Effect and Function of Green Tracks

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Effect and Function of Green Tracks

Tram tracks are greened for several reasons and cause ecological, economic as well as urban design effects. These positive aspects are especially effective in highly sealed urban areas. Greening of two kilometres double track creates a green space of 10 000 m² [1]. According to a survey at the end of 2011 Germany had more than 425 km of greened single tracks[1] [2]. This track length equals a green space of more than 106 ha, or 1.06 million m², respectively. Additionally adjacent areas are usually greened, as well. These green areas provide the positive aspects of vegetation systems mentioned above. The most important effects are presented below.

1 Urban Ecological Effects of Green Tracks

Sealing especially of urban inner city areas, high traffic volume and other factors lead to adverse ecological consequences, for example on urban climate, which are associated with considerable consequential costs. Such consequences are:

- negative impact on natural water balance by
  - increased surface run-off of precipitation, which can overload the sewerage system during heavy rainfall, and which leads uncleaned water into waterbodies,
  - higher expenditures for waterworks by water purification,
  - reduced water retention of precipitation in soil and less ground water recharge,
  - reduced transpiration rate, decreased air humidity, less evaporative cooling, heating and build-up of heat islands (e. g. due to increased absorption of radiation and lack of fresh air corridors),
- noise exposure in cities not just due to numerous sources of emission but also as a result of sound reflecting surfaces and building density,
- increased fine dust concentrations especially in inner city air. Often the most important sources are traffic, heating and industry. Fine dust is not permanently bound to sealed surfaces and can be resuspended back into the air.

1.1 Consequences of Tram Track Greening on Urban Water Balance

1.1.1 Improving Urban Water Retention by Green Tracks

Compared to ungreened tracks the water balance in green tracks is closer to nature. Water balance consists of water run-off, water storage and evaporation.

Vegetation systems in greened tracks store precipitation water initially until saturation. Further precipitation water attains the sewerage system or ground water, respectively. If the track drainage is connected to the municipal sewerage network the waterload coming from a greened track will be less than the one coming from an ungreened track. Precipitation run-off in green tracks occurs after continuing precipitation or heavy rain. The stored precipitation water is mainly given back to the air by evaporation – from the soil – and transpiration – from the plants. Thereby air humidity is increased and evaporative cooling generated. The water storage capacity of the greening systems depend on the type of vegetation system.

[1] Not all the transport companies participated in the survey. Therefore probably the number of green tracks in Germany is higher.

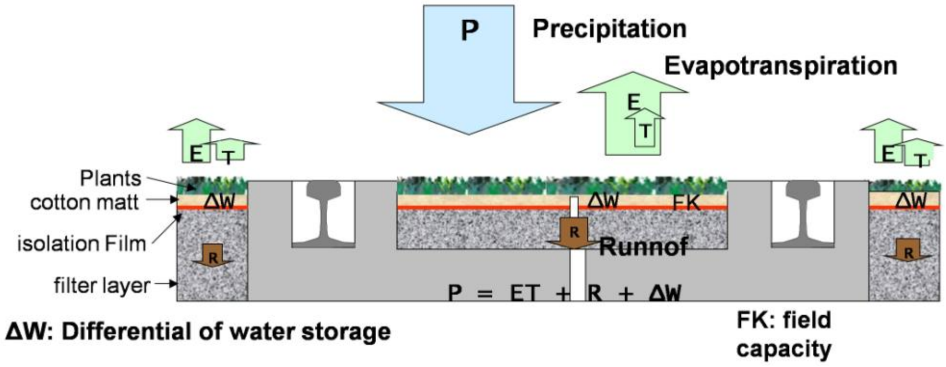

Fig. 1: Water balance elements in the green tram track [3]

P= precipitation; ET=evapotraspiration; R=run-off; ΔW=differential of water storage in the vegetation system in mm or l/m²; FK =field capacity (maximum amount of adhesive water in the vegetation system, specified as moisture in Vol. % or W in mm).

Thickness and composition of vegetation carriers differ depending on the vegetation type applied (grass or sedum). Sedum tracks are characterised by a thin carrier of 6 - 8 cm. In grass tracks the carrier should at least be 15 cm, depending on the local conditions.

Fig. 2: Sedum track (Photo Kappis, IASP)

Fig. 3: Grass track (Photo Schreiter, IASP)

Green tracks allow mean water retention of the annual precipitation rate falling onto a green track, of

50 % in sedum tracks and

70 % in grass tracks [3], [4].

