INCORPORATING TRANSPORT ENERGY INTO URBAN PLANNING:

A NEW USE FOR GIS TOOLS

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Abstract: Transport energy resources are largely finite, subject to constraints and a major cause of pollution. Transport-energy planning is not currently included in traditional transport and urban planning. A new GIS based tool has been created, the Transport Energy Specification (TES), which is intended for use within local government urban planning frameworks. The tool combines the use of GIS road network and shortest path software with energy consumption data to create a weekly estimation of minimum possible energy consumption using standardised mode availability rules. A case study was performed to demonstrate the required process to achieve a Transport Energy Specification for an urban region. Karlsruhe, Germany was selected for the case study and the results showed that a minimal 0.97MJ of transport energy per person per week was required. Use of the TES in an urban development framework has the possibility to positively direct urban development towards low energy intensive designs.

Keywords: Transport energy, sustainable transport, transport planning, transport policy, urban planning

1. INTRODUCTION

Suburban development has created further spatial separation of activities. The resulting increase in travel distances required to access activities entails an increase in transport energy consumption (Silva et al. 2001). High transport energy consumption is not sustainable because it largely relies on a finite energy source and is directly correlated to pollution emissions.

World energy resources are becoming constrained and transport costs are escalating. Geophysicists estimated that world oil production would peak in 2005 (Deffeyes 2001) and current oil prices point to this reality. Renewable resources offer only a fraction of the current energy supplied by finite sources.

Land-use planning has to date not addressed the issue of reducing the separation of activities or modifying travel behaviour to meet an energy requirement. This is because transport-energy planning is not a part of transport planning. The most commonly used modelling tool, the 'four step method,' makes no provision for energy constraints. The aim of this research is to develop tools that allow transport energy to be quantifiably included in urban planning and policy.

In the next section (Section 2), the case for including transport energy into urban planning is presented and a methodology to achieve this is explained. A newly developed GIS based tool, the Transport Energy Specification is described in detail in Section 3 and a case study example follows in Section 3.1. Section 4 contains the conclusions of the paper and references are included in Section 5.

2. TRANSPORT ENERGY AND URBAN PLANNING

Integrated transport and land use planning is a vital component of sustainable urban development. At the local government level, successful planning relies on land use and transport development policies that clearly define the desired sustainable end result. In addition to these policies, technical evaluation and assessment tools are required that are easy for decision makers to understand.

There currently exist many tools to assess the transport effects of differing spatial patterns; however it is not clear how these assessments contribute to urban planning (Frank et al. 2005). Land use planning strategies are lacking the required technical evaluation tools, especially tools that assess land use at smaller scale (Rosenbaum and Koenig 1997). Without the required tools, policy can at best only encourage (through the use of cost benefit analysis etc.) and not direct sustainable development.

In developing an adequate tool to address the issue, transport energy was examined. Transport energy use provides a good indication of urban sustainability because it is affected by both land use and transport systems. Transport energy is also related to or affected by the following aspects of urban areas:

- Transport pollution emissions
- Amount of active (cycling and walking) and public transport
- Car dependency (suburban sprawl has increased dependency (Zumkeller et al. 2005))
- Trip distances and travel times

- Urban density
- Urban and transport system design
- Reducing availability and high price of petroleum products

An energy assessment tool could assist authorities in many aspects of sustainable urban development. Recently conceived strategies, including New Urbanism and Smart Growth are already achieving some success towards developing sustainable urban areas (Litman 2005). Energy assessment tools could add robustness to these strategies by incorporating exact engineering requirements (or regulations) into policy.

Previous energy modelling research (Saunders 2005) has been further refined to create a new transport energy assessment tool: the Transport Energy Specification (TES). This new tool aims to introduce quantifiable measurable energy criteria into urban planning and policy as illustrated in Figure 1.

