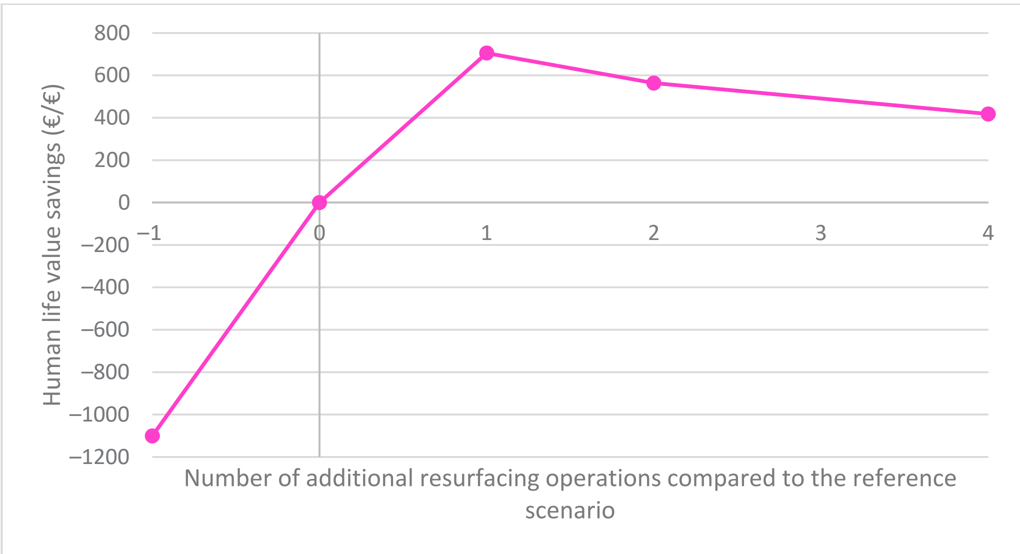

Figure 6. Total health impact per additional euro spent on resurfacing by the operator, depending on the number of additional resurfacing operations carried out over the lifespan of the road.

4.3. Sensitivity of the Marginal Gains

4.3.1. Sensitivity to the Resurfacing Technique

Based on the same resurfacing schedule scenarios, we studied the sensitivity of the results to the road technique used on French highways: 2.5 cm VTACO (baseline) vs. 6 cm SCACO, 4 cm TACO, 1.5 cm VTACO, or double prechipped surface treatment. Since the *IRI* progression model does not differ within these asphalt concrete techniques [20], the objective is indirectly to analyze roughly the variation in gains and losses as a function of the quantities of resurfacing materials used. We present the marginal gain sensitivity to the technique thickness between the baseline scenario and the minimum and maximal investment scenarios in Figure 7, based on the 2.5 cm-thick reference technique. It highlights three groups of indicators with similar behavior. Under the line of equation y = 1, the marginal gains are less affected by this technique than the baseline one (in absolute value), and vice versa. Three indicators are not affected by a modification of the technique in our model: user savings (same *IRI* degradation laws), time savings (single operation pace), and tax revenue (no VAT on road works). However, we also notice that the environmental indicators are not affected either by the resurfacing technique used; they are mainly influenced by fuel consumption, as shown above, as the direct environmental impact of road works is negligible. On the other hand, four types of indicators are highly sensitive to the technique used: the two macroeconomic gains, the global NPV, and the gain for the operator. The model also accounts for the difference in the acoustic category between techniques: surface treatment and thick asphalt concrete in class R3, thin asphalt concrete in class R2. The absolute value of the gains is more sensitive to the thickness when the maintenance rate is slowed down compared to the reference (multiplication factor for the thick asphalt concrete alternative up to 2.20, instead of 1.95, in the maximum investment scenario, on employment, production, road operation savings, and global NPV).