Thus, about 50 % and 70 %, respectively, of the annual precipitation are bound and evaporated. Applying an annual precipitation rate of 790 l/m²/a [5] in Germany, a track greening system retains more than 400 – 550 l precipitation water per m².

Hence, one hectare of a green track annualy stores

ca. 5 530 m³ water in a grass track and

ca. 3 950 m³ water in a sedum track.

Consequently the entire green tracks of Germany, which according to the survey account for 380 km single track of grass and 45 km single track of sedum [2] store more than 560 000 m³ precipitation water with considerable microclimatic effects. Potentially at least 1 150 km of Germany's tram tracks are greenable which equals an area of about 287.5 ha [2]. If this area was greened, annual water retention of 1.55 million m³ would be possible. The particular value of this retention is its urban climatic effect, which especially has an impact in highly sealed inner cities.

During summer the effect of green tracks on the regulation of the urban water balance is the biggest. Even though the highest precipitation rates occur at this time of the year, green tracks retain about 90 % of what rains onto the track (per m²). Only about 10 % run off [3].

The run-off rate of precipitation is influenced by many parameters, especially:

- from water saturation of the greening system,
- from precipitation intensity as well as,
- from absolute precipitation rate.

In contrast to winter months high evaporation by plants and soil during summer leads to mitigation of the water saturation and thus to an improved water storage capacity in the vegetation system. The following examples demonstrate the impact of track greening systems on midsummer water balance.

Example one is displayed in Fig. 4. It shows the changing water parameters in a sedum track during heavy rainfall in Berlin (13.5 l/m² with a peak of 5.7 l/m² in 15 min) [3]. The vegetation system was already saturated by 80 % before the rain.

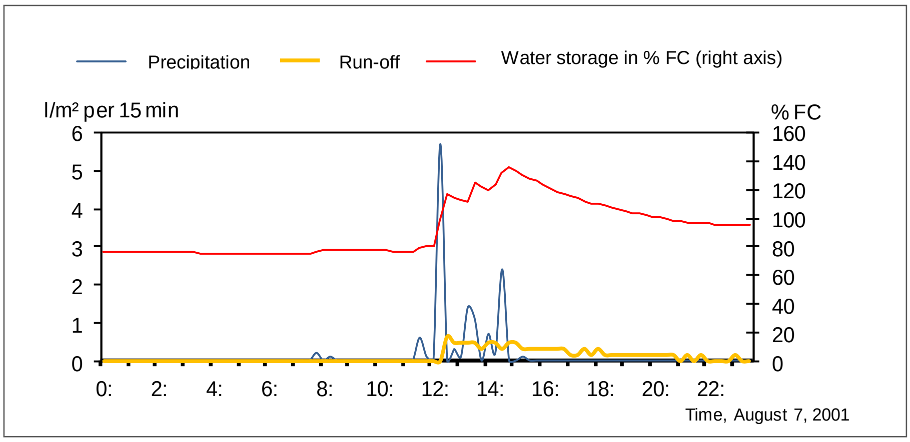

Fig. 4: Precipitation and run-off values in l/m², water storage values in % of the maximum possible water storage of the track greening soil (field capacity, FC); presaturation at about 80 % of FC [3].

Despite of heavy rainfall and high presaturation water run-off started 15 min after the precipitation peak of 5.7 l/m². The highest run-off measured in intervals of 15 min was only 0.6 l/m². Following the peak a constant and weakening run-off started.

Even better effects are achieved by vegetation systems with low presaturation. In the second example (see Fig. 5) a similar precipitation rate (11.5 l/m²) fell onto a vegetation system with only 40 % saturation. Only 0.6 l/m² run-off occurred during the precipitation. 10.9 l precipitation water was stored in the vegetation system (95 % of the rain). Run-off of the unbound water started two hours after the precipitation event and was less than 0.2 l/m² in 15 min.

Despite of different conditions in both examples the big impact of greening systems in tracks is obvious. In sealed areas which are connected to the sewerage system surficial precipitation run-off causes immediate higher water load for the sewerage system to its full extent. Concurrently the run-off water is polluted. If greened tracks are connected to the sewerage system the run-off into this system is significantly retarded, run-off rate is considerably reduced and owing to the filter effect of the vegetation system run-off water is less polluted.