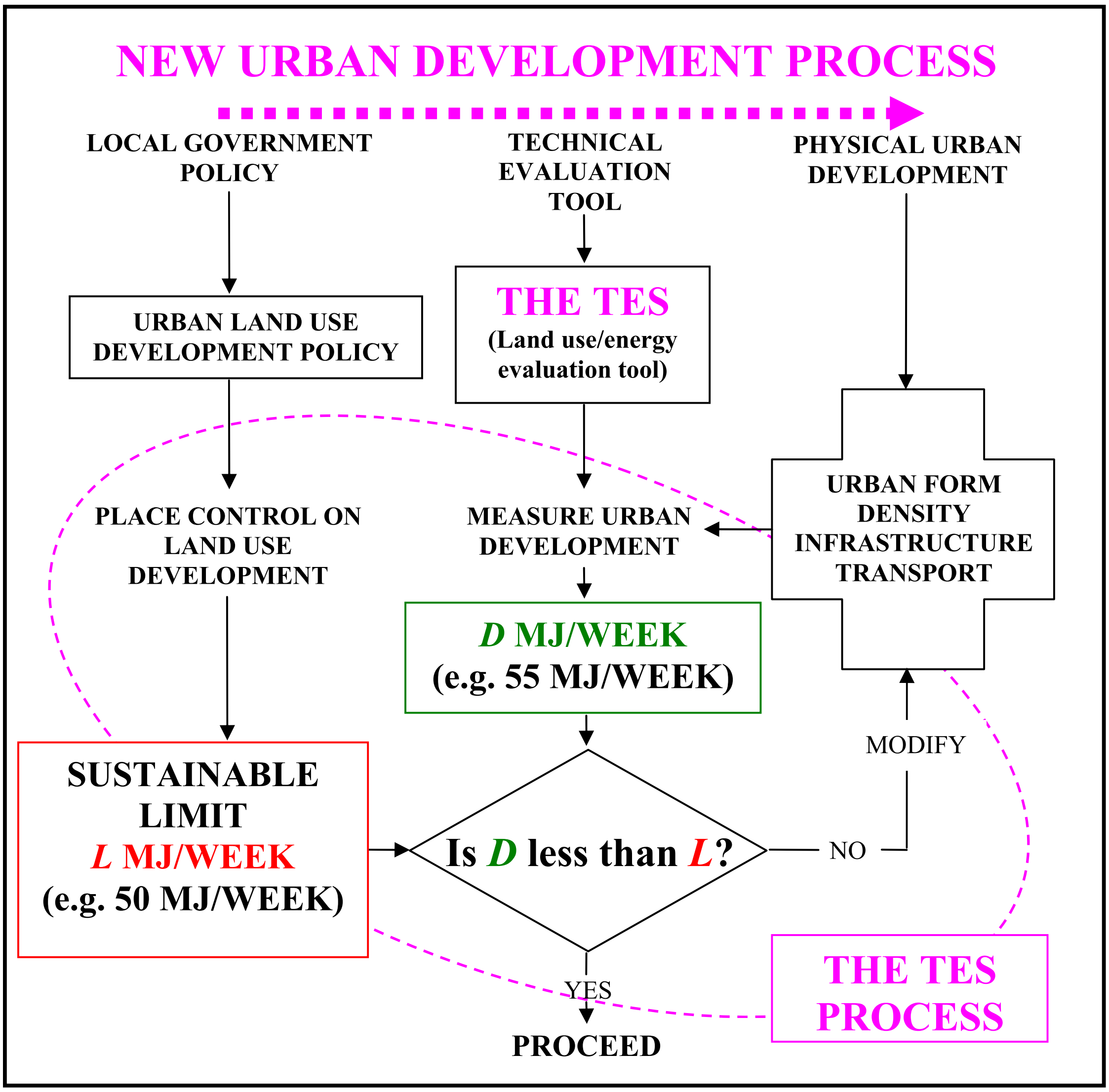


Figure 1: Possible role of Transport Energy Specifications in urban development

The TES process is primarily an analysis tool used to assess the transport energy requirements of urban regions. However, when a transport energy limit is defined as shown in Figure 1, urban development can be contained with respect to transport energy efficiency limits. In the example given in Figure 1 the TES of the development (55MJ/Week) is higher than the predetermined development limit (50MJ/Week), this signifies that modifications are required for the development. Transport and/or land-use modifications will be possible for the scenario to create a modified scenario that meets the defined transport energy efficiency requirements. Within the defined TES limits many spatial patterns and transport systems would be possible and it is left to the community to select the final desired development contained within the energy boundary. It is envisaged that planners and transport professionals will agree on individual city transport energy limits with this and future related research to be used as guidelines.

3. THE TRANSPORT ENERGY SPECIFICATION

Specifying how transport energy is related to urban form is an essential part of incorporating transport energy into urban planning. Energy specifications ensure quantitative analysis in the planning process.

A TES can be likened to software specifications that explain the minimum requirements a computer needs to run the desired software. Similarly, the TES explains the minimum transport energy requirements for a certain urban and transport system layout. The TES only describes how transport in the region could comfortably be used by its inhabitants to achieve the minimum transport energy. It doesn't say how the transport system will be used, nor is it a guideline on how to use the transport system. No attempt is made to estimate actual behaviour for an urban region. The TES is just an indication of what is possible for an urban region.

In order to standardise the TES, a method for calculating urban transport energy requirements has been created, as summarised in Figure 2. The energy required to access common urban activities within the region of interest is calculated using this method. Energy consumption is measured in both quantity and type of energy (e.g. petroleum, electricity). Walking and cycling are both assumed to consume zero energy. Also, as this specification deals only with energy, transport cost would need to be analysed with a different tool.