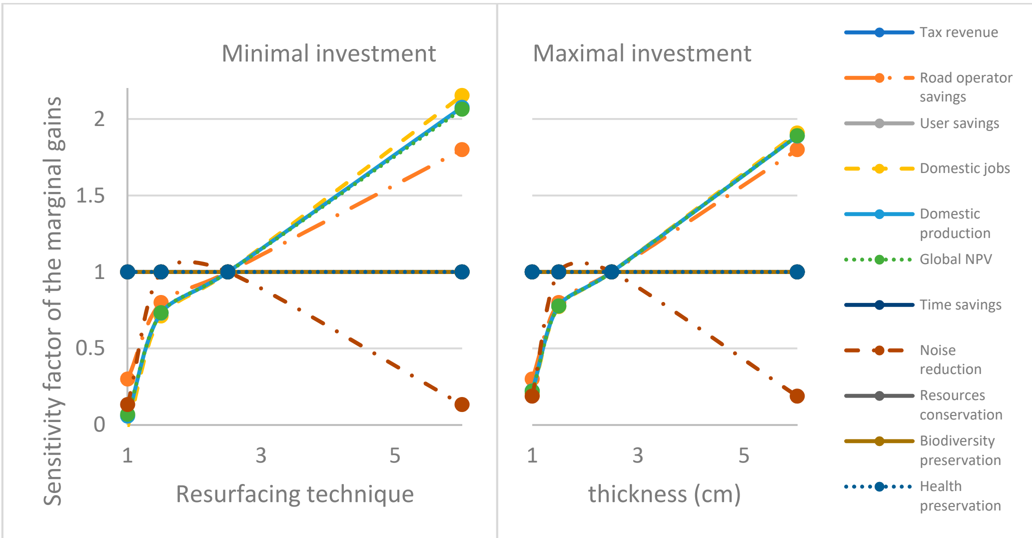

Figure 7. Sensitivity of the marginal gains to the thickness of the resurfacing technique, in the scenarios of minimum and maximum investments.

4.3.2. Sensitivity to the Traffic Level

We test the sensitivity of the results, ceteris paribus, to the AADT, with a factor of ½, 2, and 3 applied to the traffic of the highway studied (i.e., base case with approximately 10000 vehicles per day). The results are presented in Figure 8, under the minimal and the maximal investment scenarios. Under the maximal investment scenario, four groups of indicators behave similarly under changes in the level of traffic. First, there is a group of indicators perfectly proportional to traffic, which includes tax revenue, savings for users, time saved, reduction of the health impact of noise. Then, a second group gathering environmental indicators behaves very similarly. It is roughly linear to traffic, with a slightly increased sensitivity for the health gain relative to the biodiversity gain, and even higher gain in terms of consumption of non-renewable resources. A third group of marginal gains, weakly sensitive to the level of traffic, emerges; it includes the gain in employment, production, and overall economy (NPV). Finally, the manager's investment indicator is obviously not sensitive to traffic, insofar as we do not take into account the impact of works on toll receipts in the case of motorways, nor the effect of the state of the road on the route choice (highways vs. national roads vs. departmental roads). With the minimum investment scenario, we find the same four groups, with the behavior of group n°2 even closer to the behavior of group n°1 (almost identical). Finally, the gains of the third group are more sensitive to traffic in the minimum investment scenario than in the maximum investment scenario.

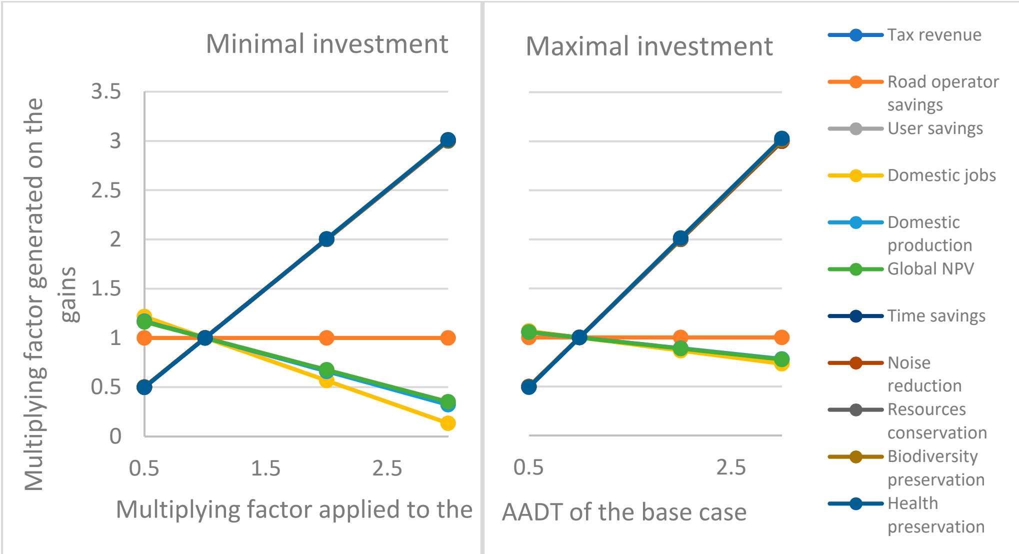

Figure 8. Sensitivity of the marginal gains to the traffic level in the scenarios of minimum and maximum investments.