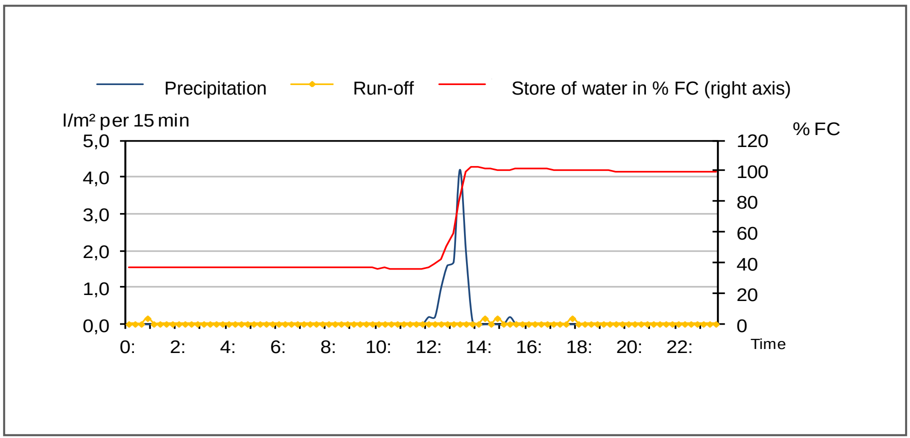

Fig. 5: Precipitation and run-off values in l/m² and water storage values in % of the maximum possible water storage of the track greening soil (field capacity, FK); presaturation at about 40 % of FK [3].

Thus, tracks greened on a large scale can relieve the sewerage system in its near surrounding compared to a non-greened track. Especially heavy rain during summer which can cause road flooding can be mitigated in its impact. Vegetaton systems have their biggest relevance during summer regarding their urban climatic impact.
Under the climatic conditions prevailing in Berlin[2] green tracks store more than 220 l water per m². This way during summer one hectare of green track (which are two kilometer double track) stores about 2 210 m³ of water. Calculating with the 45 km greened tracks[3] in Berlin about 24 750 m³ water is stored during summer which come into climatic effect in the city.

1.1.2 Improving Urban Climate by Evaporation from the Green Tram Track

Inner cities suffer from heat and drought in consequence of urban surface sealing as well as more frequent weather extremes. Often heat islands arise due to high heat absorption of buildings during the day and slow heat radiation during the night as well as on account of low evaporation rate, and -cooling, respectively. Vegetation systems can act relieving:

- Plants absorb energy for photosyntheses.
- Plants and soil evaporate water which causes evaporative cooling.
- Plants protect the soil from direct radiation.
- As result of the low heat storage capacity compared to concrete and asphalt green areas do not heat as much during the day and cool down more rapidly [6].

The cooling rate of grass tracks can be calculated [4]: The evaporation of water consumes energy, which is detracted from the environment. The evaporation of 1 l of water cools 200 m³ of air by 10 K (simulatinh a temperature drop from 30 °C to 20 °C).

Since the heat island effect is especially incriminating during summer and evaporation processes increasingly occure, the cooling capacity of vegetation is most important at that time of the year. Analogue to the calculation model of Dresden [4] the cooling rate of Berlin's green tracks during summer months is as follows:

90 % of precipitation falling onto a green track during summer is stored in the greening

[2] 580 l/m² precipitation * year or 245 l/m² in 4 summer months

[3] Status 2009

system [3]. This amounts to 220 l/m² green track. Hence, by means of evaporative cooling each squaremeter of green track can cool 44 000 m³ of air by 10 K. So the whole of Berlin's green tracks (45 km single track), which stores about 24.750 m³ water during summer, could cool 4.95 billion m³ air (5 km³) by 10 K.

Owing to the positive influence on the microlimate surrounding the green tracks they provide a valuable contribution for living conditions and thus for population's health.

1.2 Temperature Reduction in the Track

In several tests the balancing effect of vegetation systems on the surrounding temperature and on the tracks was asserted. This can be ascribed to evaporation from plants and soil with its cooling effect and the decline of the temperature gradiant in the track [3], [4], [7].