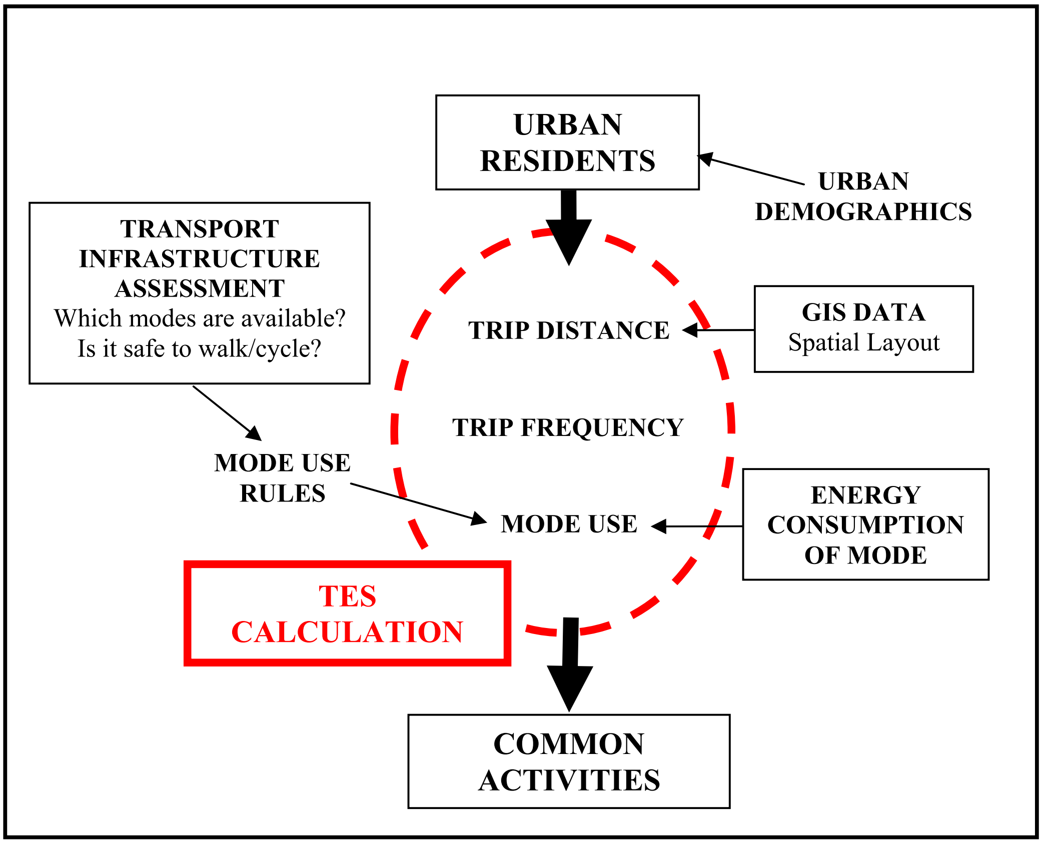


Figure 2: The Transport Energy Specification method and calculation for urban trips

The urban study region, transport system and surrounding activities (food stores, work locations, universities, schools etc.) are located and mapped into a GIS database. Data is collected (or at least estimated) that describes the demographics, number of students and the number of unemployed, which includes all individuals without full or part time work of at least 20 hours per week. The “common activities” then need to be identified as illustrated in Table 1.

Table 1: Example of “common activities” used for a Transport Energy Specification

Common Activity	Age Group (yrs)	Percentage	Frequency (x/week)
Kindergarten	3-6	100%	5
Primary School	6-9	100%	5
Secondary School	10-17	100%	5
University	18-65	12%	5
Tertiary School	18-65	3%	5
Work	18-65	70%	5
Supermarket	18 and over	100%	2
Recreation Reserve	6 and over	100%	1

Each "common activity" has a defined percentage of the associated age group performing the activity a certain number of times per week. The frequency and percentages should be gathered by surveys to reflect local data but initially Table 1 can be used as a starting point. In the example above, 70% of the 18 to 65 year old age group work at a frequency of five times per week and 15% study, which leaves 15% unemployed.

To simulate the human behaviour that would achieve the minimum transport energy consumption, certain artificial rules are applied to the study region. These rules include both how mode choice is made and where residents travel for their activities. According to these rules, residents will travel the shortest possible distance to the available activities (work, school, university etc…) using mode choice rules as shown in Table 2. The mode-distance data used should be based on actual data pertaining to the country or city of interest; however Table 2 can be used as a starting point.

Table 2: Example of mode availability rules used for the Transport Energy Specification

Age Group	1st Choice	2nd Choice	3rd Choice	4th Choice
	Walk	Cycle	Tram/Bus/Metro	Car
3-6	<300m a	N/A	<200+200m a,b	Final Option
6-9	<400m a	N/A	<200+200m a,b	Final Option
10-17	<400m	<1km c	<200+200m b	Final Option
18-65	<400m	<1km c	<200+200m b	Final Option
65+	<400m	N/A	<200+200m b	Final Option

a Children 3-9 years are accompanied by adult.
b For tram/bus users; the stops must be within 200m of the origin and destination.
c For cyclists, it must be safe to cycle and there must be storage facilities within 100m of origin and destination

In the example given above in Table 2; a 4 year old child will walk with an adult to the kindergarten if it is less than 300 metres, otherwise they will take a tram or bus if there are bus/tram stops within 200 metres of the kindergarten and house of origin. If none of these options are available to the child and adult, they will go by car to the kindergarten. The car option is based upon car ownership being high enough in the urban area. Car ownership needs to be considered.