4.3.3. Sensitivity to the Rolling Course Deterioration Speed

We now study the sensitivity of the indicators to the speed of degradation of the *IRI* as a function of time. In the base scenario, this slope is set at 0.05 m/km per year, and we evaluate the sensitivity of our calculation algorithm to *IRI* slopes affected by a factor of ½, 2 and 3, yielding respective *IRI* time slopes of 0.025 m/km.year, 0.10 m/km.year, and 0.15 m/km.year. Statistical studies of the *IRI* levels simulated according to our coating degradation laws and the effect of resurfacing work were also carried out to test the likelihood of the chosen variants. For each sensitivity analysis, we studied, in particular, the mean, median *IRI* values, and the standard deviation for each series of annual values.

This sensitivity study is presented for the minimum and maximum investment scenarios in Figure 9. Three groups of indicators with similar behavior concerning the evolution of the rate of degradation appear. First, a group of indicators appears almost proportional to the rate of degradation, which includes tax revenue, savings for users, time saved, and environmental gains. A second group of indicators, slightly sensitive to the speed of deterioration, emerges; it includes employment and production indicators, as well as the overall economy. The sensitivity to the degradation rate of this group increases when the resurfacing frequency is reduced. Finally, the manager's investment gains and the health impact of noise are not sensitive to the rate of degradation. In fact, the noise level should depend on the surface condition, but our acoustic emission model uses temporal statistical formulas that are uncertain at old age because of a lack of data on old rolling courses (i.e., >15 years), and without consideration of the IRI.

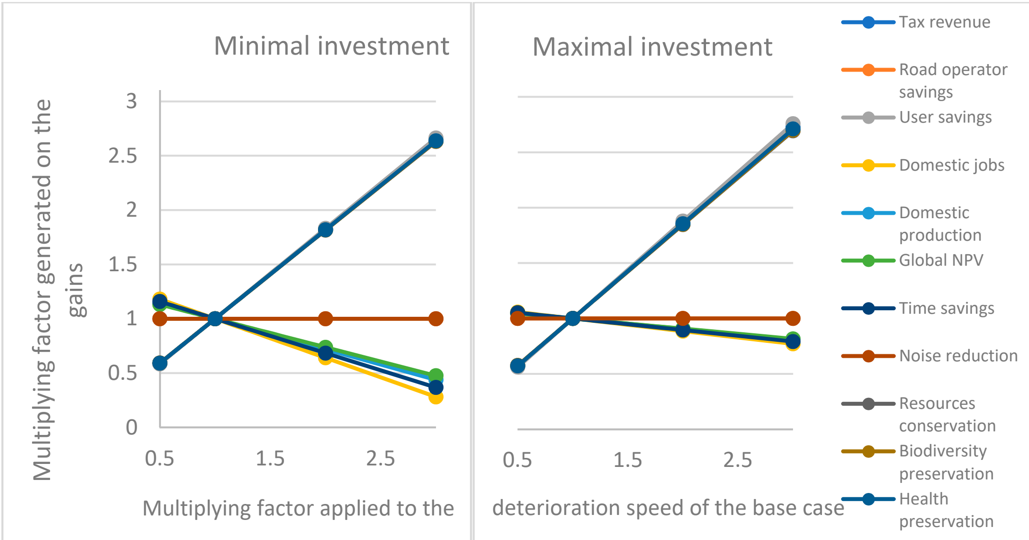

Figure 9. Sensitivity of the marginal gains to the road surface deterioration speed in the scenarios of minimum and maximum investments.

5. Discussion

5.1. Addressing the Assessment Reliability

Uncertainties and variability are essential issues in simulation models developed for decision support purposes. There are uncertainties across the whole modeling chain, from the input data to the performance results. Until these uncertainties can be characterized with appropriate mathematical approaches, the lessons obtained from case studies carried out by means of this method need to be applied with caution. In terms of variability, it would be in the public interest for the method to be applied to roads that are not privately operated, and/or with characteristics differing from highways, e.g., traffic level or operator discount rate, in order to draw trends in terms of optimum resurfacing and maintenance strategies for the country's different road network types.