This effect is especially important during summer, when areas without vegetation, such as balasted tracks, heat up extremely due to its high heat absortion (colour, surface), particularly during weather situations with high radiation. In the course of the day balasted tracks heat up more compared to air temperature. Experiments in Dresden [4] determined temperatures above 50 °C on the surface of ballasted tracks. Appart from detached exeptions the temperature of the ballasted track was always above air temperature [7]. So, even ballasted tracks have their share in the reduced urban cooling during the night. Despite of intense radiation, vegetation systems using grass or sedum did not heat up further than 25 - 30 °C. Whereas in ungreened parts such as cavity elements or ballast the temperatures raised above 50 °C [3], [4], [7]. Vegetation areas do not only heat up less but also cover the layers beneath, like soil, which provides a further heat protection of tracks and rails.

Whereas rails in ballasted tracks or in vegetation systems, which are installed until foot of rail, temperatures can raise above 50 - 60 °C [4], [8]. Temperatures in grass tracks with vegetation systems reaching to top of rail, temperatures of 25 - 30 °C were measured [4].

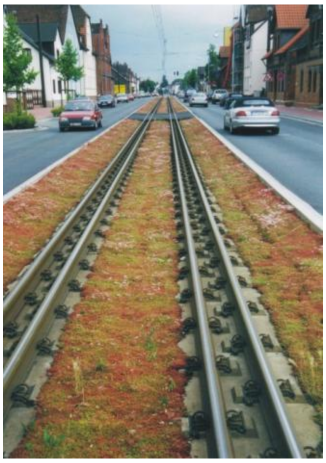

Fig. 6: Vegetation system up to the foot of the rail (photo Henze, IASP)

Fig. 7: Vegetation system up to the top of the rail (photo Kappis, IASP)

The vegetal cover can reduce extreme air temperatures during hot summer days. The extent of the effect depends on the vegetation system and is higher in grass systems than in thin sedum systems.

1.3 Absoption and Retention of Pollutants in Tram Track Greening

A main problem of conurbations is air pollution with particulate matter and attached substances. The smaller the particles are the higher is the risk for human health, since small particles enter the inner part of the respiratory tract. Particles below 0.1 µm infiltrate the blood circuit [9], [10]. Apart from particle size their chemical and physical characteristics are relevant for their harmfulness.

Vegetation systems can, depending on local conditions and system type, support urban fine dust mitigation: Particulate matter deposits on the enlarged and comparatively rough surface of the plant cover. There it is partly bound to the plant surface. Some of it is metabolized or accumulated, such as carbon monoxide or hydrocarbons [11]. By wind, vibration and precipitation other particles enter the surroundings like soil, air or other plants and animals. Plant-available dissolved substances in the soil can be taken up via the roots.

The uptake of particulate matter parts in green tracks could locally reduce fine dust concentration of the air. Presumably this effect rather applies for tracks with high vegetation cover, big deposition surface and irregular plant height. Eased thermal above vegetation systems compared to sealed surfaces reduces the reentry of dust into the air.

Moreover it can be assumed that resuspension of dust by wind turbulences for example from passing vehicles and trams is reduced compared to sealed surfaces due to dust binding on plants and soil.

Fig. 8 illustrates dust accumulation of sedum leaves and shoots from a tram track greening of central Berlin. Both pictures on the left show the thick dust layer on the plant surface compared to cleaned plants in both pictures on the right. The bottom pictures are taken by means of scanning electrone microscope and display a sedum leaf close-up.

Fig. 8: Comparison of uncleaned (left) and cleaned (right) leaves of *Sedum album.* Bottom: SEM-pictures, 700 µm and 800 µm (pictures Schreiter, IASP)

On leave surfaces of *Sedum spurium* and *Sedum album* coming from a tram track, particles were detected which possibly origin from abrasion processes of the rail wheel contact (Fe) and brake sand (Si) [12]. Furthermore heavy metals such as manganese and copper as well as polycyclic aromatic hydrocarbons (PAH) and chromium were detected. Microscopic pictures proved that deposited particles belong to the health related size fractions PM_{10} and $PM_{2.5}$.

Often the green track is situated immediaty next to one of the main pollution emitters, the traffic. Therefore and because of its big area green tracks possess the potential for dust and contaminent deposition and binding. Hence green tracks can contribute to urban fine dust mitigation.

1.4 Sound Mitigation Potential of Green Tracks

Noise is a major impairment of the environment in conurbations. The degree of sound emission in the tram track depends on the maintenance condition of rail and wheel, constructional aspects and the velocity of the trams as well as the absorption capacity of the surroundings. Apart from sound control at the source, measures for the reduction of sound propagation are usefull. Here, green tracks can provide positive contributions.