The final step in the TES process is the actual calculation. Using GIS road network and shortest path software as shown in Figure 3, the transport energy used per week by each resident (ERi) is calculated and summed to give the overall energy consumption (ETOTAL) for all residents per week for the study region. Equations (1) and (2) are used for this purpose.

$$ER_i = \sum_{j=1}^{m} TL_j F_j EC_k \qquad (1)$$

Where:
TL_j = The trip length (km) from the *ith* resident's house to the *jth* activity(s) (j = 1 to m)
F_j = The frequency (#/week) of trips of the *ith* resident performing the *jth* activity

ECk = The energy consumption (MJ/km) of mode *k* according to Table 2 mode rules

$$E_{TOTAL} = \sum_{i=1}^{n} ER_i \qquad (2)$$

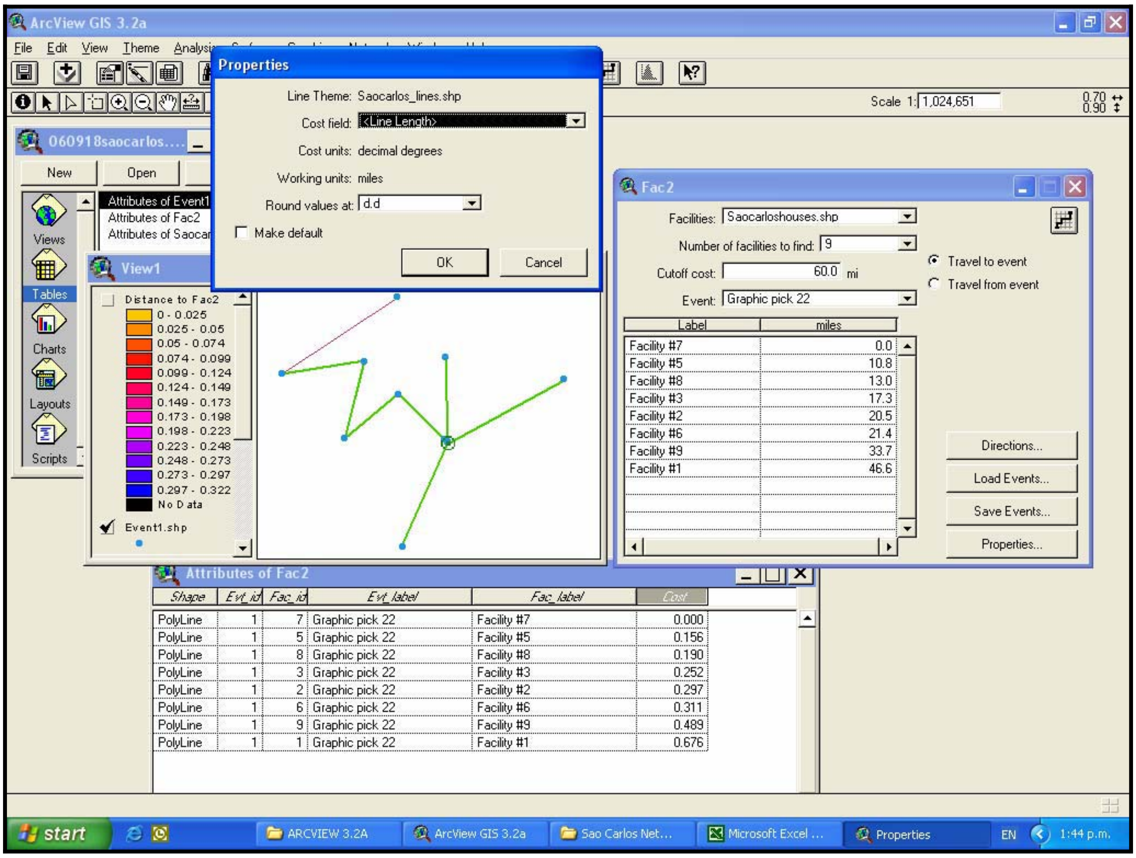


Figure 3 Use of GIS network and shortest path software to gather distance data

Using the defined behaviour rules, the above equations and GIS shortest path data for trip length, energy consumption will be given in MJ/week for all residents in the study region. This data is then separated into petroleum and electricity consumption with petrol being converted to Litres/week. The final TES data can be presented in many ways (energy per person, per trip etc.) as is shown in the case study example.