5.2. Aligning the Interests of the Road Maintenance Stakeholders

Roughly two-thirds of the performance indicators change positively with a higher frequency of highway resurfacing, while the other third changes negatively. We discuss this result and propose several avenues for performance improvement of maintenance programs. Highway strategic management schemes—and notably the relationship between a public authority and a private concessionaire—need to be modified to benefit the environment and macroeconomic outcomes. Nevertheless, the savings generated by job creation—reduced payouts of unemployment compensation and increased payroll taxes—are outside the scope of the current method, but their inclusion could offset the tax revenue loss. The additional cost to the highway operator implied by an investment increase can be justified by the public service provided: savings to users, reduction in the impact on health and noise. With respect to road concessions, a fair system of remuneration needs to be introduced to nudge investment efforts towards the multi-criteria social optimum, negotiated in the contracts between government and operators based on sustainability criteria. The overall benefit indicator recommended for highway maintenance studies in France [29] is a questionable indicator, since it sets a single discount rate and, therefore, in our view, does not represent the reality of the behaviors of the different economic agents. Moreover, two versions of this indicator exist: a 100% financial indicator (classic NPV), and a socioeconomic NPV (SE-NPV) that includes monetized environmental and social impacts. Thus, this indicator aggregates various impacts through a weighting that is politically subjective—relying on monetization, i.e., a capitalistic approach of the society—not allowing for alternative weighting representing other socioeconomic ethics [34]. Moreover, it does not encompass PVI consequences or most of the environmental impacts of road maintenance. Finally, our case study results also show that the time lost under more intensive maintenance scenarios could be reduced by improving roadwork management. It, therefore, seems possible to obtain a more consensual "optimum" maintenance strategy, so that public action becomes consistent with viable, bearable, and equitable development.

6. Conclusions

We have developed a holistic method to evaluate the sustainability of transportation policies and, especially, road resurfacing strategies [4]. Here, it is applied to a French highway section, providing elements to build a three-pillar sustainability strategy for road maintenance. Compared with the reference scenario that represents the standard French highway resurfacing scheme, increasing resurfacing frequency—thus maintenance investment efforts—has a positive effect on the majority of the 11 performance indicators: macroeconomic, environmental, and social benefits. In terms of pollution, each additional euro invested in resurfacing could generate a gain in human health equivalent value representing several hundred euros, depending on the level of traffic. Increased maintenance is also positive for road noise and user savings, potentially sparing several euros for each additional euro invested, depending on traffic levels. On the other hand, increased maintenance generates financial losses for the operator and the government in terms of tax revenues, mainly due to fuel savings generated by a smoother road surface. Thus, when resurfacing policies are modified, some actors gain, others lose. The business model of road maintenance, therefore, needs to be revised to align the currently diverging interests of the stakeholders. In particular, the optimization of high-traffic roads requires increased maintenance to reduce the damage to the environment of transportation, by reducing the energy consumption of vehicles.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su14127336/s1, Supplementary Materials File S1.

Author Contributions: Conceptualization: A.d.B. and F.L.; methodology: A.d.B. and F.L.; software: A.d.B.; validation: A.d.B.; formal analysis: A.d.B.; investigation: A.d.B.; data curation: A.d.B.; writing—original draft preparation: A.d.B.; writing—review and editing: A.d.B. and F.L.; visualization: A.d.B.; supervision: F.L. and A.F.; project administration: F.L. and A.F.; funding acquisition: F.L. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: The code used to calculate results is available on the GitHub repository accessible at the following link: https://github.com/Anne2B/PhD. Data that are not made available in the Supplementary Materials (e.g., national account tables) were obtained from various third parties and are available from the authors on a case-by-case basis, if the permission is given from the third parties (e.g., INSEE). A word document gives details on figures, modes and datasets used, and Supplementary Materials File S1 are also provided.

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Abbreviations

AADT	Annual Average Daily Traffic
BAU	Business-As-Usual
DALY	Disability Adjusted Life Years
FTE	Full-Time Equivalent
HV	Heavy Vehicle

INSEE	National Institute of Statistics and Economic Studies (=Institut national de la statistique et des études économiques)
IRI	International Roughness Index
LCV	Light Commercial Vehicle
LHV	Large Heavy Vehicle
LV	Light Vehicle
NPV	Net Present Value
PC	Passenger Car
PDF	Potentially Disappeared Fraction
PVI	Pavement-Vehicle Interactions
SCACO	Semi-coarse asphalt concrete overlay
SHV	Small Heavy Vehicle
TACO	Thin asphalt concrete overlay
TICPE	Domestic Consumption Tax on Energy Products (=Taxe intérieure de consommation sur les produits énergétiques)
VAT	Value added tax
VTACO	Very thin asphalt concrete overlay

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