According to two German guidelines ("16. Verordnung zur Durchführung des Bundes-Immissionsschutzgesetzes" and „Richtlinie zur Berechnung der Schallimmissionen von Schienenwegen, Schall 03"), grass tracks are generally allowed a sound bonus of 2 dB(A). This bonus is being disputed, because it does not consider the sound absorbing characteristics of the greening system depending on the arrangement in the track.

When vegetation systems are implemented to foot of rail the sound propagation occurs from the whole rail. Further reverberant surfaces in the track, like sleeper heads or rail beams, additionally reflect the noise. Concerning green tracks with vegetation systems at the foot of rail almost no reduction arises compared to the ballasted track (about 1 dB(A)). Therefore the bonus for the construction type "vegetation at foot of rail" is overvalued and needs revision.

Vegetation systems which are implemented until top of railembed the rail widely. Therefore sound can only be propagated from the rail head.
Assuming that wheel and rail contribute to the sound emission in equal shares, embedding the rail can reduce the sound by 3 dB(A) compared to the soundwise optimal ballasted track. In this range it is also technically proven that green tracks with vegetation systems until top of rail reduce the sound better than ballasted track with unembedded rails [13].

During numerous measurements in the track only low sound mitigation of green tracks was proven. Still the psychological impact of green tracks on the subjective acoustic perception of the noise emission should not be underestimated. Green tracks are found to be less disturbing by residents [3], [14].

Not just the construction type of the track (top of rail/foot of rail) but also the conditions of the vegetation itself (coverage rate, stand density, plant height, porosity of the vegetation carrier, water content) influences noise absorption capacity of the greening system immediately [3].
Apart from sound emission, tramway traffic also causes vibration. The influence of vegetation systems on vibration is of subordinate importance.

2 Urban Design and Appearance of Tracks

The permanently present tram tracks influence the visual impression of the urban landscape and thereby obtain great importance in city planning. A considerable advantage of green tracks is the obvious improvement of the aesthetic effect compared to ballasted or concrete tracks. This especially applies for urban spaces with little green. Particularly in highly sealed inner city districts new vegetation areas arise, for which almost no alternative area exists.

Fig. 9: Tracks before and after greening in Berlin (top; photos Dreger, BVG and Schreiter, IASP) and Düsseldorf (bottom; photos Ahrens, Rheinbahn AG)

The quality of urban open space is an important locational factor especially regarding the exploitation of settling enterprises. Studies indicated that 12 % of the customers are willing to pay higher prices in greened business areas [15], [16]. Thus it can be assumed that greening of tram tracks in shopping streets indirectly increases consumption. The optical upvaluation of urban open spaces also influences social and mental health of humans.

From urban designers point of view wide roads with open housing and flowing green structures are suitable for track greening. With the green belt an optical and ecological compensation of the traffic congestion is possible. Green tracks provide a new opportunaty for urban individuality. Together with alleys, for example, green tracks obtain an own character which serves the image of the city and the transport company [17]. Progressively green tracks become a marketing factor for city-compatible and modern public transport.

Urban green spaces have a positive impact on human health. A close relation between the proportion of green in a residential estate and different respiratory and heart diseases were apparent [18]. A calming effect of track greening was noticed by tram drivers from Kassel. According to their experience driving over greened tracks is less tiring and less exhausting for the eyes than ungreened tracks.

3 Economic Benefit

Direct benefit for transport companies [19]

Cities with divided waste water regulation can financially reward reduced rainwater discharge into the sewerage system. The regulation is carried out at the Federal State level.