3.1. Case Study for Transport Energy Specifications

A case study was performed to obtain a TES following the previously described method. A city with ample safe active transport (walking and cycling) and a high performance public transport system was selected for the case study. Such a city was selected to be used as a base “best case” scenario in order to compare all future urban regions to this case study.

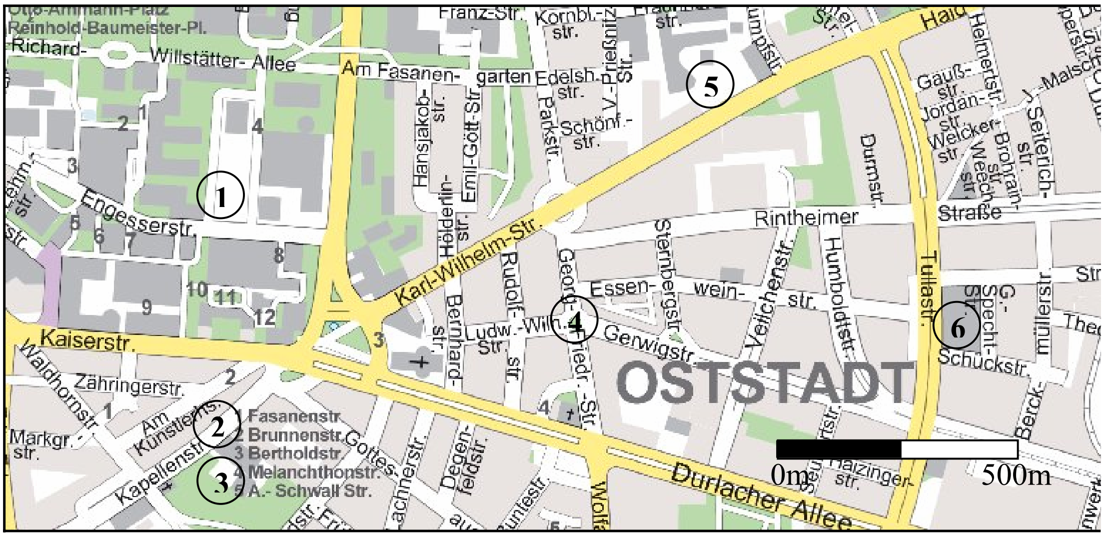
Karlsruhe (population approx. 285 000), in the South West of Germany and close to the French border was selected for study. Karlsruhe is famous in transport circles for pioneering the concept of using rail tracks for the combined use of passenger trams and regional and freight trains. The city layout also provides for easy walking and cycling. In addition, neighbourhoods contain a variety of activities (medical services, restaurants, schools etc.) within the residential areas as shown in Figure 4, ensuring that many activities are within walking or cycling distance of residents.

Figure 4: Typical residential building in Karlsruhe with activities (book/wine stores) on the first floor

The case study focuses on a typical small urban region in the Oststadt district of Karlsruhe containing 2250 residents. The region is contained by three streets forming a triangle. The three streets forming the study region triangle are: Karl-Wilhelm St, Georg-Friedr. St. and Durlacher Allee. The Durlacher Allee side of the triangle is approximately 500m in length. From the map shown in Figure 5 it can be seen that the study region contains two churches. Karlsruhe University is located to the immediate Northwest of the study region and can be seen more clearly in Figure 6 (North is at the top of the map).

Figure 5: The Oststadt district that contains the region selected for the case study

From observation of the paths and roads within and surrounding the study region, it was determined that cycling and walking are both safe. Many cyclists and pedestrians were also observed accessing their activities during the study region assessment. Cycle storage facilities were present at all major activity centres (schools, shops etc.) and it was also observed to be possible to store cycles close to smaller activity centres (securing to lampposts etc.). Many tram routes pass close to the study region, with many residents being located within 200m of a tram stop. The tram routes and stops are shown in Figure 5, surrounding activities are also highlighted.



Key: 1 = University 2 = Primary School (6-9yrs) 3 = Recreation Reserve
4 = Supermarkets 5 = Industry 6 = School (6-17yrs)
• = Tram Stops

Figure 6: Oststadt study region showing surrounding activities and tram stops

Demographic and employment data was provided by Karlsruhe University for the study region. There are 2250 people within the study region, 1225 male and 1025 female, 16% of the adult population are students and 16% are unemployed. The closest available employment is located at the University and a nearby industry sector (Numbers 1 and 5 in Figure 5). These two locations provide over 4000 jobs. Following the TES method, workers travel to the closest available work sites; therefore all workers will travel to these two locations.

A visual inspection of the location of residences within the study region was performed. It was assumed all residents were evenly distributed amongst the available housing in the study region. The housing and activity locations were then plotted onto a map to allow trip distances to be calculated using the different modes according to the mode rules specified in Table 2. The following Western European energy consumption data (Kenworthy 2003) was used for the available modes:

1. Walk and Cycle 0MJ/km
2. Tram 0.72MJ/pkm
3. Car 3.3MJ/km or 9.65Litres/100km

Energy calculations were performed for all residents using the geographic data and Equations (1) and (2). The results of these calculations are presented in Table 3.

Table 3: Energy and trip data for the study region separated into “common activities”

Age Group	No.	Walk		Cycle		Tram (.72MJ/pkm)			Car (3.3MJ/km)			
		Main Activity (5x/week) - School/University/Work										
		Trips	Dist.	Trips	Dist.	Trips	Dist.	Energy	Trips	Dist.	Energy	Petrol
0 to 2	29	0		0		0			0			
(with parent) 3 to 5	27	18	200	0		0		0	9	360	106.92	3.127
(with parent) 6 to 9	35	0		0		12	1030	88.99	23	640	485.76	14.20
10 to 17	71	0		71	820	0		0	0		0	0
workers 18 to 64	973	348	85	625	450	0		0	0		0	0
uni students 18 to 64	296	43	380	253	500	0		0	0		0	0
other students 18 to 64	250	243	300	7	420	0		0	0		0	0
unemployed 18 to 64	290											
65 and over	279											
Total	2250	652	187.76	956	490.49	12	1030	88.99	32	561.25	592.68	17.33
		Food Shopping (2x/week)										
		Walk		Cycle		Tram (.72MJ/pkm)			Car (3.3MJ/km)			
		Trips	Dist.	Trips	Dist.	Trips	Dist.	Energy	Trips	Dist.	Energy	Petrol
0 to 17	162	0		0		0			0			
18 to 64	1809	1809	300	0		0			0			
65 and over	279	264	180	0		0			15	350	69.3	2.027
Total	2250	2073	284.72	0	0	0	0		15	350	69.3	2.027
		Recreation (1x/week)										
		Walk		Cycle		Tram (.72MJ/pkm)			Car (3.3MJ/km)			
		Trips	Dist.	Trips	Dist.	Trips	Dist.	Energy	Trips	Dist.	Energy	Petrol
(with parent) 0 to 9	91	2	390	0		0			89	600	352.44	10.31
10 to 17	71	2	390	69	600	0			0			
18 to 64	1809	40	390	1680	600	0			89	N/A[b]	0	0
65 and over	279	6	390	0		0			273	600	1081.08	31.61
Total	2250	50	390	1749	600	0	0		451	600	1433.52	41.92
		Weekly Totals										
		Walk (50.8%)		Cycle (44.5%)		Tram (0.4%)			Car (4.4%)			
		Trips	Dist.	Trips	Dist.	Trips	Dist.	Energy	Trips	Dist.	Energy	Petrol
Total Trips/Week	14686	7456	243.03	6529	519.83	60	1030	88.99	641	578.63	2095.5	61.28

a “Dist.” = Average one way distance (m) to activity, for energy calculations the return trip length was used.
b In the case of children travelling by car to the recreation reserve, parents accompany them using zero energy.
c “Energy” units are MJ/Week; “Petrol” units are Litres/week of petroleum.