- Since 2009 a storm water fee of 1.897 € per m² sealed area has been charged in Berlin. Should this fee also be charged for tracks Berlin's transport company BVG could annually save 5 300 € of storm water fee per greened kilometre double track. A calculation example is given in Kappis (2010) [19].
- According to the federal law on nature protection from 2009 interference with nature and landscape normally require compensating measures. State laws regulate which projects are regarded as interference. Different compensation measures for the loss of landscape by soil capping measures are asserted by the states. In order to have an ecological planning value both German states Berlin and Brandenburg established a factor (Biotopflächenfaktoren, BFF) for particular surface types. The states Sachsen, Sachsen-Anhalt, Baden-Württemberg, Niedersachsen and Schleswig-Holstein established eco points.
- These factors are taken into account for the legal restraint of compensatory measures, which can diminish the extent of the compensatory measures. The municipality of Berlin [20] determins a BFF for different building measures. Exemplary calculations showed, that the claimed BFF of 0.3 for technical infrastructure is provided by tram track greening.
- Embedding the rails in green tracks diminishes their heating. Thus accident risks by distortion or fractures of rails can be reduced as well as associated maintenance work.
- Greening systems in a ballasted track protect the ballast against the inflow of fine particles, which decrease stability of the ballast bed. Therefore tamping of the ballast bed is needed less often, which reduces maintenance costs. Several transport companies found in their tracks relatively clean ballast below 20 year old grass covering. Thus tamping of the ballast was not needed.
- On greened tracks waste is reduced, especially on the ones which are implemented until top of rail. This saves additional cleaning [2], [19]. Presumably the positive appearance of neat green tracks creates a psychological barrier for environmental negligence.

Indirect benefit for transport companies

- Upvaluation of transport companies' image regarding their contribution to improved living conditions as well as ecological publicity.

Direct benefit for municipality and general public

- Summing up the retarded and reduced rain water run-off rates of all green tracks compared to differently covered tracks this effect could be relevant for the dimension and water load of the sewerage system and wastewater treatment plants.
- Owing to evaporation and increased albedo of vegetation the ambient air temperature is reduced. In the sum of the whole urban green these effects mitigate the formation of urban heat islands. Thus less energy costs for air condition during heat periods

arise [21]. The productivity of the working population is less diminished and heat-related health problems occur less often [see also 22].

- During planning of tracks, noise emission mitigation by track greening can be considered and can save money which would come up for other noise reduction measures.
- Upvaluation of the ambience by prestigious appearance of the street
- The greening of one kilometre double track in a densly built innercity street can improve living conditions of 2 000 to 3 000 habitants [3].

4 Conclusion

Tram track greening involves several positive effects, which are usually closely related with each other and which can exponentiate. In summary the most important effects are:

Ecological Effects

Water retention in tracks

- Annual average: 50 % - 70 % of the precipitation rate
- During summer: up to 90 %
- This equals per m² vegetation in the track: 400 -550 l/a
- Depending on the vegetation system 2 km double track retain
  4 000 – 5 500 m³ water annually and
  2 200 m³ water during summer

Evaporation of precipitation water

- Evaporation of 1 l water can cool 200 m³ air by 10 K
- Thus each m² greened track can cool about 44 000 m³ air by 10 K during summer

Reduction of track heating

- Contribution to evaporative cooling
- Protection of soil and track design of direct solar radiation and associated heat uptake
- Vegetation systems possess a lower heat storage capacity compared to concrete or asphalt. They also cool down faster.
- Insulating effect of vegetation systems at top of rail-level:
  Rail temperature without embedding of vegetation: up to 50 - 60 °C
  Rail temperature in the green track: 25 - 30 °C
- Contribution to the mitigation of local heat island build-up

Uptake and absorption of contaminents

- Potential decline of local fine dust and contaminant concentration of the air by deposition on the vegetation surface
- Partial adhesion and metabolism of contaminents by plants
- Decrease of dust resuspension in the track

Noise mitigation

- Mitigation of noise emission especially with vegetation systems going to top of rail
- Noise is mitigated up to 3 dB(A) compared to the noise wise optimal ballasted track
- Green tracks may be perceived less noisy

Contribution to biodiversity

Impact on Health and Well-being
- Positive impact of the ecological effects mentioned above on human health (noise mitigation, dust adhesion, diminishing heat islands) - Close relation between proportion of green and reduction of respiratory and heart diseases - Influence of green on social and psychic well-being - The greening of one kilometre double track in a densly built innercity street can improve living conditions of 2 000 to 3 000 habitants
Urban Design
- Aesthetic upvaluation of tracks - Higher public acceptance of transport companies - Improvement of city image and transport companies - Urban open spaces as locational factor regarding the exploitation of settling enterprises and increase of property values
Economical Benefits
- Green tracks are sometimes accepted as compensatory measures. - Noticeable relief of storm water run-off (sewerage system, run-off ditch) by green tracks compared to ungreened tracks - Reduction of maintenance needs for ballasted tracks and rails - Less waste on greened tracks reduces cleaning needs

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