According to the specification guidelines, 95.3% of trips can comfortably be performed by active transport (cycling or walking). The high possibility for cycling and walking results in an overall low transport energy requirement. Of the motorised transport (cars and trams), about 10% of these trips would be completed by tram following the mode rules in Table 2. Several factors contribute to this low mode share, such as no tram routes connecting the study region to the recreation reserve or the supermarket and tram stops not being within 200 metres of all residents and the value used here of 200 metres. If this 200 metre mode-distance was doubled so that residents were allowed to access tram stops 400 metres from an origin, the tram share would markedly increase. In future trials, more attention will be placed on determining realistic mode-distance values in the city of interest.

The summarised TES for the study region is presented in Table 4, which shows that an average of 0.97MJ of transport energy would be consumed per person per week. This is equivalent to the energy required to power a 60W light bulb for about four and a half hours. However, estimated observed energy use in German urban areas is closer to 310MJ/Week (MOP 2006). This infers that there is a large possibility for behavioural change in German urban areas. Also, while German residents choose to use transport energy, they are not entirely dependent upon high energy use to access their activities (at least not in Oststadt).

Table 4: The Transport Energy Specification for the study region

Transport Energy Specification Summary					
Car		**Tram**		**Total**	
MJ/Trip[a]	3.269	MJ/Trip[a]	1.483	MJ/Week	2184.49
L/Trip	0.096	L/Trip	N/A	%Energy Petrol	95.926%
MJ/Person/Week	0.931	MJ/Person/Week	0.040		
L/Person/Week	0.027	L/Person/Week	N/A		
Cars/1000 people	605			MJ/Trip[b]	0.149
Area					
Total Area	9.84	hectares		**MJ/Person/Week**	**0.971**
Density	228.57	ppl/hect			

a: "MJ/Trip" is the average energy used per trip by the particular mode.
b The total "MJ/Trip" is the average energy used by all trips including walking/cycling that consume zero energy.

The TES specifies that minimal transport energy is required for the urban layout of the study region. High population density (229 people per hectare) and a large share of jobs being located within the study region or close to the study region contribute to this very low TES.

This case study provides a low transport energy example for future studies and will be used as a base case for all future comparisons. It is anticipated that many future case studies will be performed on differing urban and transport system layouts to determine which urban regions have high transport energy requirements and why. Of particular interest will be to compare urban regions from different countries with differing personal income levels.

4. CONCLUSIONS

A GIS based energy assessment tool was created that is intended for use to aid in sustainable urban development. Policy makers could use this tool to specify an upper transport energy boundary for urban and transport system designs. Because transport energy is related to many urban sustainability issues, the Transport Energy Specification tackles many problems at once. Of particular concern in the future will be the gradual decline of transport's largest energy source; oil.

A case study was completed in Karlsruhe, Germany and the initial results showed that Karlsruhe is or has the potential to be a low transport energy dependent city. Further studies are required in other cities and countries to assist policy makers in determining a sensible transport energy boundary for urban design if the TES is to be used in urban planning in the future.

The Karlsruhe case study highlights many urban sustainability points raised by other researchers. For example, the positive effects of activities being integrated into residential areas and the benefits of possessing an enjoyable and safe walking and cycling atmosphere. However, the TES approach analyses urban areas on a smaller ‘neighbourhood’ scale that is typically not included in land use and transport system analysis. In this way the TES measures more than just density and its relation to energy use, but the exact spatial layout of the neighbourhood area including location of residences and activities.

After the initial trial in Germany, the Energy Efficiency and Conservation Authority (EECA) in New Zealand became interested in the TES approach and reviewed the TES for use in local government policy in New Zealand. As a result of this review, modifications were suggested for future TES development and use. These included creating a simple model to relate the TES to estimated actual energy use and some changes to origin/destination, trip generation and mode use rules. As further development of the TES continues and more trials take place, the TES will hopefully reach a point in the near future where it can feasibility be integrated into urban planning policy.